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South Korean and Japanese Automobiles in the New Era of Innovation: Investigating the Performance of the Korean and Japanese Automotive Companies Hyundai Kia AG and Toyota Motor Corporation with Respect to the Innovation Power and Technological Achievement of Volkswagen AG from 1990 to the Present

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Elisabetha Wasileva, BA

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Summary

The topic of the master thesis has been inspired by the dynamic development of the concept of the automobile and the role that it plays in our daily life. From a luxury good, the automobile achieved to be volume produced and to deliver a freedom of movement due to several innovative solutions in its manufacturing which have made it affordable for the population.

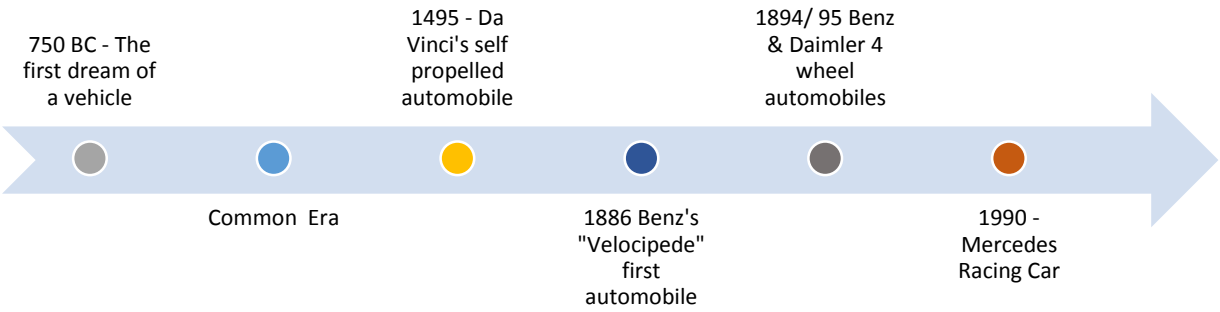
The introduction gives an overview of a few considerable milestones of the evolution of the automobile that are significant for the comprehension of its complex nature. Its advancement presents a wavelike pattern- stages with substantial progress, followed by a long-lasting standstill. The automobile has now entered a new level of technological innovation – the acceleration towards the autonomous driving technology which is still foreseen for prototypes and hybrid vehicles. Interestingly, the tendency of upgrading the high-end automobiles has affected also the middle and compact class. Answering the research question, we can follow the downward migration of innovative solutions from a trademark only for the luxury segment to the middle class – e.g. the application of lightweight materials to the body structure, the drivetrain advancement by providing power individually to the four wheels, integration of advanced driver assistance systems, etc. This migration is feasible if the main powerplant components are reshaped and upgraded. The empirical part explores the alteration of the volume produced vehicles of Toyota Motor Corporation and Hyundai Kia Automotive Group, by comparing them with the technological novelties incorporated in the mass-produced automobiles of Volkswagen AG during a particular period of time. To make the innovation of high volume automobiles a measurable construct, the thesis refers to the theory of technological innovation developed by R. Maclaurin.

1. Introduction

1.1. A Brief Overview of the Automobile's Development

The historical development of the automobile is long and multifarious. It does not owe its construction to a single inventor. The concept of the vehicle has advanced over centuries. The different components – the motor, gearbox, panels, wings and frames have been incrementally brought together to create a complete unit (Woodford, C., 2009).

A brief history of the significant milestones of the automobile's development can provide an insight into the turbulent nature of the innovation itself. It is not a rigid concept created by a single man, but rather a discontinuous process. According to the researcher Maclaurin "fundamental new concepts occur only at intervals" and not randomly (1955, p. 552). Breakthroughs are often consequences of opportunities and knowledge that are available for a long time, but have waited for the "right" visioner or the appropriate technology and effort (Ibid.). In the case of the automobile fruitful periods characterised by important technological advances are followed by years of uncertainty and stagnation. The technological breakthroughs present their discontinuous wavelike character. The introduction of the thesis aims to position the companies Volkswagen AG, Toyota Motor Corporation and Hyundai Kia AG, whose automobiles are under investigation, in this discontinuous set of innovations' emergence. After two decades of a standstill, the 90s have been marked by a technological revitalisation and analysts claim, that the automotive industry witnesses in the 21st century a strong intensification of innovative concepts in key areas ("Automotive Industry Is Entering,", 2014). The correlation of the companies in this shared wavelike process of innovation corresponds with the idea of Maclaurin that there is a "tendency for entrepreneurial activity to come in clusters", which is also important for the comprehension of the contemporary stage of the innovations' appearance (1955, p. 568). Once having positioned the companies, we can prepare the ground for further comparison in terms of technological achievements in their automobiles, carried out in the empirical part.



The dream of a powerful vehicle that can move autonomously has occupied the human mind centuries ago before it took a real shape. The first evidence of that idea can be found in the ancient Greek poem „Iliad“, composed around 750 BC where Homer describes Vulcan or known also as Hephaestus- the god of fire and forge, moulding „tripods“ in a following way:

„That placed on living wheels of massy gold

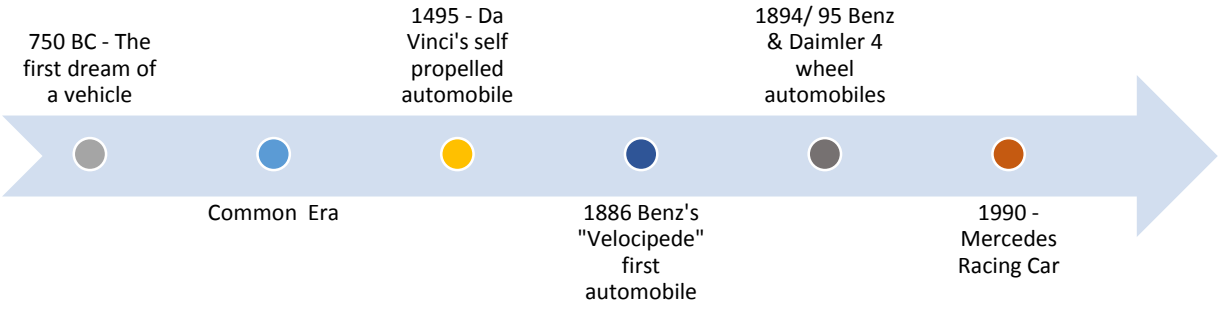
(Wondrous to tell) instinct with spirit rolled

From place to place, around the blessed abodes,

Self-moved, obedient to the beck of gods.“ (Pope, Al., 1903, The Iliad, Book XVIII, 440-445)

During the Renaissance, philosophers considered that humans are, instead of the gods, the center of the universe. Moreover, only humans are able to create knowledge. The Renaissance opens a new range of possibilities for the human learning about the natural sciences, the idea of a self-propelled vehicle is developed into a more tangible form. Leonardo da Vinci- an artist, painter, sculptor, mathematician and inventor, was occupied with the thought about people moving from one place to another. Da Vinci creates the first concept of a vehicle on three wheels that can move forward without a horse or man power. The vehicle is designed to be powered by coiled springs in the form of a crossbow. Da Vinci’s car can even turn right. Interestingly, the springs are not installed to drive the vehicle, their role is in regulating the movement. The actual driving mechanism is situated on the underside of the automobile. The coiled springs serve as an engine, located in a housing with the form of a tambour. For centuries, the concept of Da Vinci’s self-propelled vehicle remains only on paper because he has the vision, but not the technology. In 2004, a group of scientists and engineers devote their efforts to bring the concept to life. The finished machine is truly capable of moving autonomously forward. However, the Da Vinci’s machine is an invention which design is too revolutionary for its time and an example that innovators have the immense capability to predict future needs, but their ideas have to wait for the appropriate time where the technology has the capacity to meet the dream (Hooper, J., 2004).

Therefore, I decided to delve into the innovation in the context of the automotive industry. There, technology and visions can exist together and support each other.



The first automobile in terms that we can recognise it like an engine driven automobile was developed simultaneously by the German engineers Karl Benz and Gottlieb Daimler. Both inventors never met each other personally. Gottlieb Daimler and his colleague Wilhelm Maybach elaborated together an 1.5-hp one-cylinder engine that was fueled by kerosene or paraffin and installed into a two-wheeled vehicle. The advantage of that engine named "the grandfather clock" was its weight and size. The machine passed well the test drive in 1885 (Benz patent motor, 2016; Deffree, S., 2016).

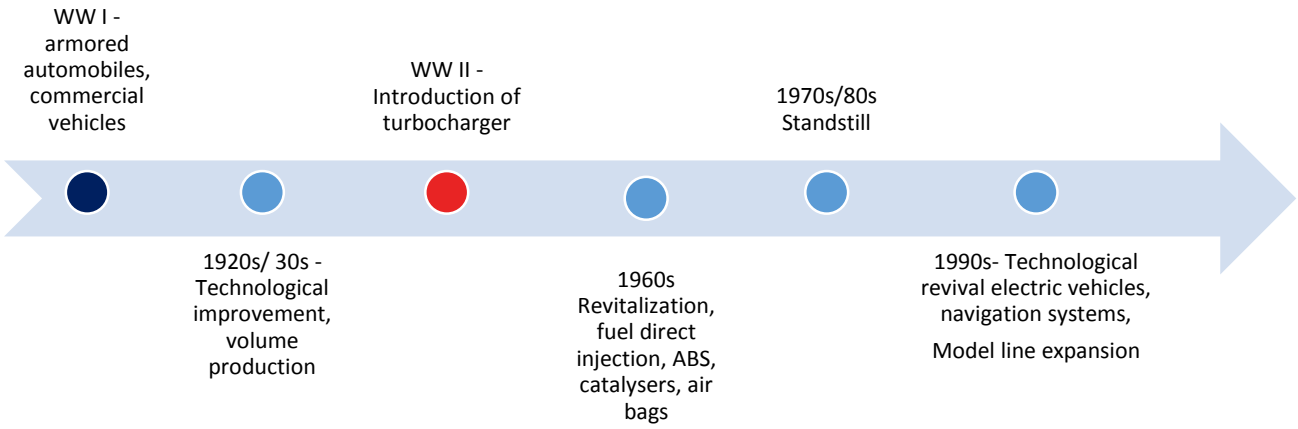
In Mannheim Karl Benz devoted his efforts to construct a four-wheeled vehicle. The engineer could not find a working possibility to steer a four-wheeler and therefore Benz focused on three-wheeled machine. He developed an 0.75 hp one-cylinder four-stroked engine powered by gasoline. Characteristic features of the „Velocipede" were automatic air intake slide, electrical vibrator ignition, brakes, tiller steering, controlled exhaust valve and water-cooled internal combustible engine. Benz succeeded in 1886 to patent his invention and the Velocipede is considered to be the first automobile in the human history with the patent – number 37435 named „Benz Patent Motor Car, model no. 1" (Benz patent motor, 2016).

After that Daimler, Maybach and Benz himself developed their concepts further and refined them as Maybach enriched the automobile with the spray-nozzle carburettor. This type of carburettor turned into one of the first major innovations of the automobile and is even used nowadays. In 1893, Benz found a solution to the impossibility of steering four-wheeled vehicle in the double-pivot steering (Ibid). Meanwhile, in other German town Gottlieb Daimler created independently a four-wheeled motor carriage believed also to be the first automobile on four wheels (Beginnings of the automobile, 2016; Long, B., 2010, pp. 8-13).

The way of the commercialisation of the invention of Karl Benz lasted around 8 years. In 1894, the Benz „Velocipede" refined with four wheels is considered to be the first automobile worldwide in series production and until 1899 the company established as „Benz & Co Rheinische Gasmotorenfabrik, Mannheim" produced around 600 automobiles. On the other hand, "Daimler Motorengesellschaft" became a successful company for engine manufacturing and expanded internationally. A noticeable invention was the four-cylinder engine geared up with the spray-nozzle carburettor (Long, B., 2010, pp. 10-11).

Initially, motor sport was an activity only for rich and prosperous people. The race tracks were used as a platform to make the innovations popular and accessible to more people by showing what are the automobiles capable of. The competition between both of the companies before the First World War was high whose results were a vast range of novelties, the construction of a bus and lorry, unconventional racing automobiles, etc (Ibid.).

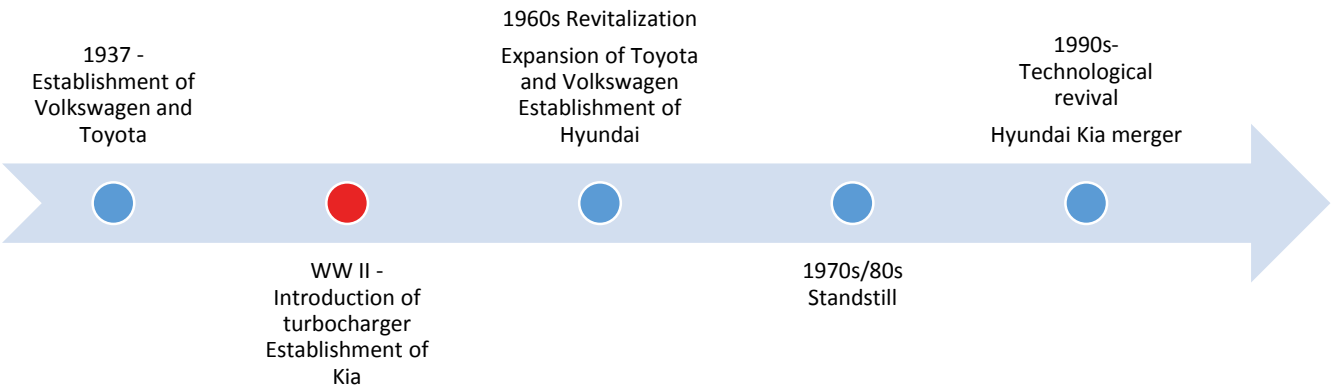
It should be also mentioned that in 1900 Daimler Motorengesellschaft designes the ancestor of the modern automobiles – the Mercedes racing car, with a lower body – a chassis frame built from steel, supplied with a 5.9 litre engine whereas the horsepower was increased to 35 hp and gear could be shifted. The racing car laid the basis for the construction of future modern cars. The rest of their lives Daimler, Maybach and Benz dedicated to further engine and steering refinements (Ibid.; Beginnings of the automobile, 2016).



During the First World War, automotive companies such as Rolls Royce, BMW, Citroen and Renault experienced their evolution as some models were engaged on the front line and others were especially designed for military elite. Unintentionally, the war gave Citroen and BMW the possibility to turn from manufacturers in the military buildup and aviation industry into successful producers of passenger cars in the postwar period (Allen J., 2014; George, A., 2014).

On the other hand, the Second World War influenced the automobile in the manner that its power was increased through a turbocharger or supercharger. Experimentations were done in the sphere of the self-shifting transmission. However, during the war-time major inventions did not occur as the manufacture of passenger automobiles came to a standstill and most of the vehicles constructed besides all types of tanks and tank destroyers were prototypes or armored cars (Buescher, J., 2011; “World War II,” n.d.).

After the Second World War came to its end, new horizons and vast industrial possibilities were opened in front of the passenger automobiles. It is an era signified by a revival of the automotive sector. In the end of the 1950s, the West German automotive industry demonstrates considerable progress. The rebuilding of “Volkswagen”, a company established during the National Socialism in Germany to produce automobiles in favour of the regime, was one of the milestones that transformed the country from the ashes of the war into an economic miracle. The progress of the German automotive industry has become a symbol for their industrial recovery (Sandbook, D., 2013).



1.2. The Development of Volkswagen

Since 1904 the idea of a people's car affordable for everyone occupied the mindset of the engineers in the German speaking area. In 1934, Ferdinand Porsche was engaged in the venture to create the people's car. The first prototype was shown a year later – Volkswagen 3-Serie (Grieger, M. & Lupa, M., 2014 ; Knorr, B. 1998).

The factory of Wofsburg developed the model of Volkswagen Limousine. In the late 40's the Wolfsburg plant constructed the half of the automobiles volume manufactured in Western Germany and started to export vehicles internationally (Ibid.).

The monetary reform in Germany influenced positively the goods market in the country and opened a new horizon for Volkswagen to increase resources and production capacity. The model of the Beetle turned into a distinguishing sign of the brand (Ibid.).

In 1956 the factory produces ten times more vehicles annually in comparison to the year before. Due to investments in the advertisement the company succeeded in its aim to personalise the automobile. In 1957, the demand for Volkswagen Beetle exceeded the supply. New plants not only in Germany but also overseas are opened. The brand became the largest European exporter of automobiles and the emblem of the "economic miracle" in Germany. The main reason behind its prosperity is its "engineering attributes" and a permanent improvement of the vehicles (Grieger, M. & Lupa, M., 2014, p. 55).

As the manufacture process was centered in the production of the Beetle, the change in the consumer taste mainly on the American market in 1967 led to a decrease of the number of the automobiles sold abroad. To respond to the new impediments, the brand needed a reorganization of the resources and a widening of the range of models (Chronik, Volkswagen, 1961-1972, p. 2,) .

The construction phase was rationalised as data processing started to be done electronically. After the establishment of the development centre, the focus was put on the improvement of the conventional propulsion methods, vehicle's safety and the emission control (Ibid., p. 28).

The brand expands and focuses on the manufacturing of the vehicles for the firefighting apparatus, the postal services and the energy suppliers.

In 1967 Volkswagen presented a vast range of technological novelties in the sphere of the automatic transmission. All the new automatic vehicles have available double-jointed rear axle which gave a start to the independent rear suspension. This innovation in the suspension allows the vertical up-and downward movement of the wheels. The new wave of vehicles characterises with the transformation of the engine from air-cooling system to water-cooling (Tracy, D., 2013). Henceforth, Volkswagen started to develop its subsidiary Audi and to acquire new automotive companies - SEAT and Škoda, and a number of the most upscale automobile brands - Bentley, Bugatti, and Lamborghini (Bowler, T. 2015).

The most influential project that would play a role for the advancement of the technologies used for the engines and also determine the evolution of the new generation is the introduction of the direct-injection turbo-diesel engine in 1991. The turbocharged direct injection (TDI) has at its command a turbocharger and relies on the direct fuel injection. The first vehicle equipped with it was the Audi 80. The TDI technology contributes to better vehicle acceleration and fuel economy (Jääskeläinen, H., 2013).

1.3. The Development of Toyota

It was not only the German company "Volkswagen" that underwent transformation and industrial success. In 1890 Sakichi Toyoda- a Japanese industrialist invented the wooden hand-loom which is an appliance that spins yarn around and winds it. Three years later Toyoda established a factory where he developed further the loom as inventing the narrow wooden power-loom. At that time, the import of looms in Japan had declined and almost 70 percent were imported from Great Britain. After that invention, Toyoda succeeded in producing around 90 percent of all the power looms manufactured in Japan. The appliance enabled the constant and fast working process with the easily breaking Japanese yarn. After putting the automatic looms in flow production, the labour productivity grew by 5 to 19 times. The outcome of the Toyoda product innovation in the late 1920's was the Japanese leadership in the global cotton textile export trade. (Rose, M., 1991, pp. 40-41).

His son Kiichiro Toyoda was responsible for the new branch of the „Toyoda Automatic Loom Works" factory – an automobile division launched in 1933. In 1935 he facilitated the construction of the A1 prototype of passenger automobile and the G1 truck. Two years later Toyota Motors was established as one of the two officially licensed manufacturers of motor vehicles in Japan, specializing in passenger automobiles and small trucks. The company experienced an expansion in 1960s and '70s. Its progress from a low-priced car producer to the largest auto manufacturer, the corporation owes to its innovative car models – Lexus from the luxury segment, Prius – the first hybrid-vehicle that was accessible to the average customer and the investment in innovation through the establishment of Toyota Central Research & Development Laboratories, Inc. („History of Toyota (1960-1969)," n.d; Encyclopædia Britannica, 2010)

1.4. The Development of Hyundai Kia

The dynamic venture of another automobile brand in East Asia deserves further attention as it experienced an unprecedented growth. In 1944, a company named „Kyungsung Precision Industry“ was launched in South Korea that was producing steel tubing and bicycle parts manually. Eight years later, the plant presented and constructed the first bicycle in South Korea called „The Samchully“ and gave a start to the development of the Korean cycling industry. The plant changes its name to „Kia Industries“. The word Kia is a composed one, derived from Chinese. The first syllable Ki - 起 stands for „to rise“ and the second -亚 for „Asia“ (Chinese English Pinyin Dictionary, 2016). A decade later Kia produced the first motorcycle c-100 laying the foundations for the Korean motorcycle manufacture. Its role as inventor for the Korean economy, Kia develops with the equipment of the plant with the first hydraulic 1000 ton capacity press used in Korea. The company started to construct light vehicles for transportation. Kia focused on the automobile manufacture by assembling initially the three wheel automobile K-360 and the first small passenger automobile with the name Brisa in South Korea in 1974. The plant invested heavily in cutting and bolting technologies which allowed the company to launch the first internal-combustion gasoline engine on the Korean market. Moreover, Kia paved the way to the construction of the first diesel engine in South Korea. After the first steps in the automobile manufacture were done, Kia experienced a brisk growth by opening new plant and expanding overseas. In the 1980s the brand stood face to face with its main competitor on the Korean market – Hyundai Motor Company. Experiencing financial and managerial difficulties like its Japanese competitor Toyota at the end of the '90s, Kia became insolvent. The brand was sold to Hyundai by Hyundai acquiring 51 % of the shares of Kia Motor and adopting the label “Hyundai Kia Automotive Group” (Murphy, A., 2015).

On the other hand, Hyundai - the largest Korean automobile manufacturer started as an engineering and construction company. The plant used to assemble vehicles for the Ford Motor Company. Under its guidance, Hyundai released the first passenger car– Hyundai Pony, followed by the model Sonata. The Pony is the first mass produced and home designed medium size automobile, making the company the first Korean automobile manufacturer. For a period of fifty years Hyundai achieved to grow from a small subsidiary to the fifth largest motor group globally. Nowadays, the company has at its command the biggest automobile plant in the world, located in Ulsan, South Korea. The auto industry owes to Hyundai Motor the world’s first hydrogen fuel cell vehicle that is put in mass production (Ibid.).

Together, both of the companies – the largest and the second largest auto maker in South Korea turned worldwide into the 7th largest automobile manufacturer with capacity measured in 2.9 million production units. Along with the joint use of engine and transmission part, the research centers of the companies were integrated and consolidated. Nowadays according to Forbes, in 2015 Hyundai Kia occupies the ninth place among the largest automobile companies in the world (Ibid.).

Both of the automotive companies Toyota and Hyundai Kia deserve the attention of the master thesis, as their development and progress would be impossible without their technological capabilities cultivated and advanced in their innovation concept. But where can they be situated in a period of 30 years back from now, when the automobile industry started to undergo a new and brisk phase in its development and reconfiguration towards the future?

1.5. The Benchmark

For the purpose of the master thesis in the pursuit of comparing the innovation power of Toyota Motors Co. and Hyundai Kia Automotive Group, the master thesis relies on the tool of benchmarking.

Volkswagen AG has been awarded jointly by the Center of Automotive Management and PricewaterhouseCoopers for the sixth time in 2016 as "Most innovative automotive company" globally. Twenty global automotive groups and 54 automobile brands have been analysed ("AutomotiveINNOVATIONS award 2016," 2016; "AutomotiveINNOVATIONS award", 2012).

In 2016, Volkswagen is awarded to be "most innovative high volume brand" because of the introduction of 89 advanced components ("AutomotiveINNOVATIONS award 2016," 2016).

The thesis will use the technological achievements of Volkswagen AG as a reference point in the comparison. This does not mean that the master thesis considers the Volkswagen AG to be superior to the other two companies. The idea of the benchmark is not to show the best performance. It serves only as a reference by which the position of the others can be defined. The technological accomplishments of Toyota and Hyundai-Kia can be compared and measured in relation to the benchmark. With the help of the benchmark both of the companies can identify areas where they fall behind other players. Or they can prove that they are more competitive in given fields compared to similar enterprises („What is Benchmarking," 2016).

1.6. Time Frame of Exploration

The historical expansion of the three brands is not enough to draw any valuable conclusions as it does not provide the mechanism for answering the research question. It just serves as a one explanation of the choice of these three companies.

The exact measurements, i.e. the quantitative ground for comparison are to be derived from the theoretical part of the master thesis and the theory of innovation.

Moreover, the master thesis cannot follow the whole line of development of the innovation capacity of the three brands. The automobile became a standard part of our lives and a dominant part for transportation purposes in the 1920s and 30s with the emergence of the big European and American automobile producers. The prewar and postwar time of the Second World War indicate a major transformation in terms of the size and the weight of the automobile. Serious technological upgrades have been adopted - the hydraulic braking mechanism on all of the wheels, the introduction of the independent front suspension, etc (Cromer, G., Foster, C.& Purdy, K., 2016).

After the technological achievements of the 20s and 30s, the next thirty years did not indicate any major revolutionary concepts with one exception that changed the way how automobiles are started and altered the engine (Armstrong, J. 2004).

Robert Bosch is the inventor who gave the automobile a new opportunity to advance. In 1967, Bosch presented the new technology of the electronic fuel injection (named Jetronic) for automobiles powered by petrol that was produced on a large scale. The model Volkswagen 1600 was first equipped with this state-of-the-art fuel injection system in the same year. After its introduction, the innovative technology established itself and displaced the traditional mechanical fuel injection and the carburetor. Traditionally, a flow of air and liquid fuel is blended together through the carburetor and that transport it to the engine. The disadvantage of this type of fuel injection is that it does not allow an effective fuel and energy economy and therefore cannot improve the performance of the vehicle. The inlet manifold can get wet because the liquid fuel drops. Furthermore, the movements of the intake runners can create and provide an unequal flow of air and fuel to the cylinders. And that is the main drawback of the carburetor – it cannot supply the four cylinders with the accurately equal quantity of air and fuel as the cylinders are not at the same distance from the carburetor (Armstrong, J. 2004).

The first injection system was the mechanical one. The spray nozzle injects the petrol into the intake port. The flow of the fuel injected depends on the needs of the engine. By the mechanical injection system the amount of the air and petrol mixture is regulated via a mechanical control system. The mechanical system is a highly complicated system consisting of many components. However, it could not quantify precisely the supply of fuel, because the mechanical assembly could only feel the amount of air (Davis, M. 2010; “How a fuel injection,”, 2016).

The mechanical fuel injection and the carburetor prove unreliable, as both of the types featured a significant waste of petrol and energy, and a high level of exhaust gases.

On the other hand, the electronic fuel injection is regulated by an electronic control unit. This unit relies on the information given from sensors installed on the engine. The sensors estimate the temperature and the speed of the engine, the air pressure, the throttle and the accelerator pedal position. The data that flows from these sensors is more reliable. Furthermore, once delivered the information from the intake ports is compared to the information and the perfect rates that have been installed on the system beforehand. The electronic unit compares them and makes the decision about the precise amount of fuel the engine demands, responding accurately even to the entire range of its needs. From a technical point of view the whole mechanic assembly and the complex components are pulled out. Just one spray nozzle injects the fuel into the inlet port. The fuel is fired by the sparking plug and the engine starts to run smoothly. Bosch advanced the system further, but the basic technology remained unchanged (Armstrong, J. 2004; Davis, M., 2010; “How a fuel injection,”, 2016).

The introduction of the electronic fuel injection is labelled as a „technology revolution“, because there was previously no injection system that can deliver the correct flow of fuel to the cylinders at the right moment. The entire amount of fuel is absorbed which leads to an improved fuel consumption. The electronic fuel system transforms the engine into a more powerful and reliable engine and it runs smoothly and efficiently. Moreover, the system reduces the exhaust emissions. The mechanical fuel injection and the carburetor were replaced by the electronic fuel injection which became the standard approach (Armstrong, J. 2004; Davis, M., 2010; n/a, “How a fuel injection,”, 2016).

Having identified the benchmark of the comparison in the person of Volkswagen AG and chosen its rivals – Hyundai Kia and Toyota Motors, the master thesis needs to set the time frame of the exploration.

The establishment of the electronic fuel system at the beginning of 1990s defines the beginning of the period of the master thesis investigation (Armstrong, J., 2004). It marks a major improvement of the injection system and therefore a technological innovation that was elaborated independently, has changed the way of development of the automobile and set a standard for the modern engines and vehicles (Ibid.). The launch of the electronic fuel system gives the automotive industry a push toward technological improvement after decades of a standstill.

Several major automotive innovations follow the electronic fuel system: the introduction of the anti-lock braking system (ABS) by Chrysler, the air bag restraint systems as standard safety equipment in the automobile, and last but not least the creation of the controller area network (CAN bus) which ultimately opened up a new horizon in front of the automobile toward the advanced computer techniques. The vast range of progressive advancements drove the development of the automotive industry to the 21st century featuring the beginning of the new era of innovation in the automotive sector.

2. Formulation of the Research Question and its Relevance

Having in mind the above mentioned milestones, we can formulate the research question of the master thesis in the following way – „*South Korean and Japanese Automobiles in the New Era of Innovation. How can the performance of the Korean and Japanese automotive companies Hyundai Kia AG and Toyota Motor Corporation be measured against the innovation power and the technological achievement of Volkswagen AG from 1990 to the present*?"

In the new era of automotive innovation, the luxury brands of the automotive manufacturers are widely discussed and compared as a token for the driving evolution. However, the master thesis concentrates on the volume produced passenger automobiles with an annual production of 100,000 units to investigate the technological breakthrough that has been made tangible and affordable for the ordinary consumer.

Written in the scope of the Master Programme "East Asian Economy and Society" the thesis delves into a field which evokes the attention of both the economy and society. According to a research of PwC, the innovation power in the automotive companies stays in a beneficial relationship for the rise of its profit. The companies with the highest innovation power expect more than 60 percent growth of their annual revenue in 5 years time (The highway to growth, p.7). The automotive industry itself is believed to be of significance for the economic growth of a country. It is linked to various branches of the economy – not only to the innovation, but also to the employment, research and development, external and internal trade, investment, etc.

The investigation of the automotive breakthrough technologies is relevant to society as well. People highly appreciate the technological advancement of the automobile because it

participates in our everyday life. The innovative safety technologies that are integrated into the vehicles have a direct impact on the passengers' safety. The driver is not alone onboard anymore and intelligent decisions can be made by the automobile itself in order to prevent or mitigate incidents.

A large part of the available inquiries on the level of integration of advanced technological solutions has been carried out in the field of premium vehicles. The master thesis contributes to the research of a rather unexplored and neglected field – the migration of the innovation from high-end vehicles to the mainstream automobiles.

3. State of the Art

After a research into the academic database one can detect that there is no single piece of literature that encompasses exactly the entire information and explanation on the development of the innovative technologies in the automobile in a certain period of time. Therefore, to become familiar with the relevant literature and gain additional knowledge on the different ways of addressing the question of the master thesis one should delve into diverse literary sources.

First, the author James M. Rubenstein presents to the audience a more general perspective on the automotive industry and its transition to the globalisation in the book „A Profile of the Automobile and Motor Vehicle Industry: Innovation, Transformation, Globalization." (2014, Business Expert Press). The author pays attention to the growth not only of the big vehicle manufacturers and competitors but also to the role of the retailers, part producers and every other supplier that is involved in the assembly, logistic and sale process of the automobile. The author examines the progress of the automotive industry by showing its importance for the other industries because he sees the origin of many innovative ideas, which find also their utilization in other industries, exactly in the automotive business. The researcher does not analyze the technological innovation as specific inventions and improvements in the automobile components. He rather observes the innovative practices in the response to the external market forces, the reorganisation of the production process, the introduction of new management and labor practices, branding strategies and giving customers flexibility of financing that actually brought the automotive industry to its expansion and serve as a model for other industries (Rubenstein, M., 2014).

As the innovation in some specific industry, for example the automotive industry in Japan, is actually a part of a national economy, the author M. Taylor provides in his book an insight into the national politics of the governmental apparatus that foster innovation „The Politics of Innovation. Why Some Countries Are Better Than Others at Science and Technology" (2016, Oxford University Press). The piece of literature is relevant as a source of information not only for the master thesis, as it compares automotive companies whose names are associated with their national states, but also for people who are interested in designing the policy environment for unlocking the innovation in companies. The author confronts with the standard assumption that the institutions and their policies create the incentives for the development of science and technology and they are the main instigators of innovation. Taylor argues that companies rather exist and function in a much broader framework that encompasses international markets and networks and the innovation does not depend only on domestic policies. The book examines different companies from distinct countries as case

studies that experienced growth in science and technology or the lack of it and in the same time looks at the national policies, trying to find in the „good“ domestic policies an incentive for innovation, and in the „bad“ a reason for their failure. The outcome is that there is no unique procedure or body of laws of a national government that is the best solution for unlocking innovation. Companies that achieved growth have also applied diverse policies and mechanisms. The author emphasises the importance of social networks as a tool for gaining an insight into international markets and foreign expertise. However, the domestic policies or the national institutions are not responsible for the companies' innovation potential. They are presented only as an instrument that has also influence on the income inequality, taxation, infrastructure, etc. (Taylor, M., 2016).

An interesting idea is the theory of the "creative insecurity" presented in the book. According to that theory companies exhibit higher innovation achievements in times of international conflicts when dangers coming from outside overrun domestic struggles. The author describes several examples to fit in the theory and this makes the research intriguing as the author relates the innovation to times of war and external conflicts. Staying for a danger, the nation can consolidate and take the decision to contribute more to the development of science, technology and education. One of the models illustrated is the transformation of Taiwan. The external threat that the country confronted were the effects of the derecognition of Taiwan on the United States and the restoration of the relations with Mainland China. The internal oppositions pacified and identified the threat in the person of China. According to the author, this was one of the stimuli for the transformation of Taiwan from an agricultural economics to technologically advanced one (Taylor, M., 2016, pp. 250-257).

On the other side, to inspire the audience to trace the development exactly in the automotive industry, serves the book of Stephen Bayley „ Cars. Freedom, Style, Sex, Power, Motion, Colour, Everything " (2008, Conran Octopus Ltd.). The author depicts in a chronological way the introduction of the best models of automobiles, comparing them in their performance, design, motion and splendour. Bayley declares that the book does not provide statistical data on different components of the automobile production or technical specifications. His intention is to depict the automobile as a living creature and explain why people feel so connected to it and how the automobile found the right way to the hearts of hundreds of people. The book draws the contour of the automobile as a piece of art. The author believes that it is particularly the art that has turned the automobile into one of the most admired products. The automobile is unique in its appearance not only because of the development of the innovative technologies that are more advanced with time but mainly because the aesthetic value and impact that it has on a person. All of the other aggregates of the automobile could be measured or compared with the exception of the aesthetic dimension, the inspiration and the sensation that the automobiles create because of their colours and materials (Bayley, S., 2008, Introduction).

Soon after the automobile is made possible for the mass production, craftsmanship is involved in the design and manufacturing. Designers follow not only the requirements of the technologies and standards, but also these of aesthetics. Every single detail is strictly measured but also unique. Therefore, car designers are compared to Renaissance artists. It is not only about the color of the automobile or how the shine of the sun is reflected on its surface. Their artistry is caught in the millimetre-precise measurements. The same difficulty experienced the Renaissance sculptors in their portrayal of the ideal human body. According

to the design director of Jaguar a millimetre change of a line segment can make the curve “fat” or “anorexic” (Bayley, S., Introduction).

Furthermore, the author examines popular models from the mass production which become an embodiment of the technology and the culture and art of their era. The author states the automobile is the reflection of the culture of a society but in the same time affects and shapes it by referring to the music or fashion style popular for this century. Nevertheless, the author does not escape from the technical data on the components of the automobiles shown. He rather attributes them to their designers as leading innovators in many spheres and even to architecture streams or poetry for their names (Bayley, S., 2008).

Delving into the personality of the innovators in the automotive industry, we can also look at the „Engineering—An Endless Frontier“(2004) from S. Auyang and specifically at chapter 7 „Leaders who are engineers“. The author depicts the change in a period of 60 years of the share of top business leaders of big American companies with an engineering education. In 1900 the share of them is just 24 percent and in 1964 over 44 percent. Engineers do not engage only in technology and science. They are nowadays the link between technology and real business. The innovative technologies determined the headway of industries like the automotive or computer businesses. The engineers have the responsibility not only for the technological dimension but also for the organization and coordination of the working process. Several stories of engineers are illustrated who occupied high managerial positions. Alfred Sloan, one of the most famous presidents of General Motors had also an educational background in electrical engineering. He introduced the organizational structure of the General Motors, highly successful as internal format for a large automotive company. He used the technical thinking in solving complicated managerial problems. In the organizational approach that he uses, engineers could identify the concept of „abstraction, modularization, and interface“ that the scientific techniques operate with (Auyang, S., p. 267). Managers like Sloan, apply their engineering knowledge to the structure of real work and that makes the book also read worthy as it shows the alive relationship between the technological advancement and the proper organization of work in the company in order to achieve its goals. One of the many faces of the innovators in the automotive industry is that of the engineer.

Because the above mentioned writings are concerned with models mainly from the U.S. and Germany and with more general aspects, to get more information about the specific research field of the master thesis, we can reach for the article „From National Champions to Global Partnerships: The Korean Auto Industry, Financial Crisis and Globalization“ from J. Ravenhill. The article examines the response and the recovery of the Korean automotive business from the crisis in 1997-98. According to the author the Korean automotive branch has undergone a serious renewal. Five of the state-owned automotive companies are analyzed. Innovative technologies used in the automobile production in Korea and in foreign companies are compared. Possible developmental paths for Hyundai, Renault Samsung Motors and Daewoo are proposed. Furthermore, the competition power of the parts industry is considered and evaluated. The transformation of the industry is depicted in a frame of the political environment in Korea and several national strategies are represented. The international context is also investigated and the author studies the technological progress of the Korean automobile within the new partnerships (Ravenhill, J., 2003, Introduction).

An overview on the second automobile producer which the master thesis is interested in and namely the Japanese automobile industry is provided by the „The Japanese Automotive Industry. A guideline how to access the Japanese market“ (Swiss Business Hub Japan, 2014).

The report draws the national specifications of the automobile market and industry in Japan – the largest automobile producer worldwide, as it is considered to be to a great extent different from the European and the American industries. The report starts with an introduction in the Japanese economy, geography and important aspects of the employment in Japan. Furthermore, the Japanese automotive industry is divided in different segments such as the producers and suppliers, innovation capacity, the safety strategy, etc. and compared with global players. Production units, financial data and a brief description of the overall activities is presented for nine Japanese automobile producers. A special attention is paid to the electric drive technologies. Governmental policies are also considered as a tool for fostering hybrid projects. However, the report argues that the energy sector in Japan needs a liberalization and the current national policies are incapable of escaping from the dependence on atomic energy („The Japanese Automotive Industry,“ pp. 36-40).

Moreover, the study describes the technological aspect of producing an automobile and its engine in Japan, the materials, resources and the general and electric components used in the process which is highly relevant for the master thesis. Value is attached to the clean technologies and the Japanese environmental policy framework for the automobile production (Ibid., pp. 60-70).

In dealing especially with the innovation capacity of the automotive firms, the reader can go through the paper „The highway to growth. Strategies for automotive innovation“ (PwC, 2013). The paper examines the manner in which automotive businesses apply innovative thinking in order to expand, the adjustment of their approach toward innovation determined by external factors and the successful strategies that lead to concrete outcomes. The results of the study rely on interviews with senior executives in the automotive business who are in charge of the innovation concept. In order the company to have a leading position in the innovation it should have available a strictly defined innovation strategy that the majority of the companies are missing. Businesses are advised to focus their investments not only in the research and development sphere and the interaction with the customers which is not sufficient anymore and they have already devoted financial resources to these areas. According to the survey, automotive industries need more innovative practices in the supply chain and new business models in the direction of new partnerships (for example corporate ventures or business incubation). Additional strategy is the creation of an internal innovation culture among the employees. In this manner the company can draw the attention of talented people (PwC, p. 29).

One of the major purposes of the innovative strategies of an automotive company is nowadays the reduction of the waste gases of the automobile and the development of environmental friendly technologies for its manufacturing. The research paper „Factors Influencing Automobile Firms' Eco-Innovation Orientation“ (2014) from Segarra-Oña, Peiró-Signes and Payá-Martínez addresses the limited literature on the topic and provides information about the matter which factors of the company's decision about the production process and the organization of work stay in a relationship with the ecological orientation of the company, in other words which factors motivate the automotive company to foster the eco-innovation. The framework that the researchers use is the Spanish Technological

Innovation Panel (PITEC) which is a panel data measuring and evaluating the innovation performance periodically. The study deals with more than 200 automotive companies and also with the latest data. The two significant variables are the variable „Fuente“ (Source) and „Object“ (Objective) where the first describes the origin of information and the second the goals that companies contemplate in their innovation activities (2014, p. 33).

The investigation searches for a relationship between the information sources of the market, the form of the innovation that the company exhibits and its ecological engagement. Applying the framework and a set of measurements the researchers come to the results. Companies that value the market information sources in their innovation strategy such as indications from customers or rivals are more likely to concentrate on the product and process innovation. This means that they try to minimise the cost, the energy consumption or reduce the waste for a manufacturing a product or they aim to increase the range and the attractiveness of the variety of products or their substitutes, expand to new opportunities, etc. Therefore, these Spanish companies are found to be more ecologically oriented in their innovation activities. The results have been also acknowledged from other researchers, cited in the study, who stated that the higher the opinion of market interested partners in the ecological matters is valued, the higher the focus of the company in its ecological engagement (Ibid., p. 36). Companies can also find valuable suggestions in the practical implementation of the product and process innovation in the recommendations‘ part of the research paper.

A comparison of the materials and resources used in manufacturing the body of an automobile back in the beginning of the twentieth century and nowadays with the vision of new components in the production stage illustrate both of the papers „Materials used in automobile manufacture - current state and perspectives“ (Wilhelm, M., 1993) and „Materials in Automotive Application, State of the Art and Prospects, New Trends and Developments in Automotive Industry“ (Ghassemieh, E., 2011).

The choice of the material compilation for the manufacture of an automobile depended in 1993 on the requirements coming from the customers’ needs and the national policies for the automobile production. However, M. Wilhelm suggests that the selection of the materials in the future years would be affected rather by environmental standards and new needs. His assumption is approved in the second paper, where the reader can witness the new class of composite materials used in the modern vehicles. In the German automobile production steel and cast iron account for approximately 70 percent of the materials utilisation in the automobile construction. Aluminium and polymeric materials constitute 5 and 11 percent respectively. On the other side, steel and iron hold their dominant share in the manufacture nowadays. However, their nature experienced several improvements and are now under further refinement to reach to innovative concepts of stainless and high-strength low-alloy steel that provide better characteristics from a mechanical point of view and stronger corrosion resistance (Wilhelm, 1993, pp 33-34).

The application of aluminium increased considerably in contrast to the past years of automobile production. It displays noticeable advantages compared to the steel because its density and lighter weight. In the construction of modern cars aluminium is the second favoured and applied material because it fulfils both the requirements of the customers for driving a vehicle with better performance and the environmental regulations as it contributes to the fuel economy of the automobile. Therefore, the aluminium usage proved to become even more admired in the automobile manufacture than M. Wilhelm proposed (Ibid., p. 40).

Moreover, the usage of the polymeric materials experienced also a predictable growth. Wilhelm suggests an increase from 11 to 15 percent for the German industry in 2000 (Ibid., p. 33). The application of polymer-composite materials in the global manufacture of automobiles grew from 6 to 13 percent within 30 years (Wilhelm, M., p. 33; Ghassemieh, E., pp. 387-388). However, we can witness not only a shift and advancement in the application of materials but also a development in the assembling techniques which play a significant role in the manufacture process. For the application of steel innovative techniques such as laser beam welding and in the metal fabricating - the hydroforming take place. The innovation in the process of metal fabricating and forming is as important as the innovation in the material's advance (Wilhelm, M., p. 37; Ghassemieh, E., 2011, p. 377).

A further research explicitly on the application of polymer-composite materials in the automobile body and parts presents the paper „Polymeric Materials in Automobile" (Strumberger, Gospocic, & Bartulic, 2005). The scholars investigate the development of the usage of seven polymer-composite materials, their advantages, disadvantages and features by manufacturing internal and external parts, engine compartment parts, structure parts and the body. Four techniques of forming the materials for the automotive parts production are described and recommendations are made in which direction every procedure of processing the polymers can be advanced.

An insight into the development of new safe systems in the modern vehicles give Staszewski and Estl in the report „Making Cars Safer Through Technology Innovation" (2013). One of the major objectives in the innovation strategy of the automotive companies is the passengers' safety. Due to breakthrough systems that can sense the environment the automobiles become more independent machines. The researchers describe the characteristics of the new technologies that enable the semi-autonomous and fully autonomous automobile navigation. In order the current safety technology to become fully autonomous, it should experience a development in four stages starting from the passive visual warning (parking or rear view cameras) through the traffic-aware cruise control adjusting the speed to maintain a distance from other vehicles to the fully autonomous sensing of the environment without the presence of the driver (Staszewski & Estl, p. 3). However, the advancement of the technologies leading to the last stage is still restrained by legal and social restraints as the innovative electronic technologies that are involved in the autonomous navigating exhibit failures and faces distinct challenges (Ibid., p. 4).

Last but not least, an enhancing of the perspective provide the scholars M. Hård and A. Knie in the article „The Cultural Dimension of Technology Management: Lessons from the History of the Automobile, Technology Analysis & Strategic Management" (2001) which is relevant for investigation as additional knowledge source because the scope of the master thesis does not cover the sociocultural aspect. The article argues that a company while investing in new technologies should maintain its manifold vision. The narrow focus only on the technological concepts is disapproved. The technological innovation functions in a set of social, organizational and legal factors of the company. It could be an invention or just an improvement of existing activities and ideas. Therefore, in the process of application of these novelties the managerial attention should be paid to issues not related only to science and technology but also to find the right place of that technology in the „cultural ambience" of the group and enable it in this way to function within the current organization of work (Hård & Knie, p. 92). The basis for the study is the theory of the „cultural ambience". According to the theory the cultural ambience is the environment which allows the new technology to

accommodate to the society which will use it. Therefore, innovators or managers have to develop specific strategies which will ensure the access of the novelty not only to the market but also to its consumers. So its consumers have to be persuaded that the novelty can fit easily in their habitual activities and even improve them. The novelty should not violate the law in this society.

The authors present and investigate four case-studies of innovations in the automotive industry applying the „cultural ambience“ theory because the automotive industry features authoritative firms and strong systems of connections (Hård & Knie, p. 92).

The four case-studies are based on different attempts of large automobile producers to innovate in the direction of offering an alternative of the petrol engine. However, in order the electric vehicle to be accepted and used in the real life, it should not be acknowledged as a peril for the petrol engine because the petrol engine itself is strongly embedded in the daily routine of drivers worldwide. Most of them in turn feel emotionally connected to their automobiles (Ibid., p. 94).

On the other hand, from an economic, legal and political point of view, many stakeholders do not have the financial interest in promoting alternative options of the petrol engine (Ibid., p. 97).

The paper provides suggestions to questions like what can the users of a novelty (such as an electric car) do, if others do not let the novelty to find its place in their environment. Or, how can an owner of a new electric vehicle maintain it, if the only one manufacturer becomes bankrupt (Ibid., p. 99).

By gaining the basic knowledge in the research field of the master thesis, the reader itself can note that the different literary sources address the single components in a different manner and touch relevant aspects which the master thesis acknowledges and applies in its intention to bring them together and develop its own stand in answering the research question.

4. Theory

4.1. Theory of Technological Change – the Five Propensities

Historically, there is in the economic studies a small number of researchers who engaged gravely in the sphere of technological innovation. The leading role among them plays J. Schumpeter who is the pathfinder of creating a space explicitly for the theory of innovation in the economic studies (Godin, B., 2008; Sundbo, 1998). In the period when Schumpeter developed the concept of the innovation theory, the Keynesian theory was the dominant concept for the regulation of economic activities. However, during the economic collapse in the 1970s the application of the Keynesian framework exhibited difficulties and new regulatory mechanisms drew the attention of the economists. These circumstances let the innovation theory take its course. In a time of depression or economic decline, the solution is seen in the innovation which has the potential to foster new ideas, development and growth. In his concept, Schumpeter believed that the entrepreneurs are the driving force of the growth as they generate innovation (Sundbo, J. 1998, p. 4). The significance of the concept of innovation is seen to be manifold. On the one hand, the national economy can benefit from the innovation during a decline of the economic activities. On the other, the theory of innovation is particularly relevant for the private business as well as it can increase its opportunity to develop and expand.

On the other end of the spectrum, according to the scholar M. Moldaschl, a theory that seeks to provide a general explanation of the innovation science could be compared to a „theory of everything“ (Moldaschl 2010, p. 8). Researchers face difficulties to elaborate a common accepted theory of innovation because as Kuznets stated „we may be doomed to a position in which we can measure only economic growth, but not its causes“ (cited in Godin, p. 351). The lively discussion on developing the right theory to explain innovation is nowadays still present.

Taking this criticism into consideration, one should acknowledge that the researchers in the field of the innovations address it through distinct approaches and focus on different forces that create innovation. A part of the theories are concerned with the technological advancement, other with the personalities of the innovators, third aim the attention to the competitive environment and the market (Sundbo, J. 1998, p. 4).

Schumpeter recognised the significance of the innovation in regard to the economic growth and the important role which technology and innovation play in the economic development. But he did not analyse the process of creation. Nor did Schumpeter dedicate further efforts on the impact of science as an engine propelling development (Maclaurin, 1953, p. 97).

An organised analysis of the process of innovation has elaborated W. Rupert Maclaurin who brought forth the concept of Schumpeter in his paper „The Sequence from Invention to Innovation and Its Relation to Economic Growth“ (1953) illustrating the innovation as a process constituted from several phases. His work, named years later „Linear Model of Innovation“ or „Theory of Technological Change“ dissects the process of technological innovation into smaller pieces and develops specific techniques to measure it (Godin, B. 2008, p. 346). The purpose is to develop specific method that involves the measurement of defined

criteria capable of determining the propensity of a developed economy or industry to innovate. The author frequently refers to the situation in the US.

In order to develop a methodical approach to tackle the innovation, one should first define the innovation. The theoretical part of the master thesis applies the definition of Schumpeter according to whom innovation comprises five constituents and the presence of only one is sufficient:

1. introduction of a new good
2. introduction of a new method of production
3. opening of a new market
4. conquest of a new source of supply of raw materials or half-manufactured goods
5. implementation of a new form of organization (Schumpeter cited in Godin, 2008, p. 344)

Schumpeter also defines the distinction between invention and innovation (Ibid.). Maclaurin develops further the distinction between them. Innovation does not follow invention as a rule. In his consequent research paper „ Innovation and Capital Formation in Some American Industries“ Maclaurin makes a stand against the interpretation of the innovation by A. P. Usher, economic historian and the author of „The History of Mechanical Inventions“ (1929). Usher claims that innovation is simply an „emergent novelty“, but Maclaurin argues that it is a more ample concept (Maclaurin, 1955, p. 552).

The invention characterises with an „operational method“ that produces a new good (Maclaurin, 1953, p. 102). The legal framework of the specific country is responsible for the opportunity to patent that novelty. Invention and innovation are two different ventures, whereas the innovation encompasses all the new and possible improvements and advancements of an object or technology and therefore is a much larger concept. As Maclaurin suggests, the introduction of a new method of production of an old product could be a more significant milestone in the progress of an industry than the market introduction of a new product or the invention respectively. As Schumpeter states:

„*It is entirely immaterial whether an innovation implies scientific novelty or not... Innovation is possible without anything we should identify as invention*.“ (cited in Maclaurin, 1953, p. 105) Therefore, most of the developments in the automobile industry Maclaurin marks as innovations that are „improvements“ of the classic technologies (Ibid., p. 106). According to Maclaurin, a commercially launched invention becomes an innovation, but innovation encompasses a broader spectrum of all the new potential improvements of a product or process (Ibid., p. 105).

Maclaurin is the first economist who devotes his attention to develop a systematic theory on the technological innovation. On the way of elaborating the theory Maclaurin consulted Schumpeter on the method for studying the innovation. Schumpeter conveyed the advice that the researcher can use the historical approach for analysing the industry or specific companies. According to Schumpeter ‘‘the emphasis is not so much on the relation between innovations and economic development or business cycle...“ but rather on the historical analyses, studying industrial monograph series and the profiles of successful business pioneers (cited in Godin, 2008, p. 346).

In that time as Maclaurin becomes determined to elaborate a theory on technological change, there is a very limited number of scholars who engaged with the factors that create technological innovation in specific industries. The advance of technology is believed to be a part of the historical and social studies and the main interested stakeholders were private companies (Ibid.).

The term technological change or technical advance does not appear frequently in the economic articles and researches to the end of 1930s. The term defined the replacement of the input of labor with capital, in other words the replacement of human employees with technical equipment. It is Maclaurin who initiates the extension of the semantics. He places the emphasis on the development of new goods and not only on the technical equipment in the manufacture phase. In this way, after the devotion of Maclaurin the economists start to use the term in both connotations (Ibid). And so the term has progressed and was defined in 1960 by the American President's Commission on National Goals as „*technological change is the development of a better way of doing a known job or the discovery of how to do a previously impossible one*" (cited in Godin, 2015, p. 5)

To explain the process of technological change Maclaurin splits it in several elements. The five distinct stages whose variations should be measured are as following:

1. The propensity to develop pure science.

2. The propensity to invent.

3. The propensity to innovate.

4. The propensity to finance innovation.

5. The propensity to accept innovation (Maclaurin, 1953, p. 98)

According to Maclaurin, the degree of the development of these propensities in the developed economies varies and is not equal. Great Britain is believed to have for 30 years time starting in 1900 a stronger propensity for developing pure science in contrast to the USA. The evidence for that statement Maclaurin sees in the larger share of Nobel Prize laureates in Great Britain which is a measurement for the development of pure science. On the other hand, there are in the same period higher number of new companies established in the USA than in Great Britain which gives the argument to state that in the USA the propensity to innovate is more active (Ibid.).

a. The propensity to develop pure science

In the innovation theory, the first determinant is the factor „propensity to develop pure science" which has not been considered before the introduction of the theory (Ibid, p. 97). Not only Maclaurin regards the pure science as an engine for innovation. Simon Kuznets, American economist and Nobel Laureate, underlines the significance of the pure science as well: „*... and if the various regions of the world are for the first time in history so closely interrelated as to be one, some new major growth source, some new epochal innovation, must have generated these radically different patterns. And one may argue that this source is the emergence of modern science as the basis of advancing technology - a breakthrough in the*

evolution of science that produced a potential for technology far greater than existed previously." (Kuznets, 1971)

The term „pure science" as science for its own sake needs further explanation. In its transformation from pure to applied science the material interest of the scientist cannot be excluded. As discussing the history of modern science in Europe emerging in the era of the Renaissance, Maclaurin assumes that the scientists were affected by pragmatic motivation. So there is always something „impure" in the science (1953, p. 98). Under „pure science" he advises to be understood rather the vigorous dedication of scientists to its creation without an instant pragmatic or material objective. The importance of the pure science is related to the power of the scientists to give responses and solutions to broad and open problems which can be applied usefully by the society. The workshop for creating pure science is the university which gives the researchers motivation and independence to develop knowledge.

Having the significance of the pure science in mind, companies started to finance their own laboratories with the notion that pure science cannot immediately perform practical results. In its further application and development pure science can successfully lead to tangible benefits. The conclusions of the investigation can lead other researchers to new findings that will be eventually of use in a specific industry.

The way of measurement of the propensity to develop pure science Maclaurin sees in several points. First, due to the new statistical tools and unrestrained information flow, a country can always collect statistics how many scientists are engaged in the field of pure science and how many of them did contribute to its progress broken down to specific areas of research in certain place and period. Based on the results researchers could assess the impact of main advancements and make predictions about „the probable time-scale involved in their commercial introduction." Maclaurin considers that the rise of innovative technologies in the automobile in 1920s could have been predicted ten years before (1953, p. 100). The inquiry can be done in two steps. First, a „probable rate of development based on past evidence" and the contemporary propensities of a state „to invent, innovate and accept innovation" can be determined. Second, an „optimum rate" of development „based on an evolutionary improvement in the institutions affecting the various propensities" should be proposed. In this way, the researchers can make statements on the „general course of development" and detect factors that can influence it (1953, p. 101).

The second element is the financial incentive for stimulating and creating science. The allocation of funds for laboratory equipment, etc., described as „ the budget of science" is relevant for Maclaurin. He states that the amount of the budget, invested in science could have an impact on the achievements (1953, p. 101).

b. Propensity to invent

Maclaurin claims that the propensity to invent has the potential to have a more instant influence on the course of the economic development of a country than the predisposition to pure science. He gives the example of the brisk prosperity of the Roman Empire that uses the pure science knowledge developed in Greece for its economic progress. The researcher underlines the characteristic trait of the invention in revealing „an operational method of creating something new." (Ibid., p. 102). The process of creating the novelty is described in

detail by its inventor in their patent application. Therefore, the number of patents issued is one of the measurement tools for the propensity to invent. The patents in turn should be separated in two groups – basic patents as pioneer patents, and improvement patents. Maclaurin argues that often more important for the inclination to invent are the basic patents because the improvement patents can exhibit just a small upgrade. The example refers to Joseph Swan in the sphere of the electric light. The first patents of Swan in the field of creating a lamp without bulb darkening showed a substantial progress in the development of concepts for further utilization. Future improvements of the lamp such as the inside frosting of incandescent lamp did not change the line of inquiry and exhibited just a slight change (Ibid).

When we speak about companies and their number of patents issued a fact should be considered. Two businesses in the same commercial field can attach different level of importance to the issuing of patents. In the same time both of the companies can similarly stimulate the research and creating of knowledge. A firm that is eager to monetise its new products and generate revenue through royalties will reasonably rely on strong patent development and application. Its desire will lead also to the engagement of law solicitors and produce a considerable number of inventions and patents respectively (Ibid., p. 103).

Researchers in the social sciences as Gilfillan, a former Research Associate in sociology at the University of Chicago and the author of „The Sociology of Invention“ (1970), denies the patent statistics as a reliable measurement tool for the invention capability (1960). In his purpose to measure the invention potential in America he studied 500 inventions valued as socially significant over time starting from 1782. He accuses the patent statistics in being inherently subjective authority as it embraces absolutely different in its nature components putting them under the same title. Gilfillan concludes that only around 15 percent of the technological inventions take place in fields where the patents are important (Gilfillan, 1960, pp. 202-210).

By giving a relative importance through government expenditure on activities for example in the military sphere and concluding a decline of patents in this field and therefore a refusal of the patent statistics as a measurement tool for invention, Gilfillan tends to make an exaggeration by giving importance to some industries and underestimating others with potential to grow. According to Maclaurin, patents reveal specific trends in different industries over time and show the influence for example of legislative changes on patents (Maclaurin, 1953, p. 103; Hall, 2004). In „Invention and Innovation in the Radio Industry” (1949) Maclaurin acknowledges the drawbacks of the patent statistics but also its importance for giving the companies the ambition to patent their discoveries and conduct research (Tew, B., 1950, p. 255).

Furthermore, Maclaurin suggests that the share of the scientists employed creating applied science in a given laboratory can be a measurement for the inventive effort. One can presume that there is a relationship between the number of scientists, the expenditure on applied science and the outcome (1953, p. 104). The same measurement tool suggests Gilfillan as well. He also adds the calculation of the amount of work done by the employees devoted to the task within a given period (1960, p. 205). Taking this assumption into consideration, we should be careful with the estimation of the efforts of a whole team of researchers and the invention capability of a single but a brilliant inventor. However, as statistics reveal the number of patents hold by companies grows constantly in contrast to the fall of the individual patents share. In 1885 corporate discoveries constitute 12 percent of the total figure of

patents. This share experiences an exceptional growth reaching around 75 percent in 1945 (Maclaurin, 1953, p. 104).

It should be also stated, that not all the researchers employed by the enterprise have the same knowledge and experience required for the creation of novelties. A further limitation for the large companies and their invention capabilities is that they do not make a proper differentiation in their reports of the personnel engaged in the research center – scientists, engineers specialised on technical issues, or laboratory assistants (Ibid). That limitation wants Galfillan also to overcome in finding the answer of how to estimate the value of the time of a skillful professor devoted to the process and the value of the time attended from a child in the kindergarten. However, statistics on these indicators are impossible and therefore he concludes that nobody can acquire such statistical investigation. The only possible direction is to *„find fair indicia... concomitant with the inventing we seek to measure*." (Gilfillan, 1960, p. 205). Therefore, Maclaurin aims the attention to the number of researchers devoted to the process and the budget in their hands.

c. Propensity to innovate

In the part „The Propensity to Innovate" Maclaurin draws very accurately the distinction between the invention and the innovation. The transition from the discovery to the innovation is clearly not by default because the innovation encompasses more far-reaching perspectives and new visions that the invention could cover.

One can actually note, that Schumpeter gives higher priority to the individual figure of the innovator as a driving force for the development of innovative concepts than Maclaurin does. Schumpeter considers the role of the innovators as „the most sensitive individual figure in the economy" (cited in Maclaurin, 1953, p. 97). Because of the value attached to the personality of the innovator Schumpeter did not believe in his first concepts that large corporations can play a significant role in the process of creating it. The same thesis defended Gilfillan as well (Gilfillan, 1960, p. 206).

According to data provided by Maclaurin, the extensive industrial research in the 1930s, conducted in the research centers has led to the establishment of a vast number of inventions concentrated only in larger corporations. For reference, in 1938 almost a quarter of the patents in the US are owned by the 450 biggest enterprises (Maclaurin, 1953, p. 106).

Because the trend continued to grow in the following years Schumpeter adjusts his views. As Maclaurin states, in the book „Capitalism, Socialism and Democracy" Schumpeter recognises the large companies as innovators. He acknowledges their innovative effort because they produce and design in their laboratories and research centers what they have consumed. But they have a more far-reaching potential according to Maclauirn as the large enterprises do not consume all in all they are able to create. The big companies develop a particular line of interest that they can further specialise on (Ibid., p. 107).

Maclaurin describes the time he lives in as a period, where the fundamental scientific discoveries could be smoothly introduced and materialised in the real life and after that practically used. The industry experiences its own individual and visionary drive to innovation that can influence the pure science and its discoveries in a productive manner. However, the reverse interaction Maclaurin has termed as weak. But here in the gap of the mutually

satisfactory interrelation come the research centers and laboratories designed specifically for industrial research sponsored by the large corporations. They possess the power to unify the pure scientific discoveries and the industrial propensity to innovate. As Maclaurin states, big television providers as Telephone Company and General Electronic could make a profit on their investments after 20 years of investing in specialised television research (Ibid.).

To measure the propensity to innovate Maclaurin suggests a study over time individually for every industry. The annual sales volume of goods which are related to the new products can be studied. One should analyze the change of the defining features of the products or the retention of them. Additionally, one can study the amount of financial means that have been invested not only in the immediate effects of the innovation but also in its secondary as well. Maclaurin claims that by carrying out this activity and announcing the evaluations this shall provoke criticism which will lead to an improvement of the concept. This process shall also show if there is a trend in the development of innovation over a period (Ibid., pp. 103-104).

In his last research paper in 1955 „Innovation and Capital Formation in Some American Industries" Maclaurin underlines that advanced technological improvements are expensive. Therefore, in order to finance innovation the company shall rely on generous financial support. According to Maclaurin, an invention to be realised does not need in any case an extensive budget. For example Thomas Edison succeeded in inventing the practical electric light bulb with basic technical equipment. In contrast, further refinements in order to achieve perfection of the lamp involved more complicated testing procedures and expensive technical apparatus. The product should be compared to other competitive products that already have been refined which makes the experiments even more costly. Therefore, the propensity to innovate is depending on the capability to finance it (Maclaurin, 1955, p. 560).

d. Propensity to finance innovation

The discovery and the innovation are not sufficient to measure the capacity to innovate. In order the new developments of a product to take place, the research on them should be financed. Maclaurin sees the solution in the establishment of private investment organizations that have the possibility to provide immediately credit to new businesses.

A further component for measuring the capacity to finance innovation is the figure of new plants developed. The researcher suggests that the number of the new plants built by an enterprise can be an indicator for its propensity to fund innovation. He claims that many American corporations construct the new plants in order to use them for the production of a new good and the old products continue to be made in the existing facilities. However, it is not absolutely sure that the new plants will be used exactly only for the creation of new products. But Maclaurin relies on the fact that it is very hard for an enterprise to support a new plant with resources coming from the profit and the increasing number of new plants built is a clear signal that fresh financial assets are „being made available for innovation." (Maclaurin, 1953, p. 110).

At the time of the research conduction by Maclaurin the figure of the research and development expenditure was not a part of the debate as the information was not available in that period. The committee on Science and Public Welfare, where Maclaurin participated as a secretary, published only a report that investigated the amount of the R&D expenditure

as a part of the national budget. Statistics become accessible at the beginning of 1960s prepared by the American National Science Foundation (Godin, 2008, p. 351).

e. Propensity to accept innovation

The last stage of the Maclaurin's model is the assessment of the propensity to accept innovation. To measure it one should take into consideration the different level of probability to accept something new in distinct cultures and societies. The researcher concludes that the path to the acceptance of innovative products in the US is not a long one and new products are welcomed if they satisfy customers' needs and its initial defects are removed. But Maclaurin challenges the trustworthiness of the past to provide an advice to the future innovations. He claims that a developed economy faces also advanced innovations and to respond to the new major developments, the industry and the government should undertake jointly steps (Maclaurin, 1953, p. 110).

The author gives an example of the aerospace industry that advances rapidly. The number of private airplane manufacturers increases and many small planes could be manufactured and sold at an affordable price. So wealthy people can use them in their holidays instead of an automobile. In order this to occur, a number of small landing terrains should be built up not only in the big but also in several small towns. However, the big cities in the US are overbuilt. This in turn would demand the expropriation of private property, with other words the government would acquire private land for public purposes (Ibid.). Therefore, the government and the industry have to act together.

Maclaurin suggests measuring the acceptance (called also diffusion of innovation) in studying the growth curves for various goods and services in distinct circumstances. The study shall be done in order to figure out what trend can be found for the time and requirements needed if there is a deviation in certain case for an innovation to be accepted (Ibid., pp.110-111).

4.2. Application of the Theory

It should be stated that Maclaurin does not publish any precise statistics in his research. Based on his approach to measure the potential of an industry to innovate, Maclaurin investigates in 1954 13 industries and tries to categorise them according to their „ technological progressiveness" in a period of 25 years. He intends to organise them depending on their capacity to introduce new and advanced products or services. In this way Maclaurin suggests three levels of classification of the industries – with high level of progressiveness (with other words with high potential to introduce new developments), with medium level and with low level (cited in Godin, 2008, p. 352). The researcher analyses the large enterprises and the most important technological innovations in the period from 1925 to 1950. To define the most important technological advancement in these industries, Maclaurin does not rely on his estimation but approaches experts in the different industries. The results reveal that the chemical, photographic, airline and the petroleum industry were found to have the highest level of progressiveness in the innovation introduction. The television and radio industries and the electrical manufacturing exhibited features to be high progressive. In comparison, the automotive, pulp and paper, and steel industries are classified to be of medium

progressiveness. As low progressive are classified the food processing, coal mining, the cotton industry and house assembling (Godin, p. 352).

Few years later, the scholars C. Carter from the Queen's University Belfast and B. Williams from the Keele University conduct research on the technological innovation for the British Association for the Advancement of Science. The scholars study 150 companies and categorise them as *progressive*, *moderately progressive* and *non-progressive* companies in respect to their capacity to introduce, develop and apply technological innovation. They classify the companies with the best accomplishments (for example those with the highest profits) as progressive and begin to search for common characteristics. After that the scholars analyse the non-progressive companies with respect to those characteristics. However, both of the researchers acknowledge that their method does not have specific criteria that could measure precisely the innovation capacity. Therefore, their method does not inspire further investigation (Carter and Williams, cited in Godin, B., 2008, p. 353).

Maclaurin's classification of the companies' progressiveness has influenced the debate in the US started in 1960 on the international competitiveness of American and European products with an emphasis on the technology. His idea about the progressiveness brought about the concepts of the „high technology" and the categorization of some industries in „technology-intensive industries" which were applied by the American Department of Commerce and after that by the OECD in evaluating the American trade performance in Europe. The name of the concept is bound by Maclaurin's classification of high, medium and less progressive industries. According to the Canadian historian Benoît Godin who has conducted a large-scale research in the history of technological innovation, the only one component that differentiates the high-technology from the technological progressiveness is the statistics. As Maclaurin also admitted, the classification of the industries in their technological progressiveness was more or less subjective. In comparison, the high-technology is explained by means of the statistics (Godin, B., 2008, p. 353).

One of the major assumptions of Schumpeter is the existence of a relationship between the innovation and business cycles and economic growth. According to Schumpeter, significant innovations influence the economic development and business cycles. The primary innovation carries a secondary wave of innovation (Godin, B., 2008, p. 355). Therefore, Maclaurin illustrates case studies of several industries with the aim to define the factors and reasons for the inconstant technological breakthroughs. The researcher aims his attention, applying the Schumpeterian methodology, to the mercurial twists of innovation's temperament that is able to cause in specific economic sectors growth, maturity or slowdown (Maclaurin, 1955, p. 552).

Maclaurin argues that the entrepreneurial spark is exceptional and infrequent. Many economists have assumed that if an industry characterises with a technological progress and there is a stimulus for economic activity, innovators would definitely come out. In opposite, Maclaurin states that opportunities and chances often are accessible for years expecting the right visionary person who can discover them. And once, the creative flow is activated and the first obstacles overwhelmed, the „imitative process" could be performed by people with secondary expertise. When the capacity of the initial breakthrough has been entirely utilised, years can pass by until the right combination of new entrepreneur, ideas and actions arrives to develop it to a higher level. Therefore, Maclaurin compares the technological innovation with a „wavelike movement". In the research paper, he traces the answer to the questionable

sequence of the propensity to develop pure science, to invent and to innovate. For this purpose, Maclaurin suggests an inquiry into the aviation industry, classified in his previous paper to be of highest progressiveness; the both industries with high progressiveness – radio and television, and electric manufacturing; and the automotive industry, categorised to be of medium progressiveness (Ibid.).

The automotive industry is characterised as one of the most energetic industries in America which experienced up to the middle of 1920s a brisk growth and strong technological innovation. In contrast, the late 1920 were market by a standstill and nobody can predict its end and the time of the new stage of development. A part of the reasons Maclaurin sees in the lack of sharper focus on the research, the quality of the management, the vigorous growth in the past and the successful domination by a few large companies (Ibid., pp. 552-554).

The development that is forced by Henry Ford and makes him successful automotive entrepreneur is the shift towards flow production and transforming the automobile from luxurious and expensive product into a mass conveyance. Therefore, he steers the technological change to that direction and the innovation that he developed is in the field of systematically reducing the costs. Ford is described as an experienced mechanic but he lackes professional expertise in terms of higher education. In his ambition to make a change in the automotive industry he (but his competitors as well) never conducts scientific research. Maclaurin states that probably many people in 1920s expected that the automobile was ready to face „basic innovations“ but in reality it was not. The entire control of the company was concentrated in Ford's hands who was becoming older and could not overcome the drawbacks of the transmission in Model T until the competition put pressure on his concept (Ibid., p. 554).

However, the leadership is not the only reason behind the problem. The automotive industry at the end of the 1920s lacked the economic incentive for the technological innovation. The customers needed a reliable and stable, but also a simple automobile at an affordable price. In order to produce the affordable automobile Ford developed an assembly line that changed the way of manufacturing of the vehicles. With the evolution of the assembly line the costs and the time for the construction were noticeably reduced. The vehicle local distribution was also well organised and private organizations were established for financing the purchase of an automobile. There was also the possibility to buy a second hand automobile and the used vehicle market functioned efficiently. Therefore, one could think that the automotive industry has arrived at its maturity. The further improvements of the concept of the automobile did not change its entire image. They were only refinements of existing ideas and extensions of the use of some accessories and automobile parts. The automobile acquired a heating system and an entertainment system. Improvements were performed in the petrol consumption and the quality of automobile tires was increased in order to have a longer lifespan. Moreover, the refinement of the automobile was encouraged by the appropriate government policies which created a better infrastructure and quality of roads so the ordinary people can enjoy their ride. That is why, the automobile was seen to satisfy its customer's needs in a sufficient manner (Ibid., p. 555).

The opinion of Usher is presented also in the research paper. According to the scholar, in a developed economy the need for technological change is continuous. The entrepreneurial to build something extraordinary goes hand in hand with the technological progress and the dynamic society. However, as Maclaurin suggests, the automotive industry has favored to

embrace the „recreational use“, and the satisfaction with the present investment and technological apparatus instead of major innovation and the large provision of new finance for technological equipment. As speaking about the year 1955, Maclaurin still does not recognise any profound technological progress of the automobile concept since the end of 1920s (Ibid.).

The lack of fundamental research in the automotive innovation is a further reason for the standstill of the technology. The research that has been applied is assumed to be only an „advanced engineering development“, which aims immediate commercial success (1955, p. 557). Therefore, Maclaurin walks away from the use of the term „research“ as he links it to the pure inquiry that does not follow steadily the delivery of pragmatic solutions. The researcher considers that it will require more time for the automotive industry to assess its research potential and he suggests that a significant shift and technological change would appear in the coming decade. Nevertheless, Maclaurin does not claim that the conduction of pure research will automatically lead to better technological results or would be a stimulus for developing major innovations (Ibid.).

The reason is that, the automobile itself relished a mass success without the conduction of fundamental research. A large automobile manufacturer has the ability to maintain itself and persist over time and as underlined by Maclaurin *„especially if it uses creative research as a method of regeneration“* (Ibid.). However, as he states, these claims do not stand for a prediction that the automotive industry is not capable of technological change. Rather, these assumptions and intimate inquiry into the industry support his view that the automotive industry is a part of those economic fields where the technological change is discontinuous and does not exhibit straight-line growth rates. Its investment growth is caused instead by vibrant forces (Ibid.).

As opposed to the discontinuous innovation profile of the automotive industry, Maclaurin suggests to investigate the continuous innovation power of the electrical manufacturing and evaluate if there are distinctions in their capability of technological change. The difference here is that the progress of the electrical manufacturing and the telephone industry is combined with the involvement of pure science and research since its early stages of development and the automobile industry was accused of not applying in their research concept fundamental science but rather developing improvements for immediate gains. Therefore, in his previous work Maclaurin classified the electrical manufacturing industry to be of high progressiveness and the automotive of medium (1955, p. 557).

Besides its advanced laboratory, the devotion to the fundamental research and the number of respectful scientists, it took for General Electric around ten years of time to take the step from the incandescent lamp to the new mode of lighting – the fluorescent lighting. According to Maclaurin, the research was conducted, the knowledge was there and the technology available still at the end of 1920s, and the fluorescent lighting was introduced ten years later. He claims that there was no obstacle for the development of the fluorescent lighting. In this line of thinking, the researcher assumes that „We have reached such an advanced stage of engineering that, if the basic research has been done, many inventions can be made to order.“ (1955, p. 560). The development of a new mode as in this case of lighting the process of the discovery or innovation is not only in the hands of the inventor. The company has at its command a professional research team, and with a wise steering and sufficient budget, the definite aim to make the shift to the new mode of lighting is mainly the responsibility of the

management. Maclaurin discloses his own belief that the only possible reason for him to delay a major technological development with ten years, despite the availability of the inquiry and technology, is the strong concern of the management not merely about new ventures but rather about the conservation of the past favourable outcomes (1955, p. 560). The automotive industry experienced the same. As a further evidence for his thesis Maclaurin states that the years of the introduction of the new method of lighting coincided approximately with the expiration of the last patents for the incandescent lighting (1955, p. 559).

An interesting point is the issue about the research on the atomic power. According to Maclaurin, the chances of the commercialization of the atomic power were unthinkable back in the 1920s and 1930s. The companies' leaders were most concerned with the preservation of the success of their current ventures and profit. And even entrepreneurs, who unfold their entire potential and innovative thinking, are not willing to rush into the far future despite the fact that in their progressive development they rely on the scientific research. As Owen D. Young, the chief counsel of General Electric, has stated: „*Fifteen years is about the average period of probation and during that time the inventor, the promoter and the investor, who see a great future for the invention, generally lose their shirts. ... This is why the wise capitalist keeps out of exploiting new inventions and comes in only when the public is ready for mass demand*" (cited in Maclaurin, 1955, p. 559).

The major technological breakthrough from the point of view of the economy, which would have introduced significant change, is the shift from steam-electric power to the atomic energy in the energy stations. But, as the time for this development is not ripe, it is not difficult to understand the reticence of the leading entrepreneurs who do not strive to force the direction of the innovation too far in costly future ventures.

Major conclusions that Maclaurin draws are that innovation and invention do not happen in parallel and researchers cannot predict the interval between them (1955, p. 568).

Fundamental breakthroughs that result afterwards in new technological developments and innovations are „discontinuous"(Ibid.).

Maclaurin states that the development of the technology has surpassed the innovation in the period of the past hundred years. Therefore, the ability of using new technology for creating innovative goods exceeds the real accomplishments (Ibid.).

Last but not least, Maclaurin predicts the rise of the tertiary sector of industry and emphasises the importance of the implementation of the „organizational innovation" in the service industry around 50 years for Andreas Knie who declares the same idea in his article „The Cultural Dimension of Technology Management: Lessons from the History of the Automobile, Technology Analysis & Strategic Management" (Knie, A., 2001; Maclaurin, 1955, p. 568).

5. Framework

The framework and criteria needed for answering the research question and applied for the period under investigation, the master thesis owes B. Godin, W. Rupert Maclaurin, the Department for Transport and the Centre for Connected and Autonomous Vehicles in the UK, and the Oslo Manual- The Measurement of Scientific and Technological Activities:

1. **R&D expenditure** of each automotive company – called also in the theoretical part developed by Maclaurin "the budget of science".
2. **Capabilities in research**
   - Laboratories, how are "pure science and engineering applications" connected (cited in Godin, B., 2008 p. 348) - structure and focus of science laboratories.
   - Collaboration with universities – the university is seen by Maclaurin as an institution that gives the "unconventional scientific minds" the most fruitful research environment (Maclaurin, 1953, p. 99).

2.1 **Number of engineers employed** - the number of the research employees is believed to be "correlated with the volume of invention" (cited in Godin, B., 2008, p. 351)

2.2 **Number of patents**– the number of patents issued Maclaurin suggests to be a component of measuring the "propensity to invent" (Maclaurin, 1953, p. 103)

3. **Exploring the number of the new plants built**- The component is introduced by Maclaurin. He suggests that the number of the new plants built by an enterprise can be an indicator for its propensity to fund innovation. The author goes about the practice that American corporations which construct new plants use them for the production of a new good and the old ones are remaining in the existing facilities. Maclaurin assumes that it is very hard for an enterprise to support a new plant with resources from the profit and the increasing number of new plants built is a signal "that new capital is being made available for innovation" (Ibid., p. 110)

4. **Annual sales volume of the improved products** - According to Maclaurin, the annual sales volume of a product is one of the components to measure the propensity to innovation, because the commercial outcome of the invention is the innovation. The examination of the annual volume sales of a product is part of an "intimate inquiry" of the industry and intends to estimate the propensity for innovation (Ibid.). Furthermore, the same indicator for measuring innovation can be seen in the Oslo Manual. An advancement in the technological components of a product or service is believed to be able to influence the sales of the new or improved products in a significant way (p. 39).

5. **Introduction of a new method of production** (Schumpeter, cited in B. Godin, 2008, p. 344)
   a. Advancement of the moving assembly line through the adoption of robotic automated systems

b. Integration of entirely new method of manufacture of volume vehicles

6. **Maintenance** – the "significant objective improvement in the service product" is considered as technological innovation (Oslo Manual, p. 39). According to automotive researchers the development of new vehicle diagnostics with respect to the advanced electronic complexity of the automobiles, has the potential to significantly improve quality, networking, and efficiency (Frank, H.& Schmidts, U., 2007, p. 1).

7. **New materials** – the application of non-ferrous metals in the automobile manufacture aims to reduce the weight of components, the fuel consumption and carbon dioxide emissions, and to increase the vehicle's performance. The lightweight materials aluminum, magnesium and multimatrix composites have the potential to replace ferrous alloys (Cole, G. & Sherman, A., p. 4).
   a. Application of aluminum in the body structure, powertrain, chassis and other components
   b. Application of magnesium alloys in the body structure, powertrain, chassis and other components
   c. Application of multimatrix composite components

8. **New technology**

8.1 New drive technology – the configuration of the predictive technology permanent all wheel drive (AWD) in the volume produced automobiles

8.2 New injection technology – refinement of the injection system of the turbocharged petrol engine, whose embrace is believed to be a long-term strategy in the manufacture of mainstream vehicles abandoning the naturally aspired engines (Madslien, J., 2015; Taylor, M., 2015; Wailand, M., 2015;).

9. **Integration of IT systems in the automobile** (Oslo Manual, p. 8) - According to the Oslo Manual, new model of an automobile, which offers, for example a stereo system should be considered as product differentiation and not an innovation as they are not any significant technical changes (Ibid., p. 39). A new feature can be considered as technological innovation if the changes that it brings „significantly affect the performance or properties of the product ..." and are „based on new designs or technical modifications to sub-systems" (Ibid. pp. 38-39). Therefore, the master thesis shall not focus on single add-on components (such as rear entertainment systems) because the majority of them does not improve the vehicle performance and contributes to the comfort of the passengers. The thesis will investigate the incorporation of IT systems that influence the driving experience, the steering of the automobile and the safety of the passengers, and namely the advanced driver assistance systems (ADAS). The Department for Transport and the Centre for Connected and Autonomous Vehicles in the United Kingdom has identified the framework of seven present and new ADAS that are further explored in the empirical part (Pathway to Driverless Cars," 2016, pp. 12-

13). In the case of incorporation of ADAS in volume passenger automobiles, the new systems are believed to „have a profound impact on our transport system, with the potential to deliver major benefits; fewer crashes on our roads; freedom to travel for those who currently find that difficult; more efficient transport networks that are safer, smoother, and swifter; ...“ (Ibid., p. 5).

6. Empirical Part

6.1. Defining the Models of Passenger Vehicles under Observation

The master thesis traces the innovation's development in the brand of passenger automobiles. The sector is relevant because of its traditional understanding as a brand that ensures quality, reasonable maintenance costs and conventional services. Furthermore, they are presumed to be produced at accessible prices for the ordinary consumer. Therefore, mainstream vehicles are basically not considered to have at their command the most progressive technologies. Nevertheless, the average passenger automobile experiences in the new era of innovation an increasing aspiration towards new technological equipment and services (Koster, Ahlemann, Hirsh, & Viereckl, 2016).

Advanced technical solutions are not only elaborated for the luxury segment or the concept vehicles (prototypes), but they can be also found in the volume produced passenger automobiles. Therefore, the empirical part focuses on the volume produced passenger automobiles with an annual production of 100,000 units or more, in order to observe the innovative technologies incorporated in the mainstream automobiles.

Volkswagen AG commands a passenger car subsidiary which produced 6,156,216 units in 2014 only with the emblem of VW. Passenger automobiles that are volume produced with annual production of 100,000 units and more are Golf, Jetta, Polo, Passat, Tiguan, Lavida, Bora, up!, Fox and Beetle. From the fully owned by Volkswagen AG subsidiary Audi, volume produced models are Audi Q3, Audi Q3 Sedan, Audi Q5, Audi A6 Sedan, Audi A4 Sedan, Audi A3 Sportback, Audi A3 Sedan. From the subsidiary SEAT, the volume models are as follows SEAT Ibiza SC, SEAT Ibiza ST, SEAT Ibiza Cupra, SEAT Ibiza Cupra R and SEAT Leon. Models from Škoda Auto under investigation are Škoda Fabia, Octavia, and Superb. Automobiles manufactured for the high luxury segments Bentley Motors Limited, Porsche and Automobili Lamborghini S.p.A. are not included in the spectrum of the inquiry as their production numbers are limited (Volkswagen Passenger Cars 2015, 2016; “Audi's automobile production,” 2016; SEAT at one glance 2016; Škoda Annual Report 2015).

Models manufactured by Toyota Motor Corporation with a volume of 100,000 units or more are Corolla (involves Corolla Axio, Corolla Fielder and Corolla Rumion), Rav 4, Prius (includes Prius a, Prius v and Prius +), Yaris (Vitz) and AQUA (in reality Prius C). Volume produced automobiles from the Lexus brand is the Lexus ES (“Number of Vehicles Produced, ” 2016).

Hyundai Motor Company identifies in its annual report the following models as volume produced automobiles - Elantra/ Avante (for the Korean market)/Hyundai i30 (renamed for the European market), Santa Fe, Hyundai Sonata and Sonata Sedan (Hyundai Annual Report 2012). Kia Motors as part of the Hyundai-Kia Automotive Group manufactures in high volume Kia Forte/ Cerato/ Cee’d, Kia Sportage, Sorento and Optima (Annual report 2015; Henry, I. 2015; “Hyundai Motor Manufacturing”, 2015). Hyundai-Kia Automotive Group does not have available statistics on the production numbers by model. Therefore, the master thesis relies on secondary literature and the indication and description as high volume or „mass-produced“ automobiles in the annual and financial statements of the company and manufacturing facilities.

It should be mentioned, that the worldwide purchase and registration of passenger automobiles increases every year and it grew only in 2014 by around 5 percent. The growing demand for passenger vehicles comes from Asia-Pacific, North America, Western and Central Europe. According to a research of the Global Industry Analysts, Inc., the global purchase of passenger cars is projected to increase further in the following five years. The majority of the consumers are attracted mainly by four important features- fuel efficiency, the new safety requirements- e.g. voice commands, driver assistance systems, etc., digital entertainment, small turbocharged engines and in-vehicle communication systems. Therefore, the growing consumer interest towards innovative solutions gives the automotive manufacturers a full scope of incorporating technological advancements into the passenger automobiles ("Steady Demand from Developing," 2015)

6.2. Research and Development Expenditure

Volkswagen

To begin with, the overall investments only of the Volkswagen AG experienced a steady increase from 1990 and onward. The investments were accounted in 1990 for 3,702 billion German marks, growing in the next year to 5,406 billion and reaching 7,840 billion in 1997. In 2000 the investments are calculated to be 8,878 billion German marks (Grieger, M. & Lupa, M.; 2014, p. 144-204). The Valens Research claims, to the investments that a company commits such as computer equipment, buildings, etc., which are supposed to have a profitable return, should be also the R&D expenses added („R&D Is an Investment, "2016). Therefore, we can presume that because of the constant growth of the investments of VW, the expenditure for R&D activities increased respectively.

A closer insight into the capital investments of the company reveals clearly the tendency of reducing the investments in tangible fixed assets as a percentage of the sales and the continuing rise of the R&D. In 1991 the capital investment in tangible assets stood at 10.9 percent of the sales. In 1992 they were accounted for 9.4 percent, decreasing to 7.2 percent in 1996 and falling to 6.6 percent in 2000 (Chanlat, J. & Clarke, T., 2009, pp. 280-282).

As opposed to that decline an upward movement of the R&D expenditure can be observed. In the early '90s, the R&D spending stood at just 3,2 percent of the sales. In the following years it experienced a constant increase, accounted in 1996 for 4.5 percent and reaching 6 percent in the year 2000 or 8,1 billion German marks (≈ 4 billion euro). That figure back in 1999 stood at 5,1 billion GM (≈ 2,61 billion euro) which is by 16,6 percent greater compared to the R&D expenditure in 1998. (Chanlat, J. & Clarke, T., 2009, pp. 280-282; Annual Report 2000, pp. 25-26).

Volkswagen AG continued to increase the financial means, invested for R&D activities and this tendency remained unchanged. The total R&D costs in 2010 were estimated to be 6,257 billion euro. This expenditure rose gradually to 11,743 billion euro in 2013 and climbed in 2015 to 13,612 billion euro („Key R&D figures," 2015).

According to the „Industrial R&D Investment Scoreboard", annually issued by the European Commission and investigating 2500 companies over the world, Volkswagen AG is the global largest R&D investor from 2012 to 2015 (IRI Scoreboard 2015, 2014, 2013, 2012).

Toyota

The data about the R&D expenditure of Toyota Motors Corporation discloses a stable tendency with slight fluctuations. The R&D spending experienced a gradual and constant growth. From 1998 to 2001 the figure increased slightly – from 444,401 million yen (approx. 4 billion euro) to 479,953 million yen or around 4,2 billion euro. In 2009 the expenditure in R&D activities almost redoubled its amount – staying at approx. 8,0 billion euro. The next four years were characterised by a slight decrease whereas the R&D investment reached 7,1 million euro in 2013. From this point on it revived and rose to around 8,9 billion euro in 2015, which is still several positions behind Volkswagen AG with 13,6 billion euro invested in research and development ("Changes in R&D Expenditures," 2016).

However, to see the big picture, PwC listed twenty companies with the largest R&D spending in the automotive industry and placed Toyota for three consecutive years – in the period from 2007 to 2009 on the first position, declaring the company the largest automotive spender in research and development. Because of the slight downward trend in the company's R&D investment, Toyota was placed in 2010 on the fifth position and in 2015 on the eighth among all the companies in the study (strategy&, 2016).

Hyundai Kia

After the Asian crisis in 1997, Kia Motors experienced serious financial difficulties, declared bankruptcy and required assistance. Hyundai Motor Company acquired and restructured Kia Motors in the period between 1998 and 1999 (Lee & Cho, 2001).

Therefore, in order to acquire reliable information about the R&D expenditure of the fifth largest automobile manufacturer worldwide – Hyundai Kia Automotive Group, we should trace its investment from that point onwards. After the acquisition Kia Motors started its R&D investment with 407 billion Korean won, which represents around 329 million euro. According to annual reports, Hyundai Motors alone spent in 2003 around 955 million euro on R&D activities. The manufacturers' combined expenditure from 2003 to 2005 indicates an amount from 1,61 to 1,76 billion euro. After that the figure rose to 2,83 billion euro and experienced in 2015 a ten percent increase (Alvis, J., 2006; Hyundai, Financial Statement 2003, 2005; Kia, Annual Report 2000, 2002; „Hyundai and Kia Report", 2015). In comparison, Hyundai Kia invested around one third of the amount that invested Toyota in research and development operations.

On the other side, for 2012 the expenditure for tangible fixed assets and current assets is accounted for around 6,5 billion euro (Lee, E., 2012).

Summary

With respect to the budget of science Volkswagen is not only the largest spender in the automotive industry but has also globally the highest investment in research and development activities. Toyota stands seven positions behind Volkswagen and is appointed to be eighth among the most generous automotive R&D spenders. In contrast, Hyundai Kia invested ten times less in R&D operations compared to Volkswagen.

6.3. Capabilities in Research

6.3.1. Research Bases, Collaboration with Universities, Personnel and Patents of Volkswagen

Research facilities

With respect to the capabilities in research, Volkswagen AG hast at its command three main research bases which operate for the entire automotive group - the Electronics Research Laboratory (ERL) in California, Volkswagen Research Lab China (VRC) in Shanghai and Technical Representative Tokyo (VTT). The coordination center is the headquarter in Wolfsburg, Germany ("Research Partnerships," 2016; "Volkswagen Presents," 2010).

The ERL aims its attention to the electric vehicles of the future and undertakes manifold research in the sphere of the voice user interface, networked speech recognition, advanced driver assistance, autonomous driving, i.e. in the sphere of transforming traditional navigation systems into intelligent and reliable co-drivers. The innovative concepts are developed in the collaboration with the Stanford University, the University of California-Berkeley and the Massachusetts Institute of Technology ("German Automotive DNA," 2016).

Because of the dynamic automotive market in China, Volkswagen AG driven by the strategic positioning has established the Research Lab China (VRC) in Shanghai. The researchers turn the spotlight to the testing of new lithium-ion batteries and the enhancement of their performance. Furthermore, in the research participate the Tongji University and automobile manufacturers (Annual Report 2011).

In the same field of research functions the Technical Representative Tokyo base. This center develops new concepts of mobility for future vehicles in accordance to the requirements of the local consumers and local urban and safety needs ("Volkswagen presents," 2010).

Further relevant research alliances and strategic partnerships constitute:

a. The Ballard Cooperation – a research alliance between Ballard Power Systems (Vancouver, Canada) and Volkswagen AG and Audi AG in the sphere of the engineering services (Ballard Inks, 2015).

b. The Cooperative Automotive Research Network (Carnet) in Barcelona in a long term between Volkswagen AG, SEAT and the Universitat Politècnica de Catalunya. The collaboration encompasses the cooperative research between industrial and academic research centers and the transformation and adaptation of academic research to the actual urban needs of society. The focus is set on developing new automotive concepts for the future urban conditions by the automobile producers, communities and possible service providers. The research project offers also a PhD programme. It gives students the possibility to elaborate a doctoral thesis whose subject matter is brought up by industrial partners and the thesis is mentored by academic professionals (CARNET Research and Innovation, 2016).

c. Volkswagen Varta Microbattery Forschungsgesellschaft (Ellwangen, Germany)– is a research cooperation with the aim of finding new solutions for the regeneration of

lithium-ion batteries and the reduction in their weight („Microbatteries – innovative energy," p.9).

d. Volkswagen Data Lab in Munich focuses on the processing of extended volumes of data and the development of new technologies that evaluate the information between "networked" automobiles. In the Data Lab collaborate business partners mainly start-up companies, universities (Munich University) and research centers (German Research Center for Artificial Intelligence) towards the creation of state-of-the-art IT technologies. The researchers have the possibility to test immediately the new ideas because of the lab equipment (Esterdahl, T., 2014).

Collaboration with Universities

Moreover, the Volkswagen Group collaborates closely with around 280 universities and research institutes all over the globe. It has developed and has established 1,500 partnership projects with them (Herwig, J., 2015). The university partnerships include various areas – from internships, student exchange projects, collaboration and engagement in research initiatives of the automotive Group, developing Master or PhD theses under the guidance of professional experts to visiting lecturers and professors (Ibid.).

Personnel

The research and development division of Volkswagen grew gradually to become one of the largest branches of the company. The employees engaged in the division in 1997 were accounted to be 8,109 individuals. With the development and expansion of that branch the number of employees was increased at first by 5,8 percent in 1998 and then by 9,8 percent in 1999. In the year of 2000 it stood at 9,822 employees, an annual growth by 8,4 percent. In the following years, one can notice that this growing trend remains stable and the personnel at the research and development division of Volkswagen increases on an annual basis between 6 and 8 percent, rising in 2010 to 27,406 professionals worldwide and reaching in 2015 48,731 individuals. This share includes the joint Chinese venture - Shanghai-Volkswagen Automotive Company Ltd. and the First Automotive Works – Volkswagen Automobile Co. Ltd, manufacturing Audi, Volkswagen and ŜKODA for the customers in China (Annual Reports 1997-2015).

In 2007 in the research laboratory and alliances in Germany were 554 researchers active, 61 PhD students and 105 students active (Vasilash, G. 2007).

The Electronics Research Laboratory is established in 1998 and had to that time at its command five engineers. In 2005, the number of the employees with higher education-engineers and project managers stood at 30 professionals out of 40 employees („The Grand Challenge," 2005). Furthermore, the capacity of the laboratory grew considerably and the ERL engages in 2014 about 140 researchers, engineers, social scientists and product designers (Harrison, D., 2014).

The research and development division employs in 2014 as before mentioned around 8 percent of the whole workforce in Volkswagen and namely 48,731 professionals („Key R&D

figures," 2015). One should consider, that this figure includes 9,780 „highly qualified" employees with a research experience higher than master degree. Furthermore, the company supports 490 PhD candidates („490 young scientists," 2014).

Patents

As the research and development division gained in importance and the expenditure for its activities and the personnel engaged increased annually, the same trend experienced the number of patents applied.

In the early 90s Volkswagen obtained around 180 patents in Germany every year. The figure grew slightly to 199 patents in 1996 (Greif, S., 1996/1997). A turning point marked the year of 1998 when Volkswagen registered 680 patent applications only in Germany, which is by around 40 percent more compared to the previous year, and 261 patents abroad respectively. In the next year that number redoubled. From that point forward the figure increased annually and in 2015 Volkswagen Group requested 6,244 patent applications (Geschäftsbericht 1999, 2005, 2015, n.d.).

With respect to the patent application Volkswagen AG is ranked by the Center of Automotive Management (CAM) the fourth place among the 18 largest automotive manufacturers worldwide. The main part of patents that have been requested by the automobile producers are in the sphere of the alternative drive system and the remain of the conventional one ("Patente der Automobilhersteller," 2015).

6.3.2. Research Bases, Collaboration with Universities, Personnel and Patents of Toyota

Research facilities

Toyota Motor operates 15 research and development bases. At the research and development centers engineers perform automobile manufacturing, evaluation of vehicles through testing, product planning or create the automobile's design. Nevertheless, not every base has at its command a research laboratory. Facilities, equipped especially for the purposes of research are Toyota Central Research & Development Laboratories in Nagakute City and Toyota Research Institute (TRI) with its three research sites in California, Michigan and Massachusetts („Research and Development Bases," 2016).

Toyota Central Research & Development Laboratories specialise in basic and applied research. The main emphasis is put on applying new materials in the vehicle manufacture, developing new and eco-friendly sources of energy, better and more reliable safety software and on the fundamental research (e.g. materials' analysis applying different techniques and equipment) („Research Fundamental Technologies," 2016).

Further relevant facilities which enable research and development are:

a. A research alliance has been contracted between Tsinghua University in Beijing and Toyota Motor Corporation and established together Tsinghua University-Toyota Research Center. Toyota Motor Corporation and the Tsinghua University cooperate in

four areas – environmental technologies, energy sources, safety systems and materials science and engineering. The research projects involve wastewater purification and treatment, carbon sequestration, analysis of automobile accidents in China, exploration of thermoelectric materials, etc. (Enright, M., 2016).

b. Toyota Motor Engineering & Manufacturing Co., Ltd. (TMEC) is located in Changshu, China. The site concentrates on developing manufacturing technologies and specialises in fundamental research. It puts the emphasis on the advancement of the testing equipment, evolving chassis dynamometers (device that measures the capacity of the engine) ("Toyota Completes New," 2013).
c. Toyota Motor Asia Pacific Engineering and Manufacturing Co. (Thailand) presents a manufacturing facility, where basic research is carried out. Furthermore, the center is responsible for market and design research, testing of the vehicle's performance and its assessment (Toyota Integrates Asia, 2007).

Collaboration with Universities

Toyota Research Institute (TRI) is focused on developing the concept of future vehicles with respect to social needs. The future the company sees in producing a vehicle that can switch between partly autonomous or fully autonomous driving mode required for elder people or those with special needs. Furthermore, TRI research operations do not include only the automotive area but also the creation of products for households. Research activities encompass the development of artificial intelligence assisting drivers, home robotics assisting in daily routine, and creation of new or refinement of existing materials. In carrying out the research Toyota collaborates in a vast spectrum of areas with Stanford University and in the challenges of the human-robot interaction with the Massachusetts Institute of Technology. Moreover, in the Ann Arbor base (Michigan) Toyota settled its Collaborative Safety Research Center. The mission of the center is to develop safer and more reliable automotive technologies. The center collaborates with the University of Michigan, the Children's Hospital of Philadelphia and Virginia Tech and declares its mission for improvement not only of the automobile's safety but also for developing of solutions to lower road accidents with young drivers and children on board („The future of mobility, "2016).

Toyota Research and Development Laboratories collaborate closely with academics of the Nagoya University. At its operations 1,011 employees are engaged in the head quarter in Japan without disclosure of their professional qualification (Company Profile, 2016).

Personnel

Overall, the professionals employed at the research and development division in Japan account for around 12,000 individuals in 2005 which is the latest available data (World Investment Report, 2005, p. 145). To that figure should be added the personnel of the fully owned Toyota subsidiary „Toyota Technical Development Corporation" that specialised in vehicle engineering and namely around 5,000 employees. The subsidiary merged with the parent company in 2015 with the aim to improve the coordination of the research and development operations ("Toyota To Assume," 2014).

The TRI partners with the University of Michigan and Stanford University in the development of artificial intelligence for the autonomous driving programme. At the Stanford lab are fourteen researchers and scientists active (Stanford Artificial Intelligence Laboratory, 2016). The center cooperates in the same field of research with the Massachusetts Institute of Technology. As the Ann Arbor base has been established in June 2016, the personnel was expected to consist of around 50 researchers (Pratt, G., 2016). Moreover, the research staff at the Palo Alto facility in California, which should have started its endeavour in January 2016, was projected to comprise around 100 researchers and scientists (Toyota Research Institute Overview, 2016).

Furthermore, the share of employees at the manufacturing facility in Thailand stood in the time of its establishment in 2003 at 275 individuals, but it expanded gradually and the personnel reached in 2015 around 2,500 individuals, whereas 1,400 of them are reported to be engineers (Toomgum, S., 2015).

The European center of Toyota, responsible for engineering operations, vehicle design and the management of the R&D activities on the continent comprises 2,700 professionals („Toyota in Europe," 2016).

Additional research and development facility in Australia with the same area of expertise as the above mentioned one employs 160 people. However, the center is announced to close permanently in 2017 and the personnel will be absorbed by other facilities of the company (Newton, B., 2015).

Relying on these figures, we can estimate that the overall research and development division of Toyota Motor Corporation engages around 25,000 individuals. However, one should take into consideration the scarce of data on the accurate number of professionals engaged at every research and development facility and particularly at the head quarter office, and their professional qualification. The number of all employees worldwide appointed at the company stays in 2015 at 344,109 individuals. Based on the above mentioned calculations the master thesis assumes that out of them around 7 percent are employed for research operations.

Patents

With respect to the patent filing Toyota Motor Corporation does not have any competitor. The automobile manufacturer began to file its patent declaration for electric vehicle concepts in the late '80s and the early '90s and showed its willingness to deepen its work on innovative clean technologies (Boyle, G. & Mitelka, L., 2008). According to a research of the Center of Automotive Management, Toyota applied in 2006 for more than 10,000 patent registrations and was the global top patent applicant and patent holder among all the automotive companies. With time the company strengthened its efforts and hold its first position in 2014, reaching more than 14,000 patent applications and being the the highest ranking automobile manufacturer in patent filing ("Die Patente der globalen Automobilhersteller," 2016). The majority of the patent applications are developed in the sphere of the electric automobiles, hybrid vehicles and with special emphasis on the hydrogen fuel-cell technologies which basically present an alternative technology to the conventional petrol engine (CES 2015, 2015; "Electric Vehicles, Hybrids & IP," 2011).

6.3.3. Research Bases, Collaboration with Universities, Personnel and Patents of Hyundai Kia

Research facilities

Hyundai Kia Automotive Group as its counterpart Toyota includes in its research and development framework the technical centers, testing facilities, interior and exterior design studios, etc. Overall, the group has at its disposal twelve R&D centers worldwide. However, only a part of them are equipped with research laboratories and are relevant for the creation of innovation. Centers devoted to scientific research are:

a. The Namyang Technology Research Center in Hwaseong City (Korea) – besides the vehicle engineering the site specialises in powertrain technologies and the development of four-wheel-drive-system parts. The facility consists of multiple sites for the various cycles from the design of the technology to its real testing and evaluation (Annual Report 2013, n.d., p. 43).
b. Central Advanced Research & Engineering Institute in Uiwang (Korea) carries out research in the sphere of the environmental studies, develops eco-friendly and autonomous concepts. It commands a Human Machine Interaction Laboratory, a Nanomaterials Laboratory and the so-called "Venture Plaza" which gives the opportunity to young scientists to become members after the submission and evaluation of their written works in the area of eco-driving technologies and intelligent safety systems and their commercialization ("Mission & Role", 2016).
c. The Mabuk Environmental Technology Center in Yongin City (Korea) focuses again on the new green solutions for the automobile of the future. It develops automobile recycling technologies and a production of fuel cell vehicles using hydrogen gas (Annual Report 2013, n.d., p. 43).
d. Japan R&D Center in Yokohama is the division situated in Japan which concentrates its research especially on hybrid engines (Ibid.).

- Hyundai Kia is building another research and development facility in the city of Yantai, China with the same field of specialization as the Namyang Technology Research Center in Korea. The Motor Group believes that this facility will serve as a central point for development of innovative vehicle concepts and technologies (Ibid.).

Further relevant research alliances of Hyundai Kia Motor Group are:

The project IONIQ Lab where Hyundai collaborates with the academics of the Seoul National University and industrial partners in its aim to find better solutions for future challenges with respect to the mobility – e.g. the mega-urbanization process and the growing digital interconnection of people and devices ("Project IONIQ lab," 2016).

The establishment of the Hyundai Kia Automotive Safety Research Laboratory in 2003 at the George Washington University presents a long-term project between the auto manufacturer and the university, concentrated on advanced research on the degree of crash worthiness of vehicles and the possibility for improvement. It main focus was put on the onboard child passenger safety (Johnson, M., 2003).

Collaboration with Universities

In addition to the cooperation between Hyundai and the Seoul National University and the Ulsan University, the company has established a platform “Hyundai NGV”, where industrial partners and academics can collaborate in the sphere of the automotive research and the advanced technical education. In the joint research center are also technical workers of the company engaged (Hyundai-NGV, 2016). Furthermore, the company initiated in 2009 a long term student exchange programme with the Moscow State University of Mechanical Engineering. Students could serve an internship at the company’s facilities (“Hyundai Motor CIS,” 2016). Hyundai cooperates also with the Kookmin University and particularly with its School of Automotive Convergence in the area of the advanced vehicle technologies („LINC(Leaders in Industry,“ 2016).

The division of Kia Motors assists in the research project of the University of California Irvine in its endeavour to elaborate algorithms to generate a two-way flow of electricity between electric automobile (battery or plug-in) and the electrical grid respectively („What is the Hyundai – Kia,“ 2016). Moreover, Kia Motors in Slovakia works in the direction of building exchange programmes between its R&D center and four universities with the opportunity of completing an internship and developing research papers („Kia enhances cooperation,“ 2006).

Personnel

In the early '90s Hyundai demonstrated serious shortage of experienced and qualified workforce. The research and development division embraced 100 employees and it could not afford their further training or recruitment of other skillful talents because of lack of financial means. However, with the establishment of the Namyang Technology Research Center in 1997 Hyundai began to unfold its potential towards a stable R&D infrastructure (Moon, H., 2016). The number of the employees engaged in the R&D operations of the company rose slightly in the course of the time. Hyundai Kia Automotive Group appoints 30 percent of its new employees since 2010 to positions within the R&D division. According to latest data, the total number of professionals engaged in the R&D operations stays at around 11, 000 individuals, of whom 10, 000 are active in Korea and the rest overseas. The European Technical Center in Rüsselsheim and India Technical Research center employ around 300 professionals each, and 170 researchers work at the American research facility (Annual Report 2015; “Facts about HMETC,” 2016; Johnson, M., 2012). The overall number of employees of the automotive manufacturer is accounted in 2015 for 112,072 individuals and the R&D division makes up around 11 percent of the whole personnel (“Employee Status,”2016). However, detailed statistics on the professional and educational profile of the employees are not available.

Patents

The patent applications requested by Hyundai Kia experienced a notable increase. In 2010 the company claimed 500 patent applications. Their numbers grew gradually reaching in 2013 1,200 patents. According to the study of the Center of Automotive Management in 2014 Hyundai Kia is ranked of the fifth position with respect to the patent filings among the 18

largest automobile manufacturer ("Patente der Automobilhersteller," 2015). The focus of the patent efforts of Hyundai Kia is set on the fuel-cells vehicles using hydrogen gas (Cho., J., 2015).

Summary

All the three companies have at their command specialised and high tech equipped laboratories. However, Volkswagen puts the emphasis on the applied research and collaborates closely with 280 universities worldwide. Available data on Toyota suggests that the company cooperates with four universities, whereas Hyundai has established partnerships with five educational institutes.

In terms of the talent employed in the R&D division, Volkswagen engages twice more professionals in comparison to Toyota Motors. In its turn, Toyota has at its command twice more R&D employees compared to Hyundai Kia.

The largest patent applicant among the three rivals is Toyota.

6.4. Number of New Plants Built

Volkswagen

The late '80s and the early '90s of the history of Volkswagen were dominated by an international expansion in terms of establishing new ventures overseas and strengthening its leading position in Europe. The vision of the company was directed toward the Asia Pacific region, the increase of the volume of produced automobiles in North America and after the collapse of the socialism in Eastern Europe, a further expansion there. During the '90s, manufacturing plants were founded in China, North America, Argentina, United Kingdom Portugal, Western Germany, and Poland. In the middle and at the end of the '90s Volkswagen was engaged with the acquisition of new automotive companies and with the reconfiguration of the work force and the management. The group acquired the new automotive brands with the production factories belonging to them (e.g. Spain, Czech Republic) and at the end of the '90s Volkswagen had manufacturing plants on five continents (Grieger, M. & Lupa, M., 2014, pp. 144-179). According to a study, in 1995 the company owned 35 production sites and in 1999 their number increased to 47 facilities (Pries, L., 2016).

The period after 2000 and onwards is characterised by a global expansion of the Volkswagen vehicle production facilities. Currently as to 2016 the Group commands overall 121 manufacturing plants (24 in Germany) whereas an additional production site is being built in Eastern China and two other come to the Group's growth project ("Portrait & Production Plants," 2016).

Toyota

Toyota owned 13 manufacturing facilities before 1990 in Japan. In the early '90s to the domestical plants were build two additional ones and in 2012 was opened the 16th vehicle production plant. Before the period under investigation Toyota commanded a network of 16 production plants overseas. Its global enlargement began in the late '80s when only for two years five further production facilities were build and the process of its globalisation

continues until nowadays. In the period between 1990 and the year of 2000 Toyota stregthened its efforts towards expansion and 14 new manufacturing sites emerged. The company aimed its attention mainly to North America, China, South Asia and Southeast Asia. This trend remained stable and the number of new factories increased remarkably as from 2000 to 2015 were established 19 production sites. The route was taken mainly to Europe with 6 new plants, North America, China and Indonesia ("Japanese Production Sites & Worldwide Operations," 2016). Toyota Motors commands 69 vehicle production plants in total. The company plans the construction of an additional facility in Mexico that will be dedicted only to the production of the Corolla (Guillot, C., 2016).

Hyundai Kia

Hyundai Motor commanded three vehicle productions sites in Korea. After the acquisition of Kia the brand contributed with three additional domestic plants. In the period from 1990 to 2000 Hyundai Motors opened two production factories in South Korea, Turkey and India. Kia in its turn had only one in 1990. As the company collapsed the decade was marked by a standstill in regard to an international expansion. It started in 2002 whereas Hyundai established five vehicle manufacturing sites located in North and Latin America, the first European production plan in the Czech Republic, China and Russia. The same expansion experienced Kia and founded four production factories in the U.S, Mexico, the Czech Republic and China, and cooperated in a joint venture with Donghee Auto Company in the foundation of the Seosan manufacturing plant in 2004 („Global Plant," 2016; „Manufacturing Plants," 2016). In spite of the establishment of new international manufacturing facilities, the production of automobiles is mainly concentrated in South Korea and the group relies heavily on the domestic volume. In terms of productions units, around 50 percent of the newly manufactured automobiles are produced in South Korea. In contrast, the share of domestically manufactured automobiles stood in 2005 at around 75 percent and since then the Group strengthened its efforts towards decentralisation of the production (Henry, I., 2015). In total Hyundai-Kia commands 6 production factories in South Korea and 11 sites overseas.

Summary

In the period under investigation Volkswagen Group started to expand globally. This can be seen by the numbers of new plants built. From 1995 to 2016 the new manufacturing facilities account for 86 plants in total. In comparison, Toyota developed its production capacity as well and established 40 new manufacturing plants. Hyundai Kia founded in total 14 new production factories.

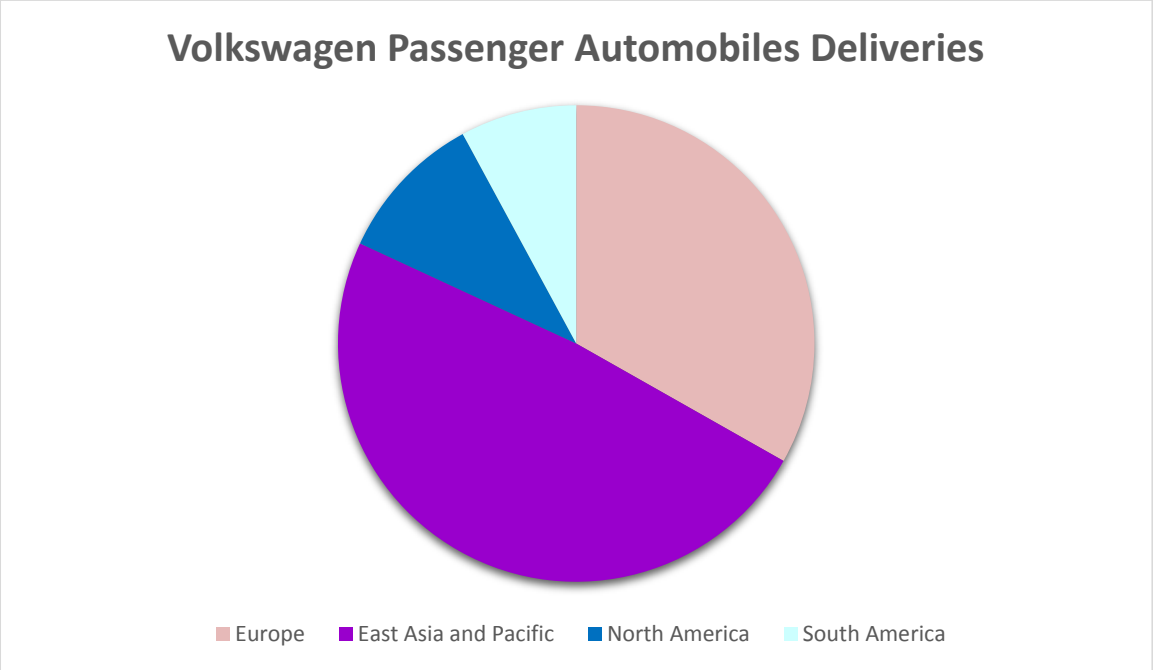
6.5. Annual Sales Volume

6.5.1. Volkswagen

The total deliveries of Volkswagen passenger automobiles experienced globally in the period under investigation an overall increase. However, there are important market specifications and the overall performance of the Group in the different environments cannot be described in a general manner. Europe and Asia account for 33,2 and 48,7 percent of the Group passenger automobiles' deliveries in 2015. In comparison the share for North and South America is considerably smaller and stays at 10,2 and 7,9 percent respectively ("Global demand," 2016"; "Volkswagen Passenger Cars 2015," 2016).

The master thesis investigates the sales number of the high volume passenger automobiles in the three markets where the larger part of the deliveries takes place.

Figure 1



Note. Adapted from Passenger Car Deliveries Worldwide, Annual Report 2015, Volkswagen.

Annual Sales Volume of Volkswagen, Audi, Škoda, and SEAT in Europe

Annual Sales of Volkswagen passenger models in Europe

From 1997 to 2005/2006 Volkswagen passenger vehicles experienced a steady increase on the European market. However, throughout the period under observation there have been significant fluctuations and market stagnation of the passenger automobiles due to the financial crisis in 2007 which can be seen in the annual sales figures from 2007 to around 2010/2011 depending on the different models. From 2011 and onwards the Italian, Spanish, British and Central European markets experienced a growing demand for passenger automobiles whereas the French and the Eastern European rather a stagnation (Ibid.).

The available data figures are derived from the vehicles‘ sales volume of 28 European countries – the EU member states, Switzerland and Norway („Volkswagen Monthly and annual”, 2016).

Beginning with the Golf family as an icon of the Volkswagen high volume passenger vehicles, we can notice that the annual sales were stable. Only the period between 2006 and 2008 was marked by a slight decrease. From 2013 the sales of the Golf family grew significantly again because of the introduction of Golf VII („Volkswagen Monthly and annual”, 2016).

The Jetta experienced an apparent increase, started with only 23 automobiles sold in 2004. The model was launched on the market as a replacement and improvement of the model Bora. The Jetta sales reached their peak in 2011 at 37,121 units sold (Ibid.).

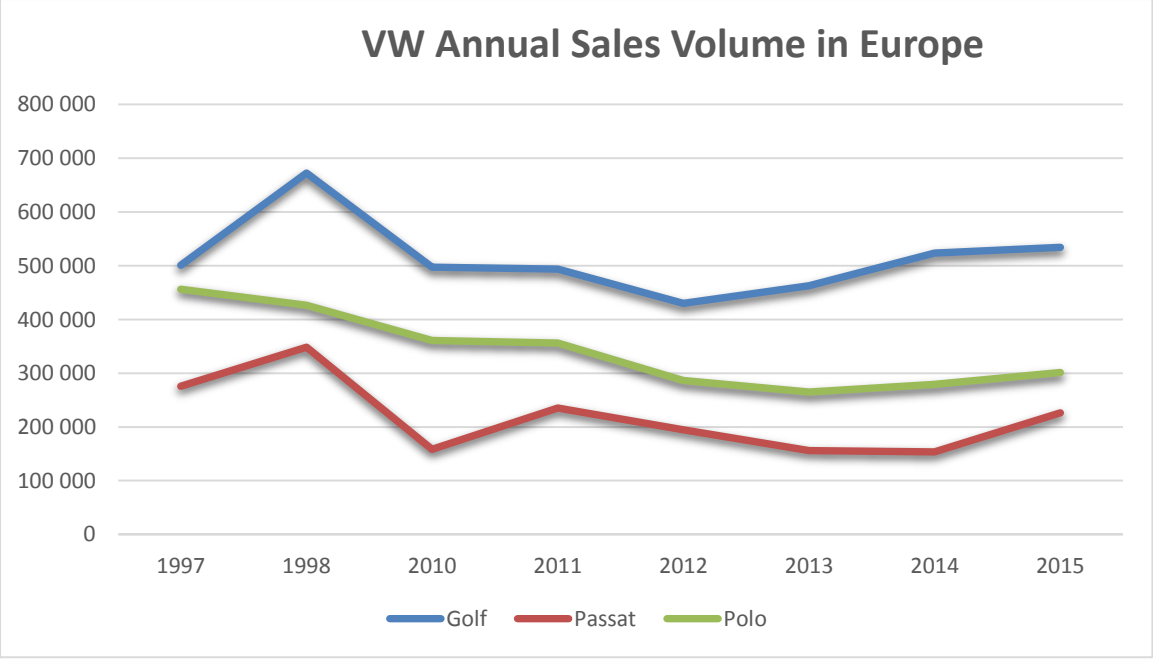
There have been a stable growth tendency of Volkswagen Passat from 2005 – 158,269 automobiles sold, to 2015 when sales reached 226,127 units. The Polo experiences an increase of sales from 2012.

Noticeable increase of the sales can be seen by the Lupo, improved and replaced by Fox and afterwards advanced to the Up! by sales staying in 2004 at 25,554 units, and in 2015 at 105,348 automobiles ().

The same tendency is seen by the new Beetle, starting in 1998 at 2,071 automobiles and coming to 25,562 units sold in 2015. The vehicles of the Touran model sold in 2002 accounted for 7 units and in 2015 for 73,767 automobiles.

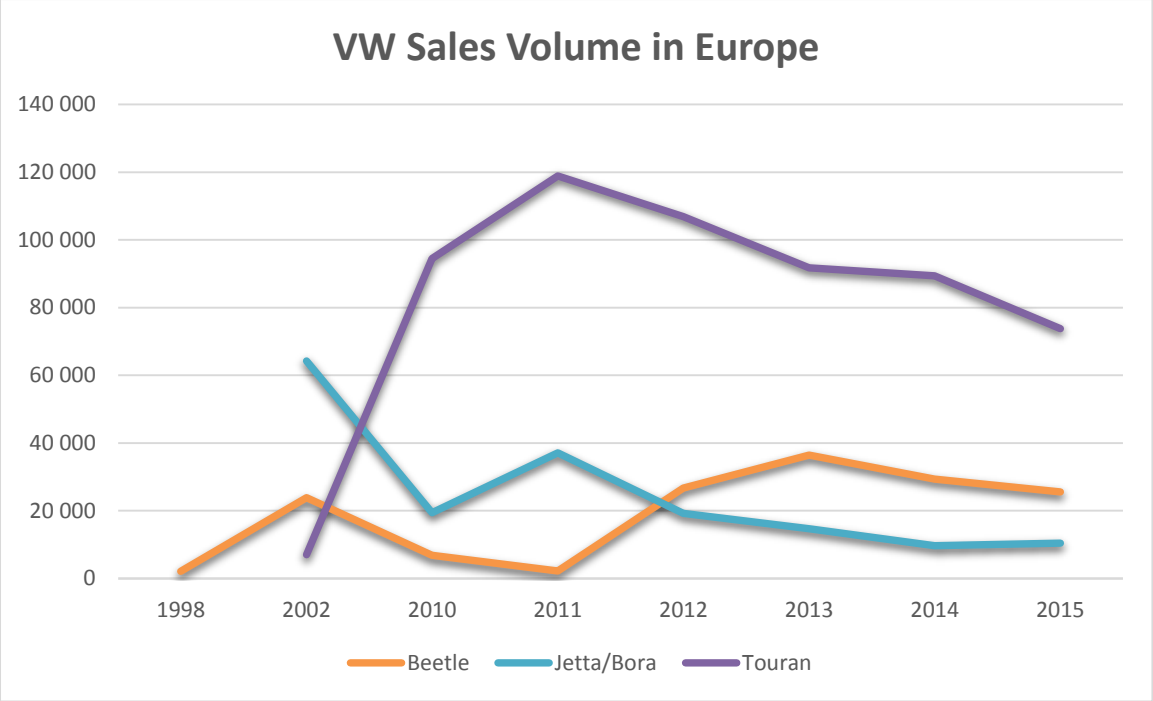
The Tiguan sales underwent a firm growth without any downward movements – from 6,891 automobiles purchased in 2007 to 148,338 vehicles in 2015.

Figure 2



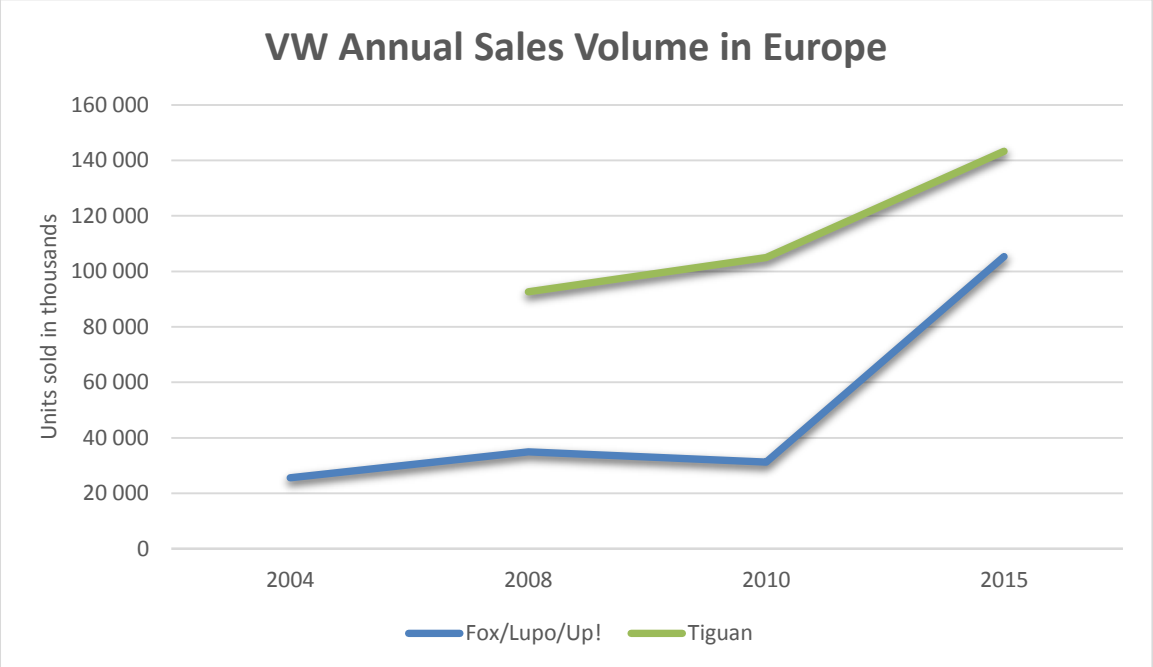
Note. Monthly and annual sales figures for Volkswagen in Europe, Carsalesbase 2016.

Figure 3



Note. Monthly and annual sales figures for Volkswagen in Europe, Carsalesbase 2016; Annual Report 2015, Volkswagen 2016, pp. 21-37.

Figure 4



Note. Adapted from Monthly and annual sales figures for Volkswagen in Europe, Carsalesbase 2016; Annual Report 2015, Volkswagen 2016, pp. 21-37.

Annual sales of Audi passenger automobiles in Europe

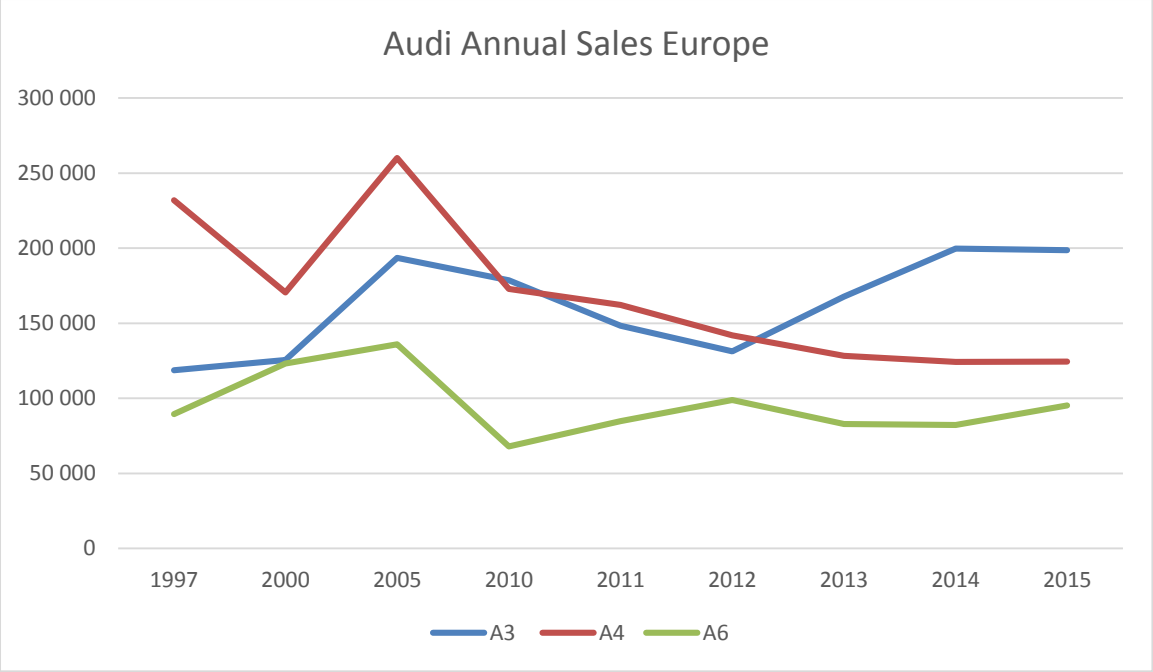
With regard to the Audi high volume passenger models, we can see that Audi Q5 and Q3 experienced invariable growth throughout the whole period ("Audi monthly and annual," 2016).

Audi A3 increased but with some fluctuations reaching in 2006 the peak of its sales at 202,811 vehicles.

The initial sales of A4 were stable around 200,000 units, but from 2008 are moving slowly downwards.

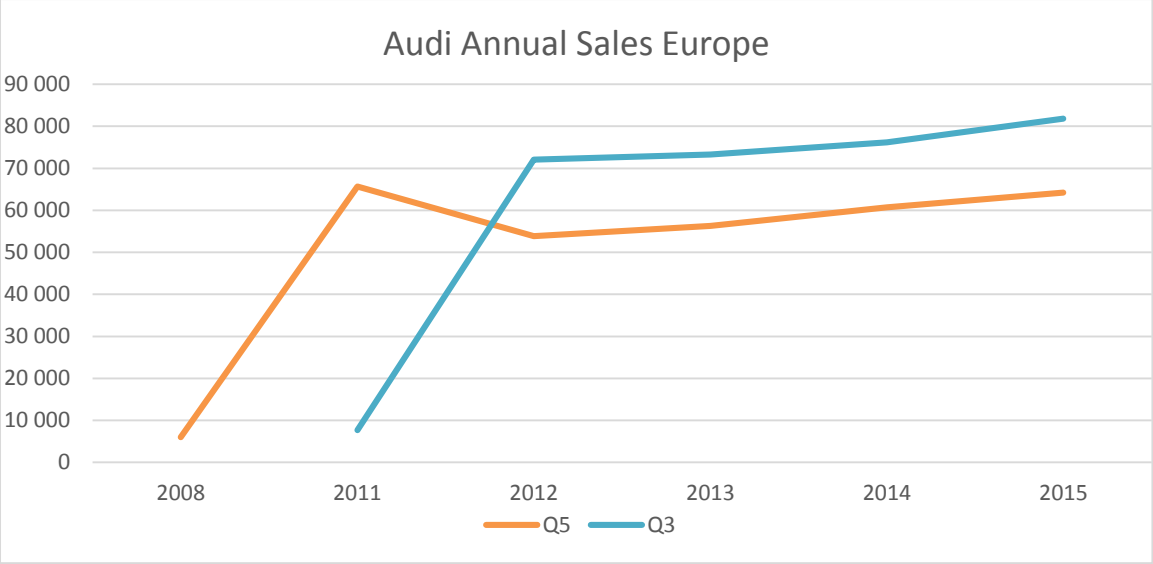
The number of the A6 purchased vehicles fluctuated moving in the range from 80,000 to 138,000 units.

Figure 5



Note. Adapted from Monthly and annual sales figures for Audi in Europe, Carsalesbase 2016; Annual Report 2015, Volkswagen 2016, pp. 21-37.

Figure 6

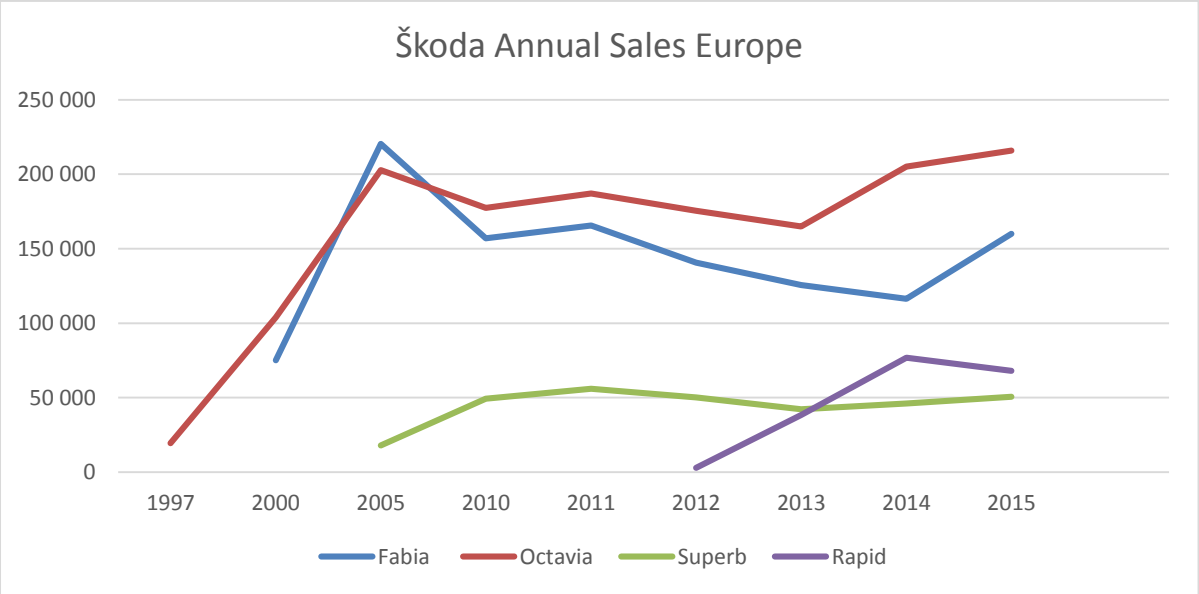


Note. Adapted from Monthly and annual sales figures for Audi in Europe, Carsalesbase 2016; Annual Report 2015, Volkswagen 2016, pp. 21-37.

Annual sales of Škoda passenger vehicles in Europe

The overall sales figures of Škoda Octavia and Fabia increased variably throughout the period, whereas Fabia reached its highest point in 2005 and Octavia in 2014 and 2015. Škoda Rapid and Superb have been continuously searched by the clients, which is better seen by the purchases of the Rapid.

Figure 7

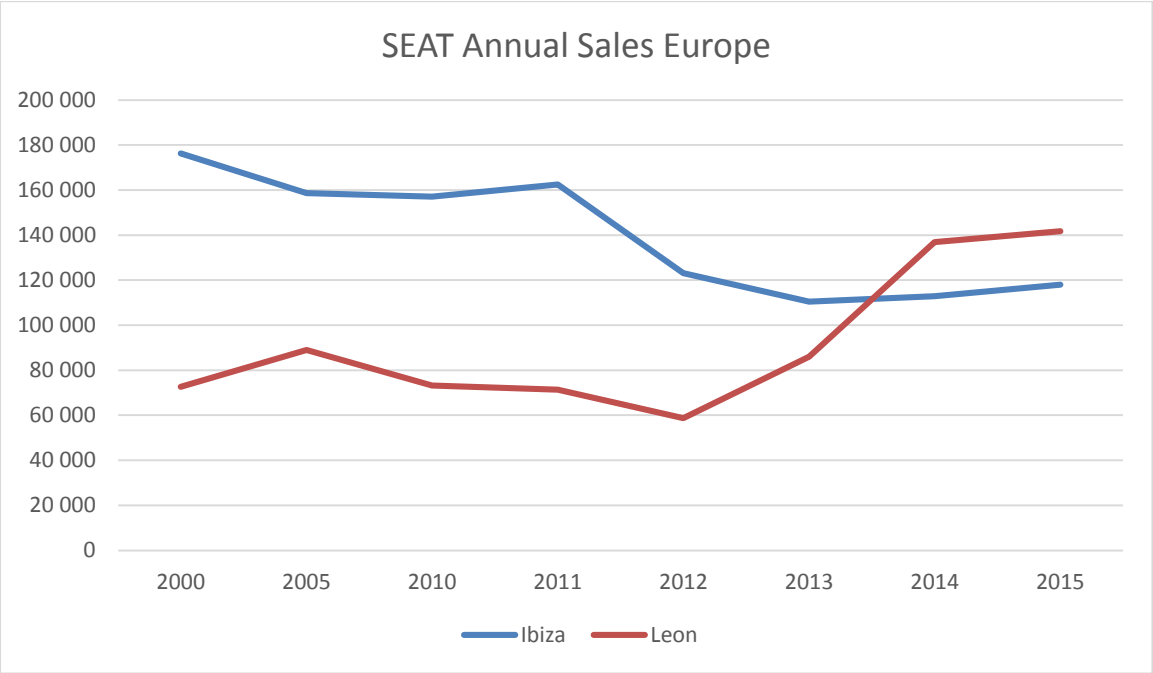


Note. Adapted from Monthly and annual sales figures for Skoda in Europe, Carsalesbase 2016; Annual Report 2015, Volkswagen 2016, pp. 21-37.

Annual sales of SEAT passenger automobiles in Europe

In regard to the SEAT purchases in Europe we can say that the Ibiza model is sold in the range between 110, 000 and 170,000 units without any serious differences. In contrast, the annual sales of SEAT Leon rose steadily from 2008.

Figure 8



Note. Adapted from Monthly and annual sales figures for SEAT in Europe, Carsalesbase 2016; Annual Report 2015, Volkswagen 2016, pp. 21-37.

Volkswagen Golf was the most purchased European passenger automobile from 2010 to the first quarter of 2016.

According to the report of the European Vehicle Market Statistics Volkswagen is the largest automotive seller in Europe for 2014 and 2015 with four out of ten models among the most purchased high volume passenger automobiles on the continent. As JATO Dynamics reports, Volkswagen achieved to maintain its leading position in the first quarter of 2016 as well (Moody, S., 2016; Pocketbook 15/16, 2016).

Annual Sales Volume of Volkswagen, Audi, Škoda, and SEAT in China

Detailed statistics on the number of automobiles purchased by model and also during the period under observation in East Asia and the Pacific Region are available only for China.

China is acknowledged by the Group as one of the most important single markets where the demand for Volkswagen automobiles grows fast. In 2014 the sales in China increased by 10 percent compared to the year before and in 2015 the deliveries to the whole Asia-Pacific region by 16.2 percent (“Global demand”, 2015).

Annual Sales of Volkswagen passenger automobiles in China

The sales figures for China include only the automobiles purchased from the Volkswagen Chinese production facilities and exclude the imported vehicles. The most purchased models in China for the last five years are Volkswagen Lavida designed for the Chinese market only, with sales figures staying in 2015 at almost 380,000 units, followed by the Passat. Despite few years of downward movement (2007-2009) the sales of the Golf grew considerably. The Polo experienced a similar trend („Volkswagen Monthly and annual", 2016).

The model Passat is sold in China in two variations – as Passat (which is the version for the American market) and Magotan (the European version introduced in 2007). By the both variations it is a matter of an automobile with identical basic characteristics. The Magotan experienced a constant increase of sales (Ibid.).

The sales figures of the Tiguan and the Sagitar (renamed European Jetta) grew permanently where those of the Bora and Touran remained stable for the last five years (Ibid.).

Figure 9



Note. Adapted from Monthly and annual sales figures for Volkswagen in China, Carsalesbase 2016.

Figure 10



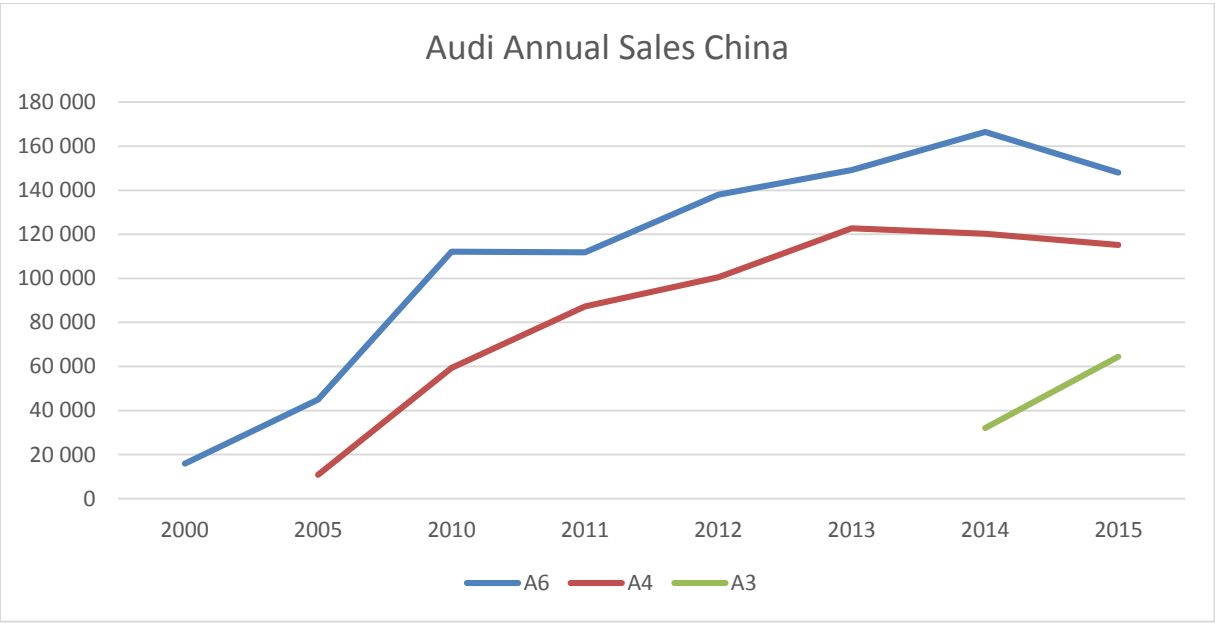
Note. Adapted from Monthly and annual sales figures for Audi in China, Carsalesbase 2016.

Annual sales of Audi passenger automobiles in China

The Audi automobiles purchased in China experienced a stable growth of sales. The Audi A6 sales figures stood after its introduction in 2008 at approx. 16,000 units and reached in 2014 around 166,000 vehicles („Audi Monthly and annual", 2016).

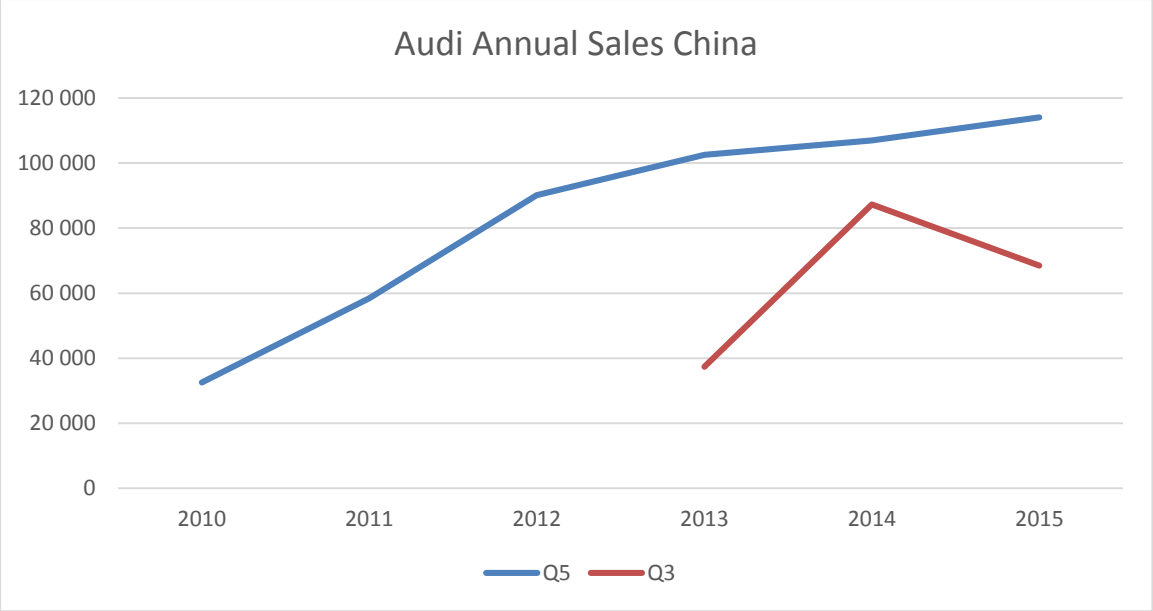
The Q5 vehicles' purchases multiplied almost four times.

Figure 11



Note. Adapted from Monthly and annual sales figures for Audi in China, Carsalesbase 2016.

Figure 12

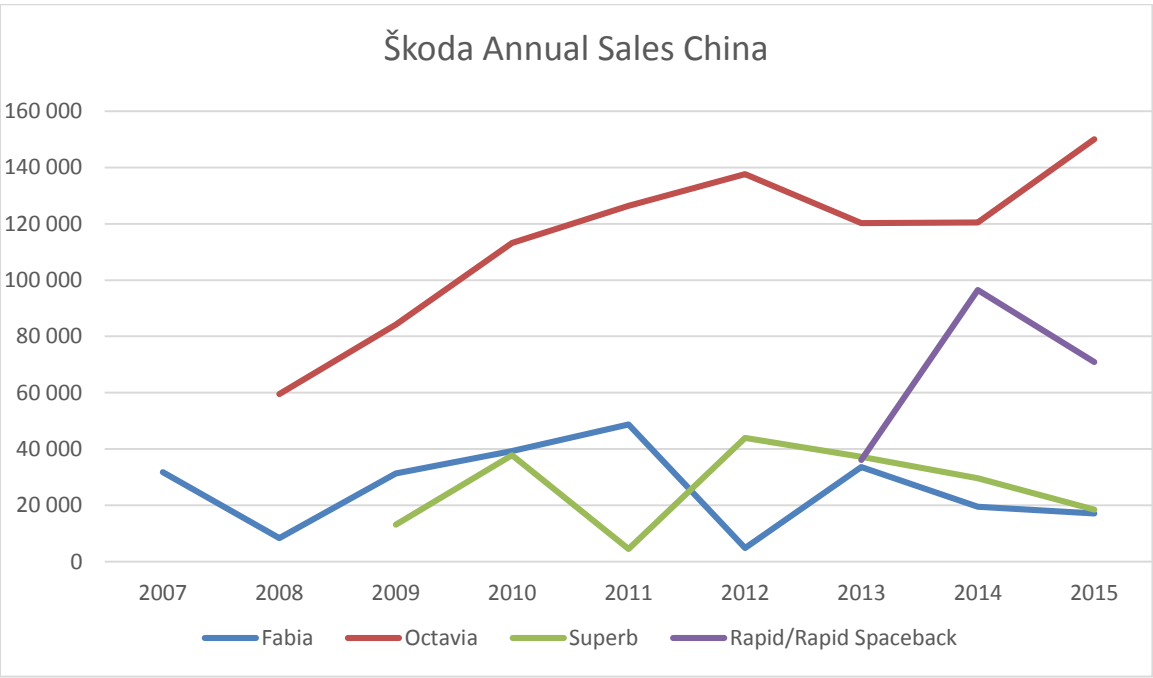


Note. Adapted from Monthly and annual sales figures for Audi in China, Carsalesbase 2016.

Annual sales of Škoda in China

The most successful years of the annual sales of most the Škoda models in China were 2011 and 2012. After that they began slightly to decrease with exception of Škoda Octavia whose sales increased in 2015 and demonstrated the best performance in the whole period („Skoda Monthly and annual", 2016).

Figure 13



Note. Adapted from Monthly and annual sales figures for Skoda in China, Carsalesbase 2016.

Annual sales of SEAT in China

SEAT Leon has been introduced to the Chinese customers in 2012 and Ibiza in 2013. Further statistics on their sales figures are not available ("Seat Ibiza on Sale," 2013; "Erste Seat Leon," 2012).

Sales Volume of Volkswagen, Audi, Škoda, SEAT in the U.S. and Global Performance

As a representative case the master thesis uses the data on the passenger automobiles statistics of the U.S. market.

From 2010 onwards the Volkswagen Group experienced a growth of the total deliveries of automobiles to the American market. In 2013 the sales of Volkswagen vehicles grew with 2,6 percent in comparison to 2012. In 2014 the total figure of vehicles sold on the American market rose with 4,3 percent and in 2015 remained equal (Annual Report 2012/2013/2014/2015). However, we shall investigate the number of the high volume passenger automobiles manufactured by Volkswagen to see whether they follow the same trend or not.

Annual sales of Volkswagen passenger vehicles

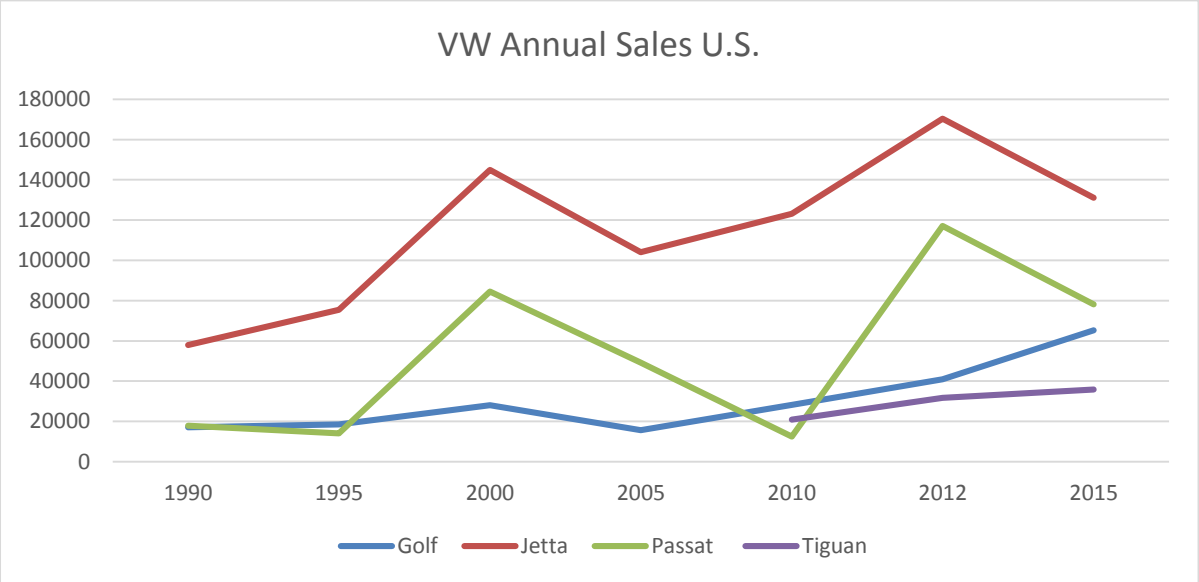
After its introduction on the American market, the Golf had its most prosperous years in the late '80s with around 200,000 units sold. The Golf has reached its best performance in 2015 with approx. 65,000 vehicles sold („Volkswagen Monthly and annual", 2016).

The sales of the Jetta did not experience any considerable changes.

The purchases of the Passat fluctuate in the period under observation. In the last four years the Passat achieved its highest sales numbers.

The Tiguan experienced a constant increase.

Figure 14

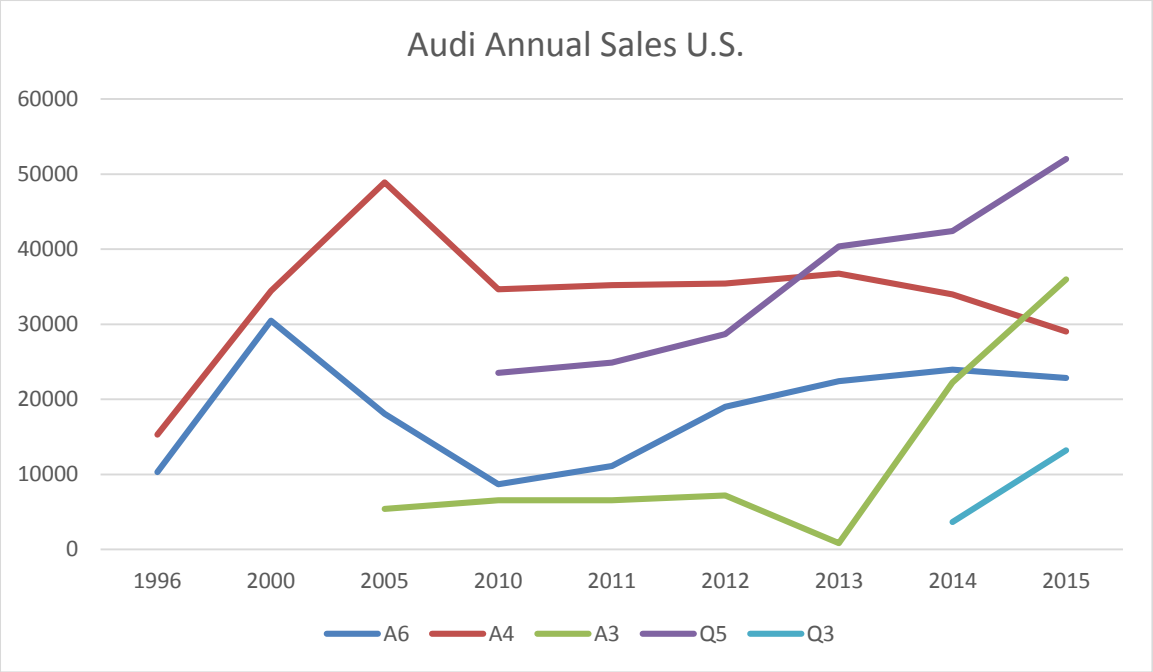


Note. Adapted from Monthly and annual sales figures for Volkswagen in the US, Carsalesbase 2016; Monthly U.S. car sales, Automotive News Data Center 2016

Annual sales of Audi passenger vehicles

In terms of the sales of the Audi high volume passenger automobiles on the American market we can clearly state that they grew, especially in the last years. The sales figure of A4 rose substantially until 2003, followed by a slight decrease and a recovery afterwards. However, its performance was better in 2014. The same pattern depicts the Audi A6, reaching its peak in 2000. The number of purchases of the A3, Q3 and Q5 models increased constantly („Audi Monthly and annual", 2016).

Figure 15



Note. Adapted from Monthly and annual sales figures for Audi in the US, Carsalesbase 2016; Monthly U.S. car sales, Automotive News Data Center 2016.

Škoda and SEAT did not enter the American market so far.

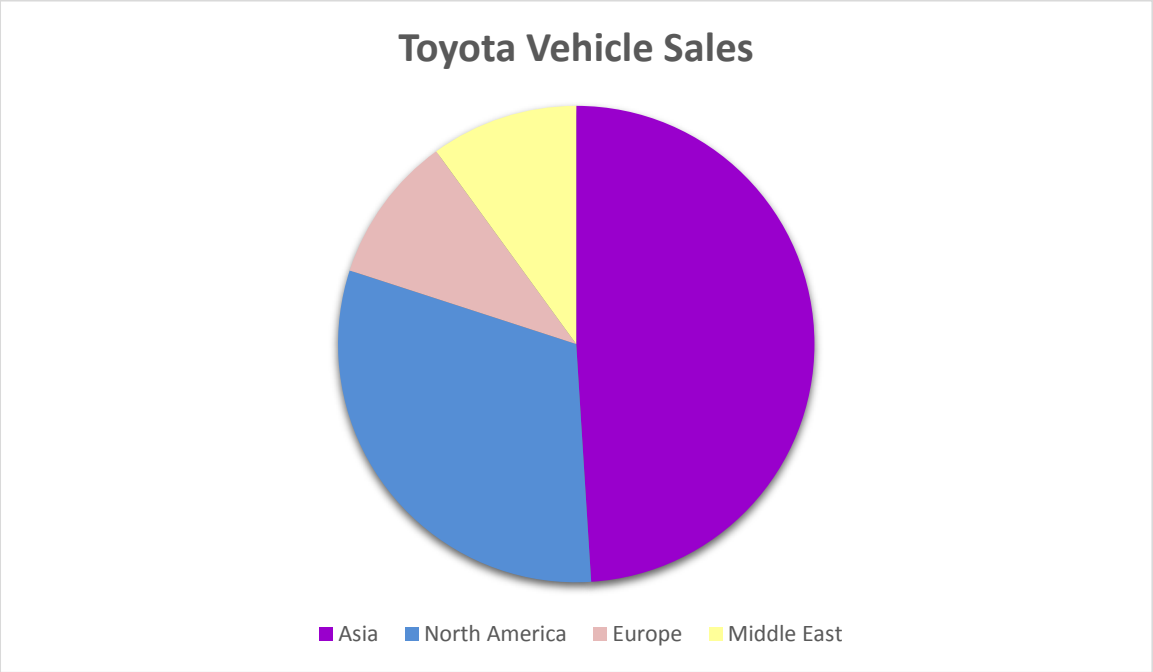
Global Performance

JATO Dynamics claims that among the 20 world top selling vehicles in the first quarter of 2016 are 4 Volkswagen models – the Golf, Polo, Lavida and Bora/Jetta. The Golf and the Polo experienced from a global point of view a slight decrease in sales by 3 percent. In contrast the Lavida/Gran and the Bora/ Jetta/ Sagitar achieved an increase in sales by 16 and 9 percent respectively (Global Car Market, p.8; 2016; "Wer macht das Rennen," 2010; Wimmelbücker, S., 2016).

6.5.2. Toyota

We can see from the consolidated financial results of Toyota 2014 and the percentage of vehicles sales, that the most important markets of the company are East Asia and the Pacific region with a share of 40 percent, North America (31 percent), Europe and Middle East with 10 percent respectively.

Figure 16



Note. Adapted from „Supplemental Material Consolidated," FY2014 Financial Results, Toyota 2016.

Annual Sales of Toyota and Lexus Passenger Automobiles in Europe

The market share of Toyota Motors automobiles in Europe is accounted for 4,6 percent in 2015. The sales of the high volume passenger automobiles Yaris, RAV 4, Corolla and Prius was reported by the company to have presented the best performance and to have contributed to the growth of the overall European purchases since 2011. The vice president of Toyota Motors Europe states that the European subsidiary gives priority to strengthening the hybrid and Lexus vehicles' sales ("Fourth consecutive year," 2015; "Record Sales," 2016). The European sales of Toyota vehicles comprise the domestically manufactured automobiles and the imported as well. In contrast to Volkswagen, the company includes in its European sales the data from vehicles' purchases in Russia (Ibid.).

Annual sales of Toyota vehicles in Europe

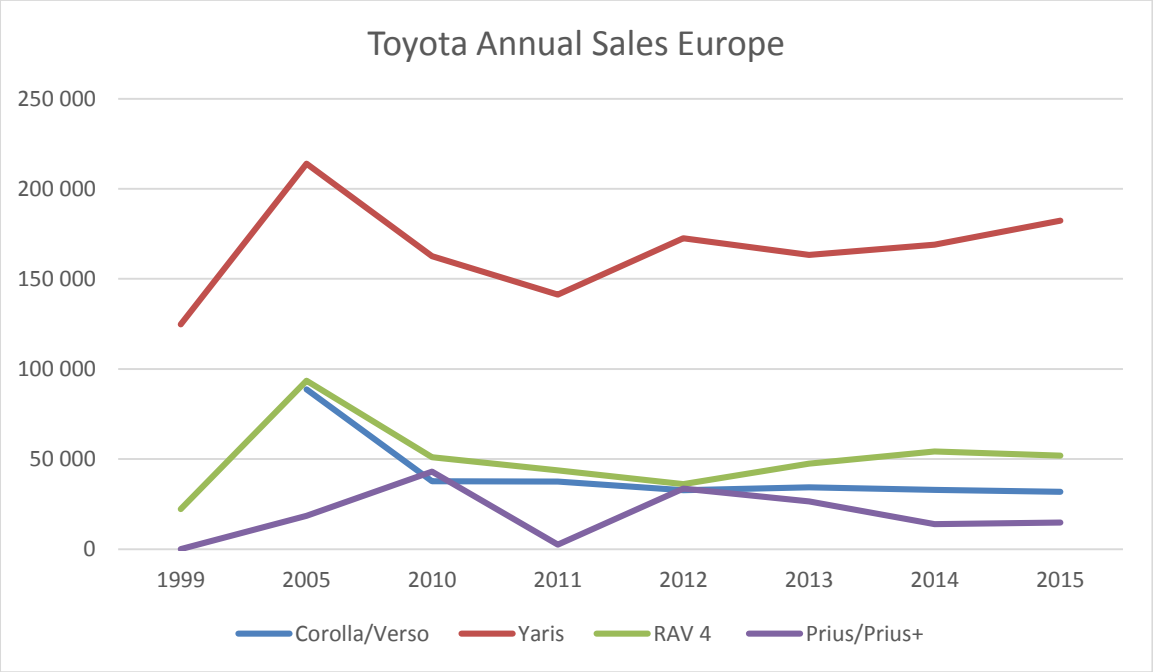
Toyota Corolla was launched on the European market in 2001. From that point on until 2007 the Corolla (known as Verso) relished an increasing demand reaching its peak in 2006 at approx. 90, 000 units sold. After that this figure started to decrease remarkably („Toyota Corolla Story," 2016; "Toyota Monthly and annual", 2016).

Toyota Yaris arrived at its highest point of sales in 2007 by almost doubling its sales figures from the early '90s. Yaris presented in 2015 a better performance in comparison to the last year and is undoubtedly the most purchased Toyota high volume automobile in Europe ("Toyta Monthly and annual", 2016).

After its steady rise from 1997 to 2006, RAV 4 sales began to fall and reached in 2015 only a half of the sales figure, achieved in 2006 (Ibid.).

The vehicles of the Prius family- Prius and Prius+ experienced from its introduction until 2010 a constant grow in sales. The last five years are characterised by shrinkage of the number of units sold (Ibid.).

Figure 17



Note. Adapted from Monthly and annual sales figures for Toyota in Europe, Carsalesbase 2016.

Annual sales of Lexus vehicles in Europe

The annual sales of Lexus ES are not included in statistic data bases or press releases of Toyota Motors. However, there are evidences that Lexus ES is purchased in Europe. According to Toyota Media, the number of LEXUS ES units sold grew in the first six months of 2016 in East Europe by around 19 % to 986 vehicles ("Record Sales," 2016).

Annual Sales of Toyota and Lexus Volume Automobiles in China

Toyota acknowledges China as the largest automotive market globally and one of its most important regions in 2015 together with India and Japan (McGrath, S., 2016, "Toyota Global Performance," 2016). The market performance of Toyota vehicles in China is relatively weak in comparison to its rivals, as the company holds an overall 5 percent market share (DeBord, M., 2016).

Annual sales of Toyota vehicles in China

Toyota Corolla depicts stable annuals sales throughout the whole period. Corolla arrived in 2015 at the highest point of its sales – approx. 250,000 units which has made it the most purchased Toyota model in China ("Toyota Monthly and annual", 2016).

The Yaris does not exhibit such a strong performance on the Chinese market compared to the European.

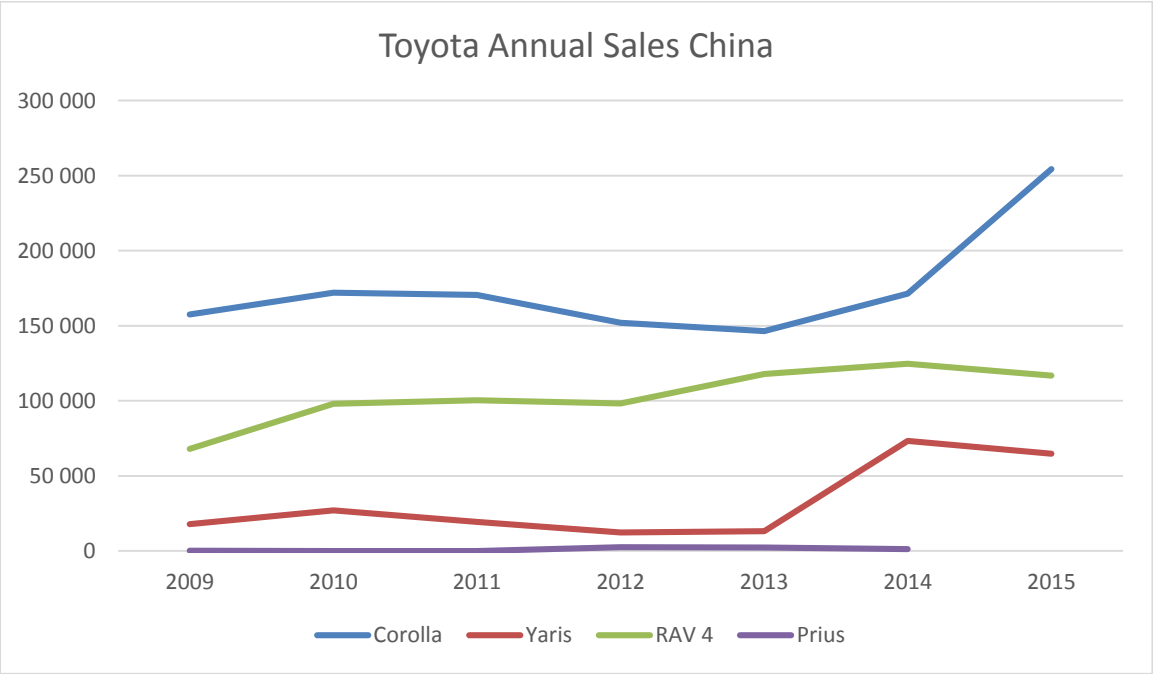
There is no clear pattern of sales of the RAV 4 model. We can see an overall increase of the units sold after its introduction (Ibid.).

The sales of the Prius are characterised with periods of sharp discrepancies. Most prosperous years for the Prius were 2006, 2012 and 2013 with around 2,000 vehicles purchased by customers. In 2015 only 408 Prius automobile sales were registered (Ibid.).

Annual sales of Lexus vehicles in China

There is no manufacture facility in China that can deliver the Lexus ES to the market. Therefore, the consumers rely only on imported vehicles. According to the company, the model ES is the most purchased one among the Lexus family. The number of vehicles sold amounted in 2015 to 33,164 automobiles. In reference to 2011 just after its launch this figure accounted for 28,971 units ("Lexus ES Among," 2011; "Lexus Sales," 2016).

Figure 18



Note. From Monthly and annual sales figures for Toyota in China, Carsalesbase 2016.

Annual Sales of Toyota and Lexus in the U.S. and Global Performance

Toyota vehicles are among the most popular automobiles in the U.S. Toyota earns around 14 percent of the total sales in the American automotive industry (Cain, T., 2015). The high volume passenger automobiles Toyota Corolla and RAV4 are among the ten best-selling automobiles in U.S ("10 Most Cars," 2015). Basically, Toyota vehicles characterise with long presence on the American market. The first two models introduced were the Corona and the Corolla in the late '60s (Company History, 2016).

Annual sales of Toyota and Lexus vehicles in the U.S.

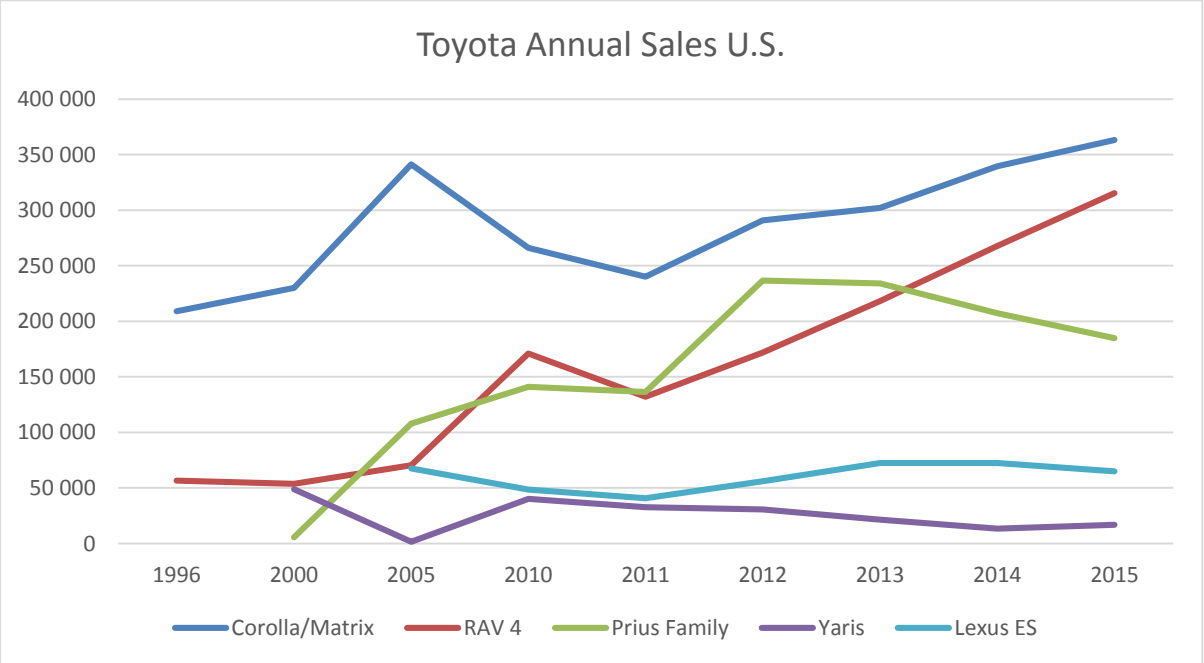
The sales of the Corolla, that is called in America „Matrix", were stable from the late '90s until nowadays ("Toyota Monthly and annual," 2016).

A steady increase in sales experienced the RAV 4 displaying only for one year a doubling of sales – from approx. 70,000 units sold in 2005 to 150,000 vehicles in 2006 (Ibid.).

The annual sales of vehicles of the Prius family grew significantly after their introduction in the late '90s. The sales came to their highest point in 2012. Afterwards the Prius family reported deterioration in performance (Ibid.).

In regard to the Yaris sales, we can see that the model demonstrated an overall downturn during the last seven years. Toyota Yaris has replaced the Toyota Echo in 2006. The number of vehicles sold arrived at its peak in 2008 with around 100,000 units purchased. From this point on it declined constantly (Ibid.). The purchases of Lexus ES did not experience considerable changes and remain stable between approx. 40,000 and 60,000 units sold.

Figure 19



Note. From Monthly and annual sales figures for Toyota in the US; Monthly and annual sales figures for Lexus, Carsalesbase 2016.

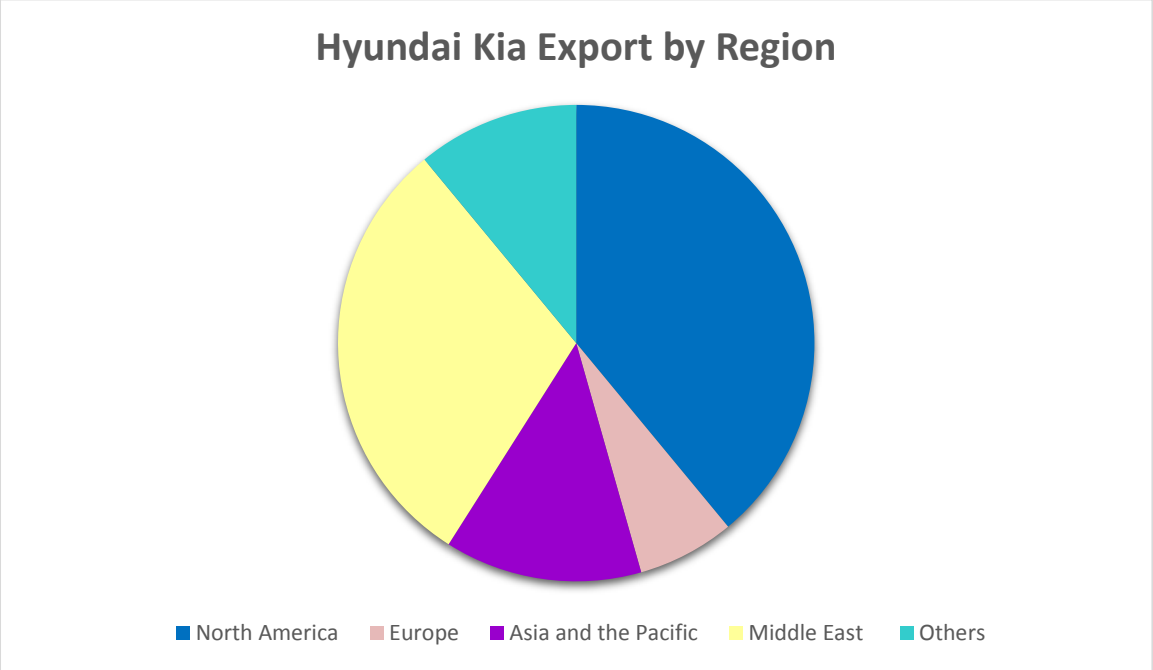
Global Performance

According to JATO Dynamics, there are two Toyota high volume passenger automobiles (Corolla and RAV 4) among the 20 top selling automobiles globally whereas the Corolla is claimed to be the automobile with the highest sales worldwide. Both of the models experienced from a global perspective a rise in sales by 5 percent for the Corolla and 15 percent for the RAV 4 (Global Car Market, p. 8, 2016).

6.5.3. Hyundai Kia

From the international activities statistics of Hyundai Kia, one can recognise that the most important markets for the company in 2015 are North America and prevalently the United States, with around 82 percent of the whole North American sales occurring there, Europe, Asia and the Pacific Region, and Middle East.

Figure 20



Note. Adapted from Export by Region, Sales Performance, Hyundai 2016.

Annual Sales of Hyundai Kia Passenger Vehicles in Europe

The European market share of Hyundai Kia accounted in 2013 for 6,6 percent which is an increase compared to 2011 when their market share stood at 5,1 percent (“Good Performance,” 2014; Madslien, J., 2013). According to P. Schreyer, the automobile designer of Hyundai Kia, one of the most important tasks in front of the company that will have a direct impact on the consumer’s mindset and therefore on the sales in Europe is the differentiation and individualization of the two brands (Madslien, J., 2013).

Hyundai Kia introduced their passenger vehicles to the European customers for the first time in the late '70s. Nowadays, around 95 percent of the automobiles sold in Europe are domestically manufactured (“Hyundai Achieve,” 2014).

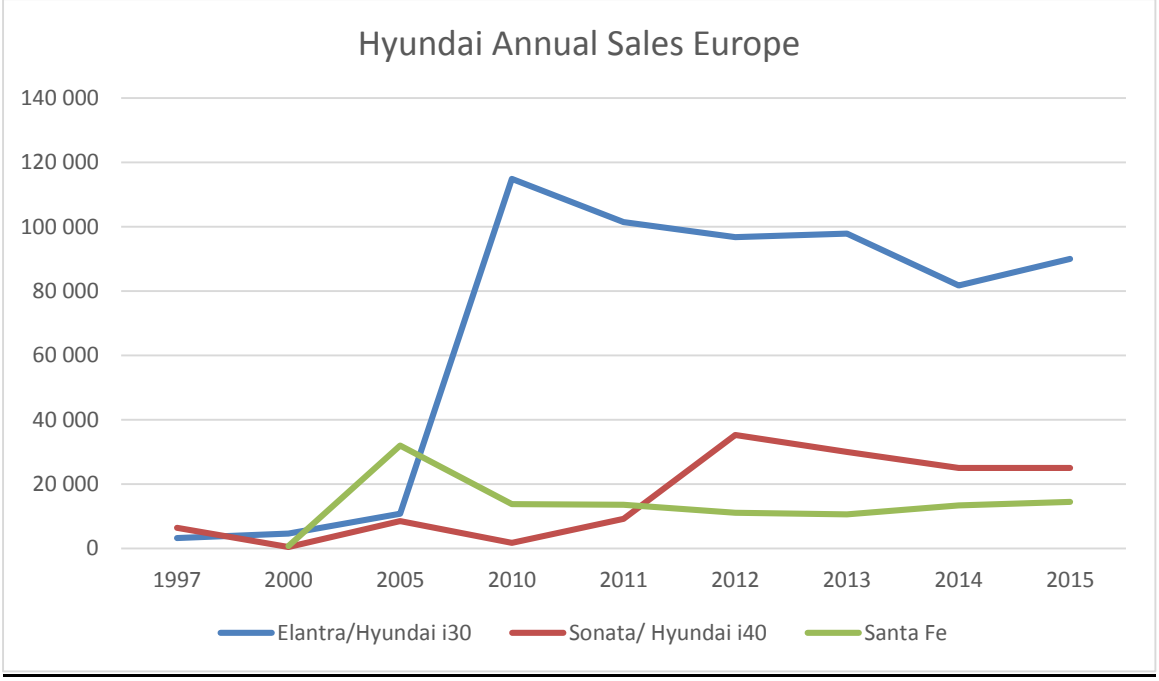
Annual Sales of Hyundai volume automobiles in Europe

The performance of Hyundai Elantra is marked by peaks and drops. The Elantra achieved its best accomplishment in sales in 2001 staying at around 18,000 units sold. After that Elantra was replaced by Hyundai i30 whose annual sales increased noticeably until 2011 and then started to shrink („Europe Retail Sales," 2016).

Hyundai Sonata or Hyundai i40 presented a moderate growth until 2010. The number of vehicles sold came to their peak in 2012 and then started to decrease (Ibid.).

The Santa Fe displayed an increase in sales until 2006 accounting for approx. 50,000 units sold. As the above mentioned passenger automobiles, this figure began to fall as well reaching in 2015 almost five times less units sold (Ibid.).

Figure 21



Note. Adapted from Monthly and annual sales figures for Hyundai in Europe, Carsalesbase 2016; Europe Retail Sales by Model, Hyundai 2016

Annual sales of Kia automobiles in Europe

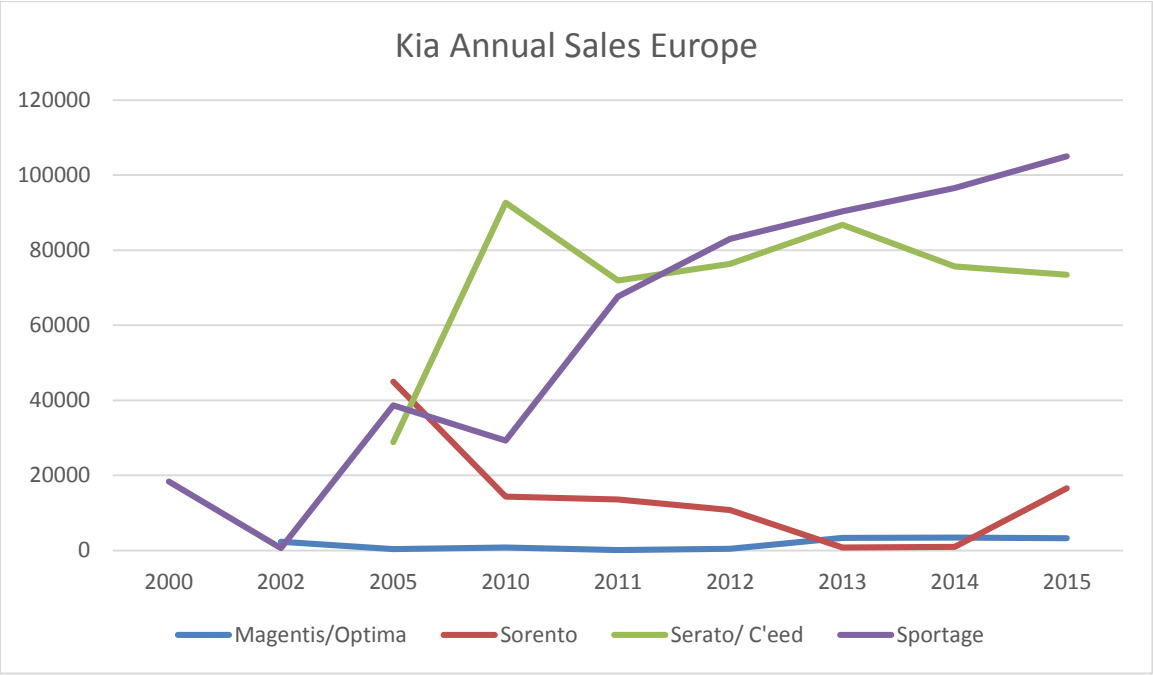
The European sales of Kia Cerato, also known and renamed as Forte or Cee'd, arrived at their maximum in 2008 and 2009. From this point on they fell gradually („Kia Monthly and annual", 2016).

The Kia Magentis, replaced by the Optima followed the same pattern as Hyundai i40 and from 20013 began to shrink (Ibid).

For the Kia Sorento the most successful years were 2005 and 2006. Then the number of units sold decreased gradually. However, Kia Sorento demonstrated a recovery in 2015 (Ibid).

Kia Sportage is the only one passenger automobile of the brand that demonstrates a constant upward movement of sales throughout the whole period (Ibid).

Figure 22



Note. Adapted from Monthly and annual sales figures for Kia in Europe, Carsalesbase 2016.

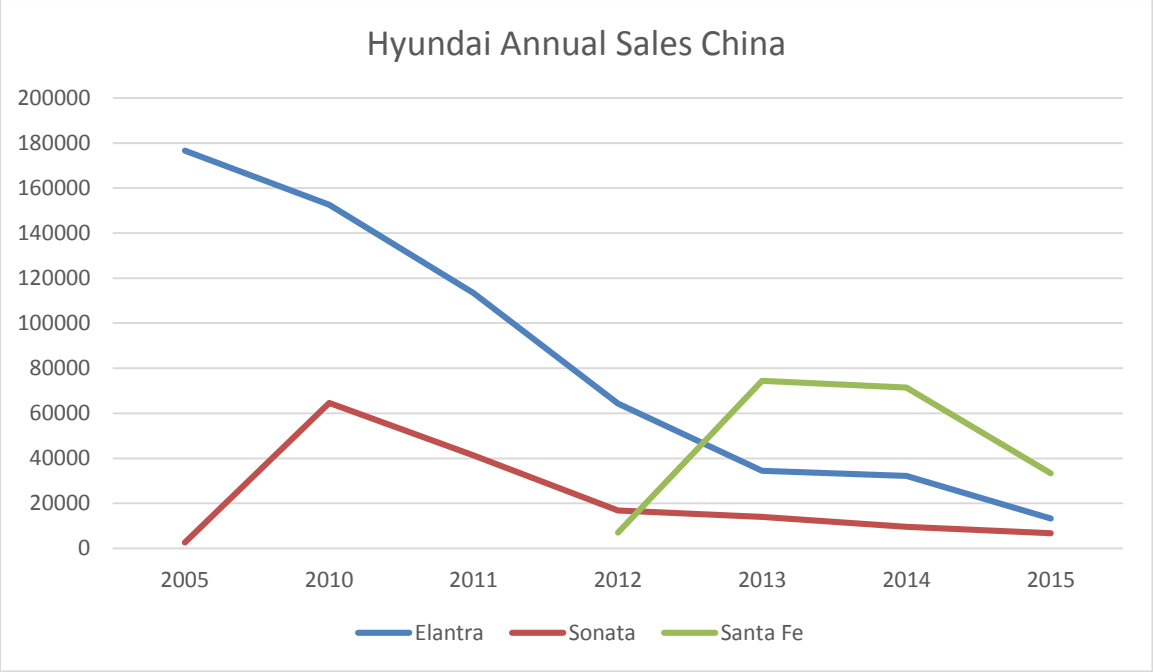
Annual Sales of Hyundai Kia Passenger Vehicles in China

Since 2012 Hyundai Kia proved a market share between 8 and 9 percent separately. For the last 7 years both of the companies achieved their goals in terms of sales. However, the situation changed in 2015. The annual sales for 2015 depict a decrase of sales for the two affiliates.

The high volume passenger automobiles Elantra in the sedan segment, which has four variations on the Chinese market Langdong, Yuedong and Lingdong, and i30 experienced a serious challenge. Their sales fell in the first half of 2016 by around 50 percent for the Elantra Sedan. This negative downward trend follows also the sales of the Kia Cerato and Sportige reporting 50 and 33 percent fewer sales. The Kia model Cerato/ Forte had the best performance among Kia high volume passenger automobiles, but from 2013 and onwards its sales began to decline remarkably. The Hyundai Santa Fe in the SUV segment demonstrated a noticeable drop of sales as well (Lee, C., 2016).

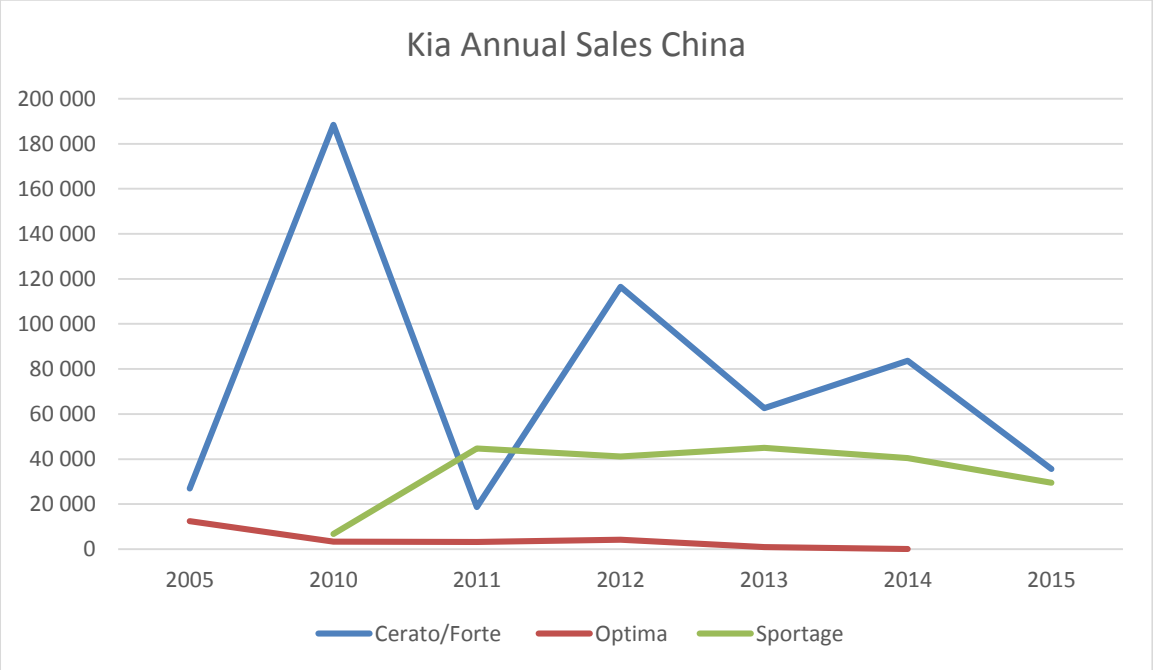
It is also difficult to differentiate between the four models of the Hyundai Sonata. Basically all of the variations are the same automobile under various names – Moinca, Hyundai Sonata 8 (YF), Sonata NF, Sonata NFC. The Sonata sales started to decrease in 2012 and their fall becomes apparent in 2015 and the first half of 2016 (“Hyundai Monthly and annual,” 2016).

Figure 23



Note. Adapted from Monthly and annual sales figures for Hyundai in China, Carsalesbase 2016.

Figure 24



Note. Adapted from Monthly and annual sales figures for Kia in China, Carsalesbase 2016.

Annual Sales of Hyundai Kia Passenger Automobiles in the U.S. and Global Performance

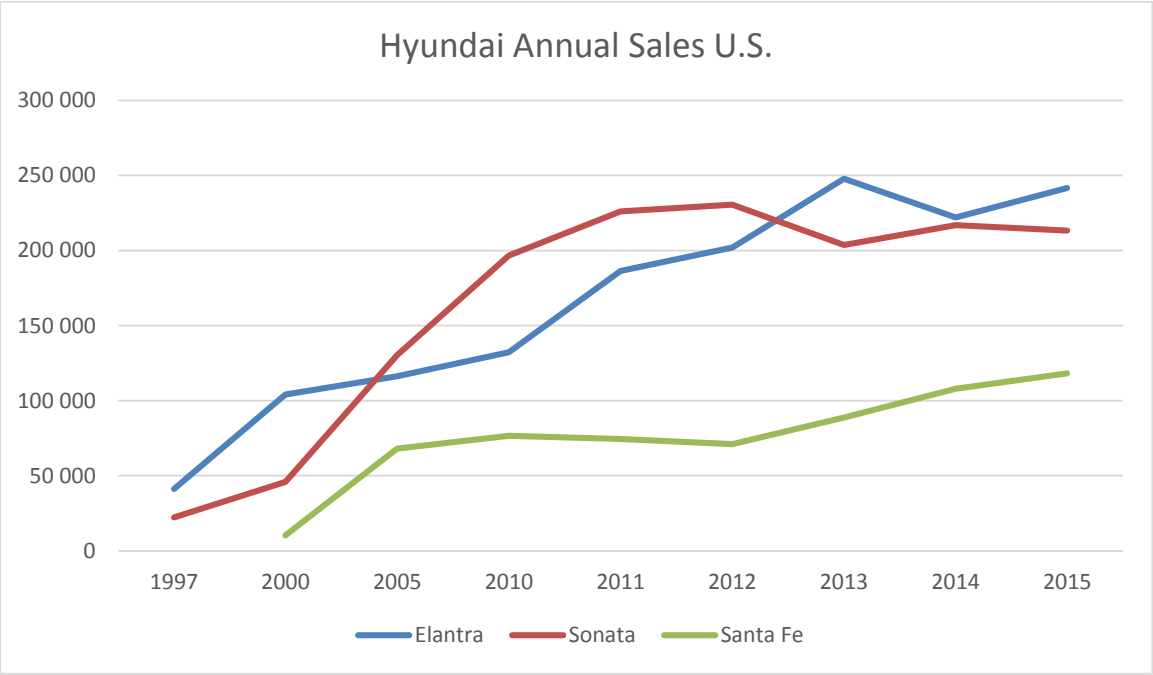
Hyundai offers its vehicles to the American customers since the late '80s. The market share of the two affiliates stood in 2003 at 1,4 for Kia and 2,4 percent for Hyundai. With time the companies established themselves on the American market and their combined market share accounts in 2015 for 8 percent („Hyundai Kia aims," 2007; Jin, H., 2016). According to latest data, both of the companies face the slowest growth since 2003 as the number of sales in the first half of 2016 compared to the same period in 2015 increased by 1 percent (Cain, T., 2016). However, there are two Hyundai passenger automobiles among the ten top selling automobiles in the U.S. –Sonata and Elantra (10 Most Cars, 2015).

Annual sales of Hyundai passenger automobiles in the U.S.

This can be also seen by the sales figures of the two automobiles. The Elantra reported a steady increase in sales. The Sonata experienced also an overall rise of sales and their highest point was achieved in 2013 ("Hyundai Monthly and annual," 2016).

With regard to the SUV segment, the sales of Santa Fe reached their peak in 2004 (Ibid).

Figure 25



Note. Adapted from Monthly and annual sales figures for Hyundai in the US, Carsalesbase 2016; US Retail Sales by Model, Hyundai 2016.

Annual sales of Kia passenger automobiles in the U.S.

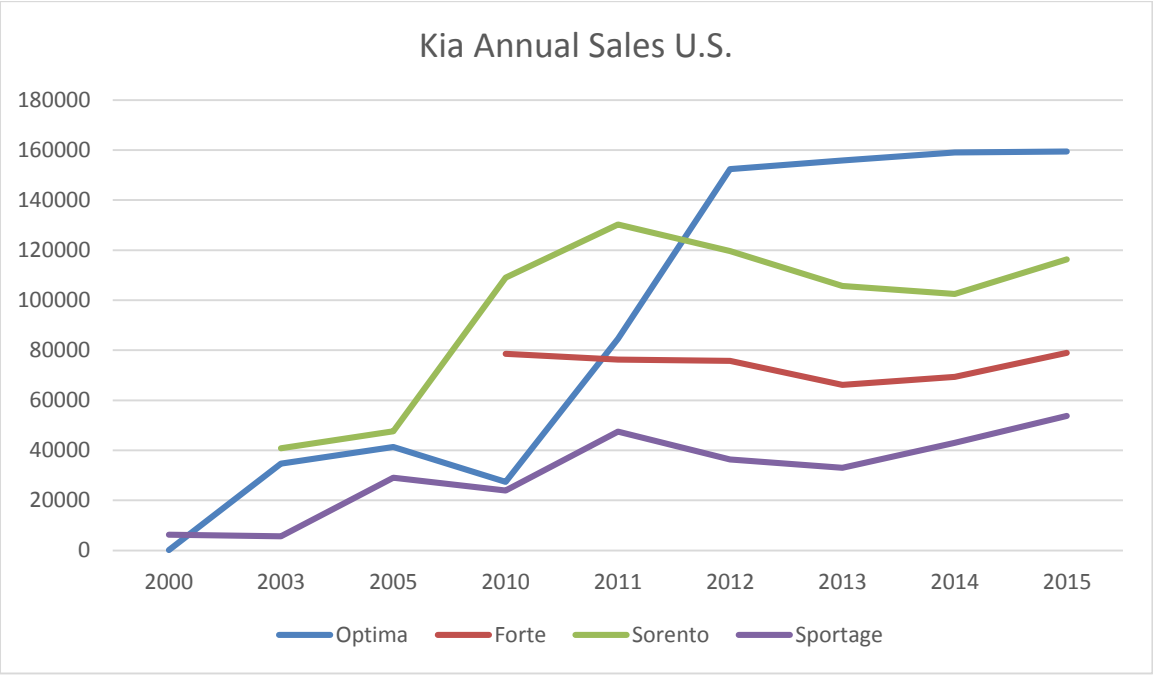
The Kia vehicles follow a fairly stable pattern for the last five years. The exception is Kia Optima, whose sales experienced noticeable increase („Kia Monthly and annual," 2016)

The Forte demonstrated sales without any strong deviations.

The purchases of Sorento grew until 2011 and then began to fall slightly, depicting higher sales volume in 2015 compared to the previous year.

The Sportage SUV model was acquired by American customers in diverse manner. The sales have presented their best performance in 2015 (Ibid.).

Figure 26



Note. Adapted from Monthly and annual sales figures for Kia in the US, Carsalesbase 2016;

Global Performance

According to JATO Dynamics the high volume passenger automobile Hyundai Elantra/ Avante/ i35 is among the 20 top selling vehicles globally for the first half of 2016. Compared to the same period in 2015 the Elantra experienced from a global point of view a decrease in sales by 21 percent (“Global Car Market,” 2016, p. 8).

6.6. Automation and New Production Method

6.6.1. Continuing Advancement in the Automation and Optimisation

At the beginning of the automobile manufacture workers performed mechanical production by assembling the automobile fully by hand. The revolution in the automotive industry was initiated by Henry Ford due to the further development of the concept of assembly line designed by Ransom Olds. Ford turned it into a moving assembly line and marked the beginning of the "Power Revolution" in the automotive industry (Cordey, R., 2014; Jeschke, S., 2015).

Automobile manufacturers used the moving assembly line a long period without any serious improvement or innovation of the concept. But as the demand for automobiles rose gradually, the producers had to find other solutions for further mechanisation of the process. In this way, the automotive industry entered the new stage of innovation of the production processes and adopted the robotic automated systems (Cordey, R., 2014).

The first robot used in the automotive industry is "UNIMATE" and could perform single movements like the function "pick and place". The first programmable robot is engaged in the production in the late 60s. Nevertheless, the revolutionary step between the robot arms with limited movements and the highly flexible and intelligent operators is the six axis robot "FAMULUS" created by KUKA in 1973, capable of performing various tasks (Jeschke, S., 2015). Nowadays according to the International Federation of Robotics, the automotive industry presents the greatest applicant of industrial robots ("Industrial Robot Statistics," 2016). Robots are engaged in almost every automotive activity. They perform more than 90 percent of the operations in the press, body and paint shop, and around one quarter of the work in the final assembly process (Jeschke, S., 2015).

6.6.2. Volkswagen - Application of Robotic Intelligence

From 1983 and the purchase of the first industrial robot in the shed 54 in Wolfsburg for the assembly of the Golf, Volkswagen focused its vision on the further automation of the processes in the factories and began to purchase or develop individually robotic arms and industrial robots. In the late '80s and early '90s robots designed in the Volkswagen facilities made up 25 percent of the production of robots in Germany (Jacob, D., 2004). On the one side, in the late '80s 90 percent of the operations in the press shop of Wolfsburg facility, 40 percent in the paint shop and 25 percent of the final automobile assembly were executed by robots (Hessler, M., 2014). On the other side, in 1993 the automation level of the automobile's final assembly in the shed 54 is accounted for 80 percent which turned the facility into the plant with the highest automation level (Metal trades Committee, 1994).

Nevertheless, the robots could not function without human supervision. In total 275 professionals were responsible for the surveillance, maintenance and repair of the robots. However, it should be stated that because of the engagement of robots the number of mistakes in the production processes of the automobile decreased significantly (Hessler, M., 2014).

There is no available and detailed statistics on exact numbers of robots purchased and applied in every production facility afterwards, but even the beginning of the '90s reveals the direction of Volkswagen towards robotic automation. The majority of the industrial robots are engaged in the production of the high volume passenger automobiles. Two types of industrial robots can be seen in the press shop and the assembly plant, especially in the automobile body manufacturing – KUKA and Fanuc. KUKA are engaged in the foundry facility and in the paint shop. There they are supported by painting robots designed and installed by Dürr AG (Dürr Installiert, 2012; Kruschke, G., 2012). Furthermore, Volkswagen still develops robots for the automotive purposes of the Group only (“Der Roboter,” 2016).

Image 1. KUKA Industrial Robot



Note: Industrial robot KR 90 R2900 for production of high volume passenger automobiles. Copyright (2015) by KC Robotics, Inc.

Fanuc are applied in the Volkswagen facilities since 2003 with an initial purchase of 160 industrial robots of the type R-2000i for the production of the Golf in the headquarter Wolfsburg. The robots function in cells and are capable of accurate and precise movements. Volkswagen has developed its individual operating systems for the control of the robots which has been integrated in the Fanuc mode of operation (“Fanuc-Robotics,” 2016; “Industrie Forum,” 2016). We can gain insight into the Volkswagen’s path toward further automation from the single delivery from 2011 to the end of 2012 of 4,700 industrial robots of both KUKA and Fanuc solely for the manufacturing of high volume passenger automobiles with the logo of Volkswagen, Audi, Škoda and SEAT (Kroh, R. 2011). From 2013 to the end of 2014

Volkswagen acquired 6,000 KUKA industrial robots which presents the largest delivery of industrial robots in the history of KUKA Roboter GmbH, whereas they were deployed in the production of passenger automobiles (Passat, Audi A4) only in five manufacturing plants (Kruschke, G., 2012). Every manufacturing facility is equipped with industrial robots in accordance to the capacity of the plant e.g. 182 KUKA robots for welding processes in the body shop of the plant Anchieta (Brazil), 398 Fanuc robots in the body shop of plant Chattanooga (Tennessee, U.S.), 1,600 Fanuc, KUKA and VW robots in Puebla (achieving 80 percent automation level of the body shop), and 2,500 robots in the body shop of Audi A4 in Ingolstadt, which is the largest European manufacturing facility after Wolfsburg (Healey, D., 2016; Henry, I., 2015; Perry, J. 2014).

According to a research of the Robotics Business Review, KUKA and Fanuc are among the 50 most innovative and advanced robotics companies of 2016 worldwide, whereas 23 of them are in the manufacturing industry (Crowe, S., 2016)

Collaborative robots UR5 coming from Universal Robots are applied in the engine plant of Salzgitter. In comparison to the above mentioned robots, Universal's are light weight 6 axis robotic arms that imbed glow plugs into the cylinder head, a complicated and detailed work done previously manually. The robots can operate without surveillance because of their safety sensors (Gibbs, N., 2013).

In the plant of Anchieta Volkswagen deploys one of the most innovative solutions for improvement of the performance of the press line – the ABB robot line (ABB Robotics). The ABB line is equipped with two seven axis robots that are faster in comparison to the six axis robotic arms. The ABB line is used to produce parts for the high volume passenger automobiles Polo, Saveiro, Fox and other parts. After the installation of the new robotic line, the number of produced units per day grew significantly from 170 panels to 3,880 panels for particular group of parts (Webzell, S., 2009).

Volkswagen sees its future in the further engagement of robotic intelligence. Because of the automation and use of flexible robots, the Wolfsburg plant has achieved to produce more than 3 million possible variations of the Golf whereas the most commonly chosen modifications account for 300,000 assemblages. H. Neumann, member of the board group of management with responsibility to the human resources, claims even that the robots are part of the solution of the aging workforce at the company. The employees which are from the baby boom generation in Germany (1955-1975) are expected to retire between 2015 and 2030. Their number is accounted for 32,000 professionals which is around 25 percent of the whole personnel engaged in the manufacturing process. Robots are seen on the one side as a possible replacement of aging workers. On the other side, robotic intelligence can undertake the repetitive tasks that can be seen in the assembly process or in the fitting of components. The current robots are highly efficient and capable of versatile movements in the welding, assembly and material handling processes. In this way, the company can reduce the employment positions that require hard and tedious work, and employ or reposition and train the human potential for more qualified and specialised jobs (Neumann, H., 2015).

The latest evidence for the direction of Volkswagen towards surge in the automation is the engagement of the KUKA sensitive robot "LBR iiwa" in May, 2016. It presents a seven axis robotic arm with the capability of learning and working with an individual, picking up parts and performing accurate operations at hard accessible places without the chance of collision

with the human worker because of its sensitivity to its surroundings. The robot is active in the mass production of the Golf at Wolfsburg and Salzgitter facility (Nejati, M. 2015; "KUKA flexFELLOW," 2016).

In total, as to 2014 Volkswagen commanded 28,000 robots globally as the majority of them are industrial robots functioning in cells and just three of them are collaborative (Powley, T. 2014). The automation level of the body shop of the European Volkswagen facilities and in Mexico stays at around 80 percent, in the Wolfsburg facility at 96 percent where human work is needed for the installation of the doors (Healey, D., 2016; Vondruska, J., 2001).

Introduction of the Modular Assembly

The employment of robots does not change entirely the production method that is used in the automotive industry since 1920 – the automatic assembly line. But we can clearly see to what result has led the development of the robotic intelligence. The division of Volkswagen - Audi has developed a new concept toward the future manufacture of vehicles – the modular assembly. Until September 2016 the realisation of the project "The Smart Factory" has been in progress applied to the manufacturing plant in Győr, Hungary (Audi TechDay, 2016, p. 3). In October 2016 in Mexico was opened a production facility that does not command conventional assembly line anymore and "The Smart Factory" modular assembly concept is fully integrated in the production flow of the high volume passenger SUV Audi Q5 (Francis, S., 2016).

The researchers from Audi consider that the modular line in the Smart Factory increases the productivity by 20 percent. The new modular assembly gives the manufacturing plant more flexibility as the vehicle diversity increases on a daily basis. The conventional assembly line is reluctant to meet the new needs or to be efficient in the cases where only a couple of automobiles should be equipped with additional accessories and components. The innovative concept of Audi splits the production line into single stages. The resulting assembly work stations are under command of one or two employees. The conveyor has been abandoned and the transportation of the vehicles body structures, parts and components has been undertaken by driverless transport systems which can move autonomously in a flexible manner. If required the driverless transport systems (autonomous forklift trucks, driverless floor conveyors) are controlled by a central computer which is a part of the "Laser Tracking System". The airspace at the plant is utilised for the logistics as well. The light components like the steering wheel are transported and delivered to the new assembly station by drones. Intelligent robotic arms are employed in the actual vehicle's assembly and collaborative robots are used for the precise application of delicate components ("Audi TechDay," pp. 5-13).

The information flows into a „shared data lake". Due to algorithms the data is being framed and after that precisely analysed. Every production location is connected to this data lake. In this way machines and processes become completely connected and can be controlled and coordinated by an employee at any manufacturing facility ("Production fit," 2017).

Image 2 Modular Assembly



The new assembly islands, Copyright (2016) by Audi AG.

Image 3 Logistics



Driverless floor conveyor. Copyright (2016) by Audi AG.

Image 4 Logistics



Component delivery by drones, Copyright (2016) by Audi AG.

Another approach called „the assisted reality“ is applied in the engine plant for the Audi A3 where the engine is assembled manually according to the customers‘ requests. The engine assembly is one of the most complicated activities as there are hundreds of miniature similarly looking parts that surround the station. The employee uses in this case the Google Glasses connected to a server. The employee gets in front of his eyes the corresponding manual of the engine assembly ordered. When looking to the section of the various parts they become visible with their serial numbers. However, the information is presented only if the employee searches for it (Ibid., pp. 19- 20).

For the planning of the welding shop and even of the body shop employees use the approach of the „augmented reality“ with the help of the Hololens glasses of Microsoft. Through measurement of the surroundings to the employee is depicted a hologram of the working process of the virtual welding robots and the robotic arms in the body shop. The employee can reorganise their position and activities or to follow their activities in consecutive stages. Therefore, if a breakdown or a flaw has been detected, the holograms that can be seen by several employees in different plants can assist in finding the cause for it. To assess the new production method and the satisfaction of the workers with the new technologies, a team of researchers attends the workflow and documents data in Győr (Ibid.). Gradually, the concept of the assisted and augmented reality is being applied in other Volkswagen manufacturing plants. They are currently a constant character feature of the production activities at the Wolfsburg plant (Robarts, S., 2015).

6.6.3. Toyota - Development and Adoption of Robotic Intelligence

Prior the introduction of industrial robots Toyota elaborated the concept of „lean manufacturing“ that influenced many companies in the automotive branch. Basically, the lean manufacturing places the emphasis on the maximization of the value creation and minimisation of the waste produced by the manufacturing process such as industrial waste, automobile parts of materials that become useless, etc. The company division „Toyoda Machine Works“ devoted its efforts in the '70s to develop industrial robots that would match its individual manufacturing needs („How Toyota Uses,“ 2016; Hunt, D. 1983, p. 306). Toyota applied for the first time in its history an industrial welding robot in the early '80s whereas its installation marks the beginning of automation of the company. In this way the company achieved the objectives set by the concept of the lean manufacturing, upgraded the quality and not only the waste buts also the costs have been decreased (History Toyota, 2016). In the early '80s Toyota had at its command 200 industrial welding robots and showed its willingness to purchase more 700 Kawasaki welding robots until the end of the decade (Hunt, D. 1983, p. 305).

According to an archive document of the company, the vision of an autonomous manufacturing process and the term „complete assembly line“ appeared for the first time during a discussion of the head managers. The „complete assembly line“ has been built in the facility of Kyushu and presented a line „that finally combined the physical, functional, and organizational elements of the new system and crystallised them as autonomous complete assembly process.“ (Fujimoto, T., 1999, pp. 258-259).

The industrial robots applied by Toyota are active in the welding, painting and manufacturing operations. For the welding and handling processes in the body shop Toyota uses nowadays Kawasaki (Kawasaki Robotics GmbH), Nachi (Nachi Robotic Systems Inc.) and Yaskawa (Yaskawa Electric Corporation) industrial robots. Toyota uses the Kawasaki robotics also for the paint shop (Edwards, D., 2016). For example in the Motomachi plant (Japan) in 2014 the number of the industrial robots applied is accounted for 760 units and the number of employees in the whole plant for 7, 391. Furthermore, Toyota specialised in the design of robots used for lifting heavy loads, palletising and delivering components (Motomachi Plant, 2016; Trudell, C., Hagiwara, Y. & Jie , M., 2014).

In the year of 2000 Toyota started the development of „partner" robots that should function along with humans and are created in the scope of the vision toward man-machine cooperation. In five years the division „Partner Robot Development" was founded and started operation. Together with Yaskawa, the company started an initiative in 2005 for developing a collaborative robot that can help in the most difficult and delicate job in the final assembly of the automobile (Gudorf, P., 2007, p. 190).

In 2010 a collaborative robot was presented by the company whose duty is to load spare tyres in the final assembly. The light weight robot can work together with an individual without the chance of accident because of its technology (Anandan, T. 2013).

However, by describing the history of its production system Toyota does not underline the importance of the automation processes. There is no available statistics or even characteristics of the robots engaged in the manufacturing process of the vehicles. We can just find the brands they are part of, but not their models or number. Nevertheless, Toyota uses advanced robotic intelligence in order to standardise its production (Ponticel, P., 2003).

In the early '90s the automation level of the final assembly line in the body shop of Toyota is accounted for 8 percent (Metal Trades Committee, 1994). In comparison, ten years later in 2003 the automation level in the paint shop of the Georgetown facility stays at 40 percent and that of the automobile's final assembly at around 15 percent. According to the vice president of Toyota Kentucky, the level of automation of the other manufacturing facilities is approximately equal. He considers that Toyota will rely on the further automation "as long as it's a flexible piece of equipment (...)" (Ponticel, P., 2003, p. 89). Therefore, one can say that the company uses robots in its manufacturing where the processes need to be automatised (Ibid.).

The company materialised its vision in 2007 in the shape of the a collaborative robot that installs the windshield of the automobile. The windshield assisting robot spares the employees the difficulties with the big size and heavy weight of the windshield and in the same time the incorrect installation („Toyota Partner Robots," 2016).

In order to understand the automation process occurring in Toyota we shall cosider the core values of the company that are embodied even in the manufacturing process. The philosophical concept relies on two pillars – jidoka (自働化) and „just-in-time production" established in the early '90s. Jidoka appears at the beginning of the automatization processes in the automotive industry in order to replace the „automation" concept and establish the „autonomation" as a guiding principle in the new era of manufacturing. Autonomation is understood as „automation with a human touch". It refers to machines with the capability to stop functioning when a problem appears. In this way the continuous monitoring of the

machines is not required any more. By separating the machines from the men the concept increases the productivity as one operator can supervise various machines („Jidoka," 2016; „Toyota Production System," 2016). In the present production line of Toyota jidoka has found its place when a robot or machine detects a problem in the manufacturing, breaks the process, and signalises to the human operator who is in charge to find the mistake and to correct the defect. As it name reveals the „just-in-time" principle means a production without industrial waste, deviations from the concept and without any „unreasonable requirements on the production line" („Toyota Production System," 2016).

There is no evidence that Toyota develops a new method of production or is willing to restructure and reorganise production processes.

The vision of Toyota toward its further automation differs from that of Volkswagen AG. The future strategy of the company is oriented to lesser the amount of work done by robotic intelligence and to bring human work back to the production processes. The executive vice president of the Unit Center Mitsuru Kawai believes that not the robotic intelligence but the advanced human skills and diligence are the key for increased future efficiency. He values more the manual work of experienced workers on the production line than the robots despite the fact that robots perform their tasks faster and at a reasonable price. Kawai states that by engaging employees on the production line they can improve their competence and also find solution for further improvement of the manufacturing and assembly process. With his appointment as executive vice president Toyota Motors will halt its expansion projects and will not build further manufacturing facilities until 2017. However, Kawai just continued the tendency started in 2011. Since then Toyota opened around 100 manually labor intensive vacancies (Trudell, C., Hagiwara, Y. & Jie , M., 2014).

The main area of interest for Toyota in the development of artificial intelligence is the design of partner robots that can help families and people with special needs. The Human Support Robot and Robina help people with limited movement abilities in doing housework, giving water or meal and picking up objects. The Walk Assist Robot is designed for people who suffer from loss of muscle function and assist the individual to walk again. Robina is a robot that can do the housework or provide medical services. Care Assist Robot supports patients at medical institutions or at home in standing up from the bed and/or bring people from one place to another („Partner Robot Family," 2016).

6.6.4. Hyundai Kia - Application of Robotic Arms

Kia acquired the first two industrial robots in 1979 and every robot took the place of three welder operators (Hunt, D. 1983, p. 312). Hyundai introduced in 1986 the first welding robot that was designed by the company for its automotive needs. Hyundai Heavy Industry Co. was established in 1973 as a shipbuilding company. It started to specialise and develop industrial robots in 1998. In 2002, Hyundai Heavy Industry had the capacity to manufacture 100 industrial robots per month and holds 40 percent of the Korean market for industrial robots. However, with respect to the global share Hyundai Heavy Industries holds around 3 percent of the robotic market (Eui-dal, S., 2003; „History 2000-2009," 2016).

There are no available statistics for the number of the robots purchased, manufactured and introduced in every production facility through the years. We can extract data on several Hyundai Kia production plants. The only one European manufacturing facility of Kia located in Zilina, Slovakia, commanded in 2011 413 industrial robots, whereas 198 of the robots are engaged in the welding, 12 in sealing and 110 in various processes in the body and the press shop. The automation level of the welding is 100 percent. The number of employees is accounted for around 3,500 professionals which makes a proportion of one robot per around 8 professionals. The industrial robots deployed are prevalently from Hyundai Heavy industries and from ABB robotics. Dürr Automatic Guided Vehicles perform in the final assembly the delivery of the automobile's underbody (Holt, N., 2010; "Kia factory in Slovakia," 2012).

Within the Kia production plant in Pesquería, Mexico function in 2016 420 industrial robots which are engaged in the press, body and paint shop. For welding purposes are engaged 300 industrial robots, whereas the largest part is delivered from Hyundai Heavy Industries- the industrial robot Hyundai Wia, and from Fanuc and KUKA respectively. The level of automation of the welding activities is accounted for 85 percent. Hyundai Wia industrial robots are deployed in the paint shop as well. In total, the Mexico plant employs 3,000 professionals which makes again the ratio of a machine per 7 professionals (Perry, J., 2016).

The production facility of Hyundai in India commands more than 400 industrial robots and around 4,848 manual workers – Hyundai Wia and KUKA KR16 positioned in the press and body shop operating welding and sealing processes, and Dürr robots deployed in the paint shop. The automation level of the body shop stays at 100 percent whereas that of the final assembly at 10 percent („Robots Rising," 2015; "Hyundai Motor India," 2014).

The production facility in Ulsan, South Korea is believed to be the largest manufacturing facility of passenger automobiles in the world which consists of five production facilities located in a common area and the Hyundai main production plant („The world's biggest," 2016). In 1999, the number of the industrial robots operating in the facility was 257 units (Lansbury, et al., 2007, p. 79). Nowadays it manufactures 5,600 automobiles per day. In 2008, the number of total robots stood at around 600 units (Ramesh, M., 2008).

An insight into an additional Hyundai manufacturing plant in Namyang and also into the future path of the company toward automation gives the statement of the director of the Manufacturing Engineering Group Sung-Sup Do:

„To make a flexible manufacturing system, it is better to deploy as many robots as possible." (cited in Holt, N., 2009)

Basically Hyundai Kia uses the artificial intelligence from Hyundai Wia for the chassis assembly and the welding, handling and pressing operations in the different shops of the automobile assembly. The largest part of the robotic arms is from Z-series that have a vast range of activities – assembling, spot welding, material handling and palletising. The robotic arms have 4 or 6 axes, can lift from 100 to 300 kilogrammes and the wrist twists are allowed to rotate 360 degrees ("Robot/ Jig," 2016; "Hyundai Factory Automation," 2016).

Image 5 Industrial Robot Z-series



Hyundai WIA industrial robotic arm ZX130S/130L. Copyright (2015) by Hyundai Motor Group.

With regard to the application of collaborative light weight robots, there is no data on the presence of a collaborative artificial intelligence within the work flow of the manufacturing facilities of Hyundai Kia.

Hyundai and Kia Motors were interested in an upgrade of the automation level of its facilities still in the late '80s. Both of the companies aimed improved quality and enhanced production possibilities (Park & Lee, 1997, p. 287). From the early '90s and onwards Hyundai strengthened its investments in the advancement of the automation. Hyung Je Jo describes the path toward automation in Hyundai in the following way:

"(...) it did not expect education and training to have positive effects given the deep distrust between management and labor. Consequently, Hyundai developed a 'labor-exclusive' production model, which minimises dependence on factory workers." (Hyung, J., 2010, p. 105).

The trend of the heavily financing the automation production operations characterises not only the development in the '90s, but also the period of the global expansion of the company – from 2002 and onwards. As mentioned above, the Alabama plant in the U.S. has a fully automated welding and handling operations (at 100 percent). The production facility employes around 2,000 professionals and manufactures around 300, 000 high volume passenger automobiles annually (Ibid, 2010; Chappell, L., 2005). The focus on the further automation of the company's production facilities can be recognised from the other new plants overseas. Nevertheless, there could not be found any indication that Hyundai Kia plans to restructure its present production practices or introduce a new method of manufacture.

Summary

Volkswagen, Toyota and Hyundai Kia have at their command a range of highly flexible industrial robots. The companies differ in the focus of their strategies for future automation and their attitude toward the human- robot collaboration in the manufacturing operation. Only Volkswagen has developed a new method of production, reorganising processes and adopting evolutionary technologies in series application.

6.7. Maintenance and Development of Advanced Diagnostic Programmes

Volkswagen

Volkswagen developed an extensive and advanced diagnostic programme which includes versatile diagnostic tools and testers equipped with special software called „Offboard Diagnosis Information System". Basically the diagnostic tester is used before the repair process. When plugged in the diagnostic testing device connects the board computer of the automobile through the off-board diagnosis information system with the main database of the Volkswagen Group, and detects the area of the fault. The diagnostic tester is perceived to be an artificial intelligence - a robot without a body (Jeschke, S., 2015, p. 21). Volkswagen developed its diagnostic devices in a high range of variations according to the specifications of the area of the automobile – engine, gearbox, suspension diagnosis, and they are developed in that way that they can supplement each other functions. In turn, every of these specialised diagnostic tools is designed in accordance to the individual traits of the automobile model or group of models – for example the engine diagnostics for the high volume passenger automobiles produced on the same shared modular platform are performed by one identical testing device ("Step by Step," 2016; "Bosch Workshop World," 2016). The testing devices are affordable not only for authorised dealers or automobile repair shops, but also for the ordinary consumer.

Toyota

When it comes to the development of the diagnostic testers (a robot without a body), Toyota designed the Global Tech Stream (GTS) Diagnostic System. One needs the following requirements – a personal computer, a cable (TS2 Vehicle Diagnostic Unit) and the diagnostic software that can be downloaded free of charge. To correct the faults one should have access to the Toyota database via license which can be paid for depending on the period one wants to be connected to the server ("GTS Diagnostic Tools," 2016).

Another tool for diagnostic is the Toyota Intelligent Tester 2 that performs diagnostic of the whole vehicle due to its software that has to be updated. The tester is capable of diagnosing other automobiles such as Suzuki (Ibid.).

Hyundai Kia

With respect to the robots without a body, Hyundai Motor and its subsidiary in America designed a software called "Global Diagnostic System" which diagnoses a fault in the main components of the automobile through a connection between the interface of the testing device and the information terminal of Hyundai, and if needed presents a link to the purchase of parts ("Global Diagnostic System," 2016).

The testing tools that are developed for vehicles of Hyundai Kia are multi-system diagnostic testers produced by external firms that can perform diagnosis of all the components of the vehicle. Hyundai "CareCar" diagnostic tool is provided for all the Hyundai vehicles and Kia CareCar for all the Kia automobiles respectively. Specialised devices – for reading faults in the engine or an airbag tester have not been developed by the company itself ("Hyundai Kia Diagnostic Tools," 2016).

A more advanced diagnosis can be done by the computer based Hyundai Maxiecu tester which is a device with broad functions, detecting faults not only in the Hyundai passenger automobiles but also in other brand's vehicles manufactured before 2012. The device proves the main components such as the engine, the immobilizer, parking brakes, etc. For newer vehicles produced after 2012 there are only testing devices fit for the vehicles of the group (Ibid.).

6.8. New Materials

6.8.1. Leightweight Materials in the Automotive Industry

The automotive rivals characterise with a competition also in terms of the materials used in the manufacture of passenger automobiles. The materials shape not only the design of the vehicle and its outward appearance, but have a direct consequence on its weight, performance, fuel consumption and carbon dioxide emissions which in turn affect the environment and the human health (Miller, et al., 2000, p. 37).

With the strive of the automotive companies to enhance the luxury, the passengers' comfort and the vehicle's safety, a range of additional components and accessories has been incorporated in the automobile and thus the weight has been increased. The air bags, a stronger and in this manner safer vehicle frame and various interior comfort systems provide additional weight to the automobile. To react to this challenge the manufacturers have developed new designs and power plant concepts. But they did not contribute to the lessening of the total vehicle's weight in an evident way (Ibid., p. 38).

Researchers in the automotive field claim that the only way to produce lighter passenger vehicles can be achieved only through an extended application of lightweight materials and structures. It is considered that the elimination of 10 percent weight leads to a decrease of the fuel consumption by 8-10 percent (Ibid.). Therefore, manufacturers do not only strive to reduce the weight of the single components such as the engine air coolers, exhaust manifolds,

etc., but rather to create a new lightweight body structure of the automobile (Berger, et al., 2009).

The automobile's construction has relied since 1920 heavily on the extensive usage of steel and iron. For 70 years a modest progress has been reported in the intention of the automotive industry to reduce the share of steel. In the early '90s the figure of steel in the material matrix of an average automobile was accounted for around 60 percent. We can see that the automotive manufacturer recognised the need for other materials and decreased this share by around 10 percent only in ten years. Another material with a high density that is used to produce automobile parts and thus increasing their weight is cast iron. The reduction of steel is followed by a decline of the usage of cast iron as well (Miller, et al., 2000, p. 38)

According to G. Cole and A. Sherman, the lightweight materials aluminium, magnesium and metal matrix composite demonstrate the capability to replace ferrous alloys. To embrace any new material the manufacturing company should consider not only the advantages of the usage of the material (chemical, physical and mechanical properties) but also its price. Both magnesium and aluminium can be used in wrought or cast shape. But both of the materials in their wrought form are more expensive in comparison to cast iron and steel. Therefore, to make the replacement affordable the company should decrease the manufacturing costs of the components. Cast aluminium structures and components are claimed to be less expensive to create or form because of their better response to the cutting process, increased manufacturing cycle efficiency, the castings' allowance for thinner walls, simplified assemblies, ability to be produced close to their net shape – a manufacturing technique that reduces the finishing costs, and the lower expenses for their melting and metal-forming processes (Cole, G. & Sherman, A., 1995, p. 4). The lightweight materials demonstrate a high scope of applicability in the automobile manufacturing. Aluminium can be used for chassis (wheels), body structures (engine bonnets) and powertrain (cylinder heads, manifolds). Single aluminium parts of the chassis and the powertrain can be found in the automotive industry. The employment of aluminium in the body structure of the automobile is considered as a highly innovative approach which only a few companies were able to realise (Ibid, p. 5-6).

Magnesium alloys are considered as an additional opportunity to replace ferrous materials. Magnesium is lighter compared to aluminium and its corrosion resistance is higher. Furthermore, magnesium components demonstrate better machinability and production efficiency. The structures and components allow thinner walls. The process of solidification runs faster and for the same time needed to produce an aluminium component, one can produce between 25 and 50 percent more magnesium castings. In the same time the magnesium ingot is between 50 to 100 percent more expensive compared to aluminium. However, the magnesium structures present a range of drawbacks regarding their mechanical properties. Therefore, specifically designed for magnesium manufacturing procedures are required. Magnesium could be employed in pistons, engine blocks and in the transmissions of the powertrain, in the wheels, brackets, brakes' components of the chassis, and in the doors and seats as parts of the body structure (Ibid., p. 6-7).

The metal matrix composites (MMC) are the third option to substitute conventional steel and cast iron. Organic compounds with aluminium are employed in the automotive manufacture since the mid '60s. These composites are "engineered materials" and therefore their properties can be altered and modified (Ibid. p. 7). Therefore, in comparison to aluminium and magnesium the metal matrix composites demonstrate improved physical properties. In

terms of affordability the MMCs are considerably less expensive. The MMCs can be applied to the cylinder liners of the engine and the pistons. As a consequence, G. Cole and A. Sherman predict a promising future development of the application of magnesium alloys and MMCs (Ibid., p. 9).

6.8.2. Application of Lightweight Materials in the Volume Passenger Vehicles of Volkswagen Group

Application of Aluminium

The first Volkswagen high volume passenger automobile where aluminium and magnesium were employed is the "Lupo 3L" back in 1998. The vehicle had a cast magnesium frame with aluminium skin, front wings, engine bonnet and doors completely manufactured of aluminium (Regan, J., 2012). The production of Lupo 3L illustrates also the successful application of metal matrix composites to automobiles. The drums brakes of the rear wheels have been fashioned of discontinuously reinforced aluminium – a reinforced aluminium with silicon-carbide (SiC) (Evans, A., et al., 2003, p. 337; Miracle, D., 2005). Furthermore, for the wheels were used magnesium alloys. As a result, Lupo 3 L was an exceptionally light vehicle that consumed three litres of petrol per 100 kilometers (Regan, J., 2012).

The new Tiguan features an engine cylinder head and wheels of aluminium alloys ("Tiguan Technical Specifications," 2016).

The new generation of Volkswagen Passat (presented in 2014) achieved a weight by 85 kilogrammes lighter than its previous model because of the application of hot-formed steel and aluminium. Aluminium has been used in the electrical system of the automobile to make the electrical components. It should be stated that the eight-generation of the Passat is the first high volume passenger automobile of Volkswagen that employs aluminium in its body structure. The body panel at the back of the rear passenger seats is completely made of aluminium. (Lüttgemann, M., 2015; Rendell, J., 2014).

An additional vehicle, where the manufacturer has employed lightweight materials, is the Golf VII. Volkswagen has build the body and the chassis with a high number of components of aluminium and carbon fibre. The front bulkheads, the floor panels (conventionally produced of steel) and the windscreen surround frame have been shaped of aluminium and the engine bonnet as well as the roof of carbon fibre. Because of the lightweight materials used, the weight of the Golfs' Body-in-White (the body shell that has been welded together) could be reduced by 23 kilograms. (Pander, J., 2012/ „Volkswagen Golf VII," 2012).

The automotive subsidiary within the Volkswagen Group that places a special emphasis on the development of lightweight automobiles and especially on the research of the aluminium application is Audi. The division specialises intensely in the creation of weight-saving constructions employing aluminium and metal matrix composites since the late '80s. In 1994 Audi demonstrated on the Frankfurt Motor Show its first vehicle A8 whose entire body was designed of aluminium as a result of the elaboration of the lightweight technology"Audi Space Frame® (ASF®). However, the vehicle was a luxury sedan and therefore was not provided to the mass market. In the next decades the company has carried out in-depth research and studies into the subject of the lightweight metals' application to the bodywork, electronics

and the components of the automobile. Audi established partnerships with the the Aluminium Company of America in the beginning of the '90s, the Swiss industrial group Algroup Alusuisse and after that with the European Aluminium Association. The first volume passenger automobiles that adopt lightweight materials in their body construction are Audi A3 and Audi A6 provided to the automotive market from 2011 and onward. They are also considered to be ones of the very few high volume passenger automobiles globally that employ extensively lightweight materials and MMCs in their bodywork and disc brakes (Macke, et al., 2012; „The Aluminium Automotive Manual," 2013; „Multimaterial Space Frame," 2011).

The last generation Audi A3 was launched in 2012 and the model's weight achieved a reduction of around 80 kilograms in comparison to the last version mainly due to the employment of lightweight structures. The figure of high strength steel accounts for 26 percent of the bodywork. Aluminium is mainly applied in the front part of the structure whereas the engine bonnet and the front wings have been produced of aluminium. Among the components and applications made of aluminium count the front axle subframe, aluminium wheels, pivot bearing and the structure module or the so-called "Crash Management System". For reference the details on the picture coloured in light green have been manufactured from aluminium sheet ("Audi A3: design story," 2012).

Image 6 Audi A3 2012

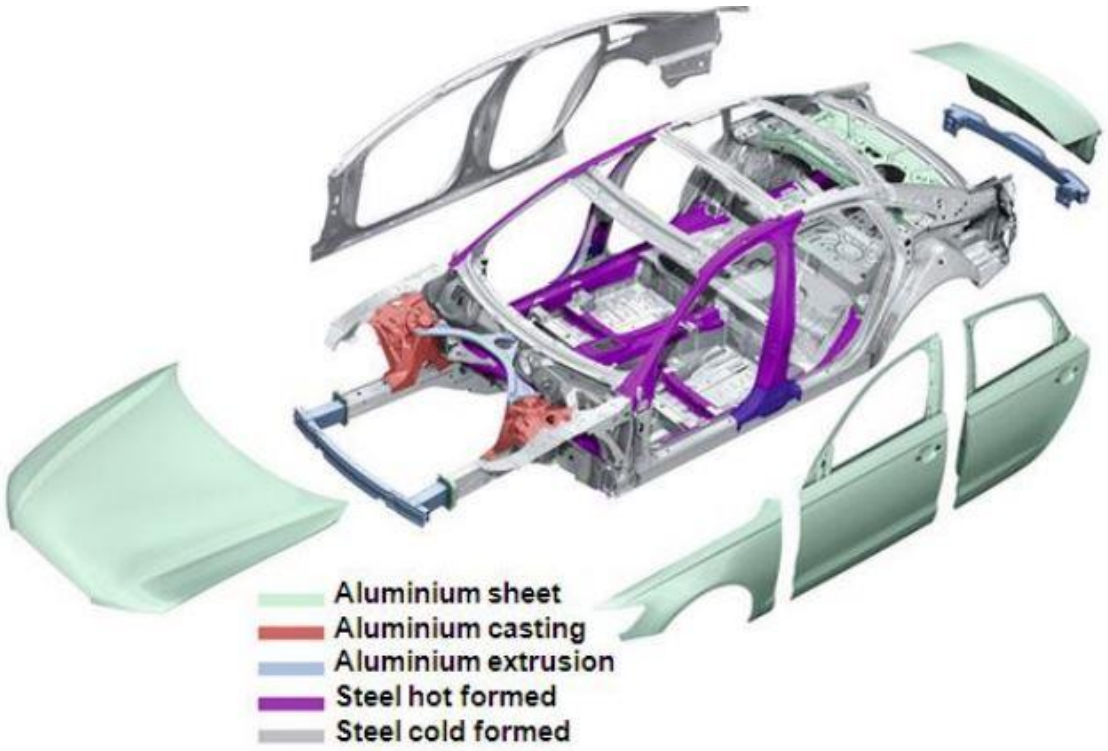


Materials and aluminum components in the body structure of Audi A3. Copyright (2012) Car Body Design.

The new version of the Audi A6 (2012) features a body structure made of aluminium and steel. The share of aluminium of the bodywork accounts for approx. 20 percent. The body

construction employs aluminium sheet, castings and extrusion. The aluminium extrusion is used to mould specific details of aluminium alloys into a definite form. The body structure presents a concentration of aluminium components in the front and the end part of the vehicle. The engine bonnet, front wings, the doors assemblies, the rear shelf panel at the back of the seats and the luggage comportment lid have been produced of extruded aluminium and aluminium panels. A range of components as the pivot bearing and the wheels carriers feature aluminium application. The application manner of the hot formed steel resembles the concept of the Audi Space Frame. The design of the A6 is considered by the European Aluminium Association to be a progressive development of the lightweight technology from aluminium alloy monocoque system to a new multimaterial frame ("The Aluminium Automotive Manual," 2013, p. 80). The multimaterial body frame of the Audi A6 can be seen on the picture below:

Image 7 Audi A6 2012



Materials and aluminum components in the body structure of Audi A6. Copyright (2013) by European Aluminium Association, p. 80.

Application of Magnesium

With regard to the magnesium application we should say that Volkswagen Beetle (1950) is considered to be the first passenger automobile that employs in its structure a large quantity of magnesium. The housing of the crankshaft (crankcase) and the transmission housing were produced of magnesium. After that the application of this lightweight material in the automotive industry has declined noticeably mainly because of the economic stagnation during the 1970s (Blawert, C., et al., 2004).

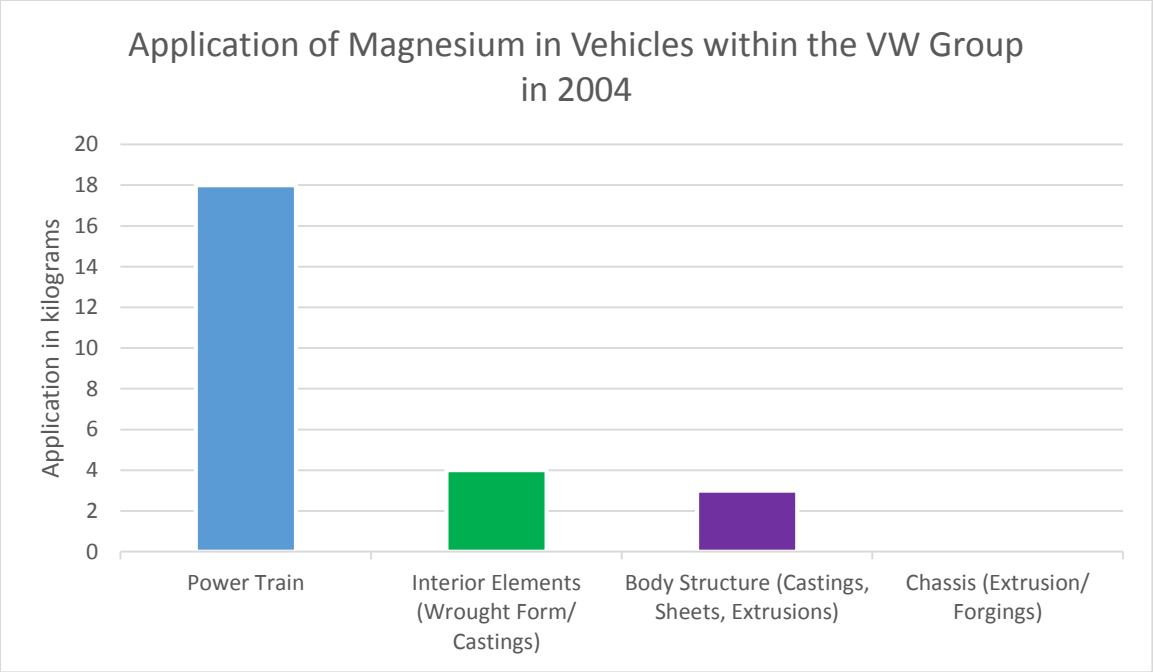
The use of magnesium was revived by Volkswagen and its automotive subsidiary Audi in 1996 with the new approach of applying magnesium to the drive train as the company designed the B80 gearbox housing in AZ91 magnesium alloy - nominal composition Mg- 9% Al; 1% Zn; 0.3% Mn (Chalupová, M. et al., 2009; Friedrich, H. & Mordike, B., 2006, p. 506).

One of the disadvantages of the magnesium is that the alloys are prone to corrosion. This drawback has been overcome by Volkswagen in coating the steel bolts with a silicate sealing and thus creating a protection layer (Blawert, C., et al., 2004, p. 403). The magnesium gearbox housing is by around 8 kilograms lighter compared to an aluminium one that already uses lightweight materials. The first CVT (continuous velocity transmission) gearbox housing of magnesium that was incorporated in high volume passenger automobiles was the Audi/Volkswagen VL300 (Friedrich, H. & Mordike, B., 2006, p. 509).

Further application of magnesium can be seen in the air intake manifold of the engine version W12, cylinder head covers on the eight cylinder engine V8 and the gearbox housing of the five speed manual transmission of the Golf, Jetta and Audi A4 (Blawert, C., et al., 2004, p. 405).

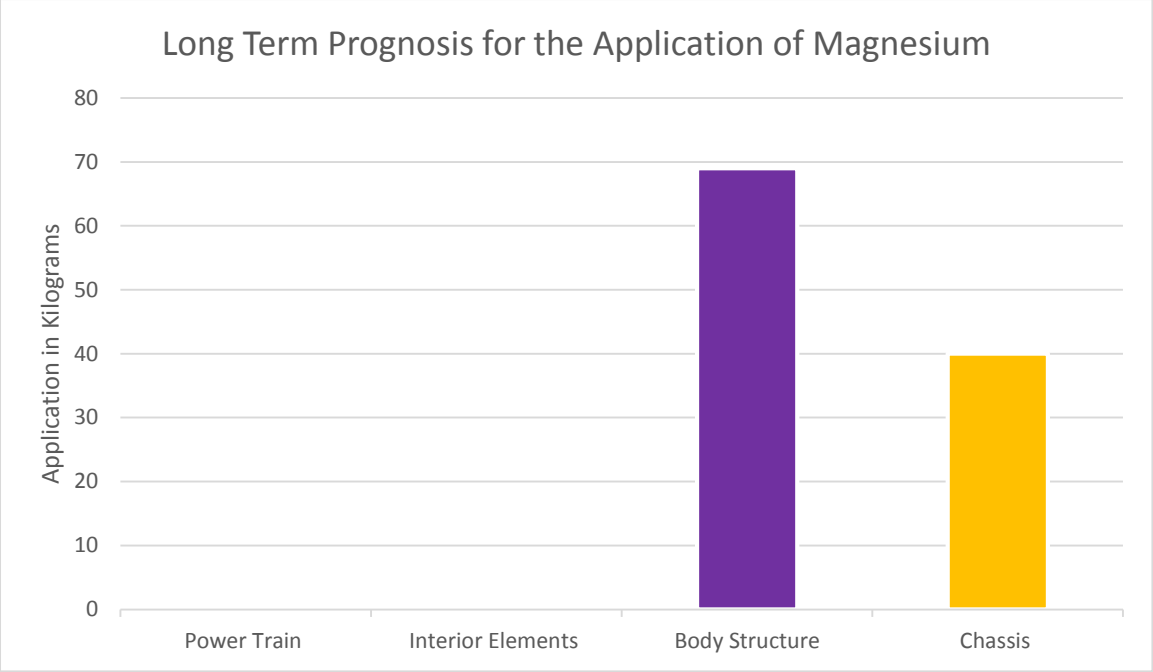
As in 2004 Volkswagen Group uses magnesium alloys, wrought products, sheets and castings in a total of 25 kilograms of its body structure and components. In medium term (longer than 5 years) the company aims to increase the employment of this lightweight material mainly in the power train and even start to apply it to the chassis of the vehicle. In a long term (longer than 10 years) the Group plans to extend highly the utilization of magnesium for the body structure and the chassis, and to terminate it for the power train and the interior elements (Ibid., p. 406).

Figure 27 Magnesium's Application



Note: Adapted from Automotive Applications of Magnesium and its Alloys. Blawert, C., et al., 2004, p. 406

Figure 28 Magnesium's Application Forecast



Note. Adapted from Automotive Applications of Magnesium and its Alloys. Blawert, C., et al., 2004, p. 405.

6.8.3. Application of Lightweight Materials in the Manufacture of Volume Passenger Vehicles of Toyota

Application of Aluminium

In terms of the application of Toyota of the lightweight material aluminium one should say that the company employed aluminium and cast iron for the manufacture of the cylinder block of the engine type 1ZZ-FE used from 1997 to 2000 in the Corolla. The housing of the crankshaft is also produced of aluminium. There is no evidence of the application of aluminium in the bodywork or the chassis of the automobile of high volume passenger automobiles („Toyota ZZ series," 2013). According to the press the company aims to apply aluminium in the future body structure of its commercial and high volume vehicles and to use it in the production of the engine bonnet (Trop, J., 2014).

Application of Magnesium

In regard to the usage of the non-ferrous metal magnesium, Toyota applies the magnesium alloy AM60 to the manufacture of steering wheels of some Lexus models. The alloy AZ91 is only employed for the cylinder head cover of the Soarer, introduced in 1991 and not in mass produced automobiles. Generally, magnesium is not employed in high volume vehicles („Technical Development, Materials," 2016).

Application of MMC

For the first time in the automotive history Toyota applies MMCs in the production of a piston for the diesel engine from liquid metal infiltration in the early '80s (Miracle, D., p. 2533). In 1996 the company developed a material for the production of the lip of the piston chamber that employs in its structure silicon carbide (SiC). In this way the company achieved an improved protection of the piston from the heat fatigue. Furthermore, Toyota applied MMCs with a special liner-less technology to the cylinder block bore. The surface and the piston outskirt were coated by a Fe-P alloy in order to avoid abrasion (Ibid.).

A further application of MMCs to the components of the high volume passenger automobiles is the development of an aluminium MMC plate with silicon carbide. The plate was incorporated in the insulated gate bipolar transistor module (IGBT) of the power inverter. This electronic device has been used as a power device for the Toyota Prius ("Heat dissipation," 2016)

Summarised we can claim that Toyota places the emphasis of the lightweight material usage on the development of MMC components. But all things considered, the high volume Toyota passenger automobiles rely heavily on the application of steel.

6.8.4. Application of Lightweight Materials in the Manufacture of Volume Passenger Vehicles of Hyundai Kia

Application of Aluminium

The fifth generation of the Hyundai Sonata, produced from 2004 to 2008 characterises with an engine called 2.4 L4 Theta engine. It was designed of aluminium (Hyundai Sonata 2004-2008, 2016). Furthermore, the suspension of the last generation Sonata features relatively small suspension components produced of the lightweight material. The suspension demonstrates aluminium steering knuckles and aluminium front lower and back upper control arms. In terms of the powertrain of the Sonata, aluminium has been applied to the engine block and cylinder head. Aluminium wheels are offered to the customers as an add-on component as well (Sutton, M., 2016). Overall, Hyundai specialises in the production of aluminium cylinder heads and blocks. The usage of the lightweight material is concentrated only in the power train area of the automobile. The manufacturing facility in Chennai, India is equipped with an aluminum casting facility – aluminium foundry where the cylinder heads and blocks are produced separately. The foundry has at its command three aluminium smelters where two tons of aluminium ingots are melting annually (Holt, N., 2015).

According to H. Jin and M. Cho Hyundai, Kia considered the transition from steel intense manufacture of automobiles to more extended application of lightweight materials to the body structure and chassis of their future vehicles. However, as the affiliates see one of their advantages in the reasonable prices of their automobiles, the shift to aluminium is believed to be a costly venture mainly because of the reorganisation of the manufacturing processes and techniques, and the suppliers network (Jin, H. & Cho, M., 2014).

Application of Magnesium

The researchers J. Kim and D. Han studied the automotive magnesium application in Hyundai Kia. The main areas where the company uses the lightweight material are the interior parts-seat frame, steering wheel core, driver air-bag housing, lock body and steering column housing. Hyundai Kia carried out an individual research on the magnesium application and adopted the magnesium die cast alloy AM50A in the production of components because of its high ductility. However, as to 2008 the magnesium cast alloy was incorporated only in three vehicles – Hyundai Azera (known as Grandeur), Kia Amanti (Opirus) and Hyundai Genesis, as none of them is a high volume passenger automobile. However, the company claimed that it will enhance further the components produced of cast magnesium (Kim, J.& Han, D., 2008, pp. 893-895). According to data from 2014, we can see that Hyundai Kia applies magnesium to the production of cylinder head covers and continues to use it for interior and steering components. The areas of the transmission, engine block and the wheels remain steel intense without the employment of the lightweight material and its alloys (Hussein, R. & Northwood, D., 2014, p. 533).

Application of MMCs

The only information on the application of composites to the high volume passenger automobiles within the Hyundai Kia family is the long glass fiber polypropylene (LGFPP) resin used as a substitute of the steel for the door assemblies of the Hyundai Sonata. The LGFPP resin is used mainly in injection molded parts. Due to the mechanical properties of the LGFPP resin the weight of the door panels and the production costs of the components have been decreased ("SABIC Innovative Plastics," 2010). However, the LGFPP composite resin is rather a hydrocarbon polymer reinforced with glass fiber. The compound is not a metal matrix composite but a polymer composite which depicts another new trend of the vehicle modules manufacture – the advancement of polymer-composite materials and the upgrade of the processing techniques of conventional materials such as plastics (Poucke, J. & James, A., 2006, p. 11).

In respect to the application of metal matrix composites, Hyundai Motor Company holds the patent on the method of procession of Ni-doped TiO2 nanotube-shaped powder and sheet film (IFI CLAIMS Patent Services, 2007). The composite stands for doping of titania nanotubes with nickel. The powder and the sheet film are embedded in hydrogen tanks for the fuel cell electric vehicles (Li, et al., 2014). Nevertheless, fuel cell vehicles are not high volume passenger automobiles. Further data on the application of metal matrix composites to the high volume automobiles is not available.

6.9. New Drive Technology

6.9.1. Four Wheel Drive vs. Permanent All Wheel Drive

One of the most significant innovations in the automotive development towards its last stage nowadays - the autonomous driving, is believed to be the innovation within the driveline and namely the permanent all wheel drive technology (Braun, P., 2016). To understand the advancement of the drivetrain, one should differentiate between the two main approaches- four wheel drive (FWD) and permanent all wheel drive (AWD) technology (Ingram, A., 2016).

The general concept of FWD has an important advantage compared to the two wheels driveline. By the conventional two wheels drive the engine power is distributed to the front or to the rear wheels, it makes them spin and therefore the vehicle moves ("Difference between," 2015). In comparison, the driving technology by the four wheel drive is more complicated and many aspects should be taken into consideration. Basically, by the FWD vehicles the engine power is distributed to all the four wheels and every wheel moves individually. In this way the vehicle can be used for every terrain because of its advanced on-road handling. If the vehicle faces difficulties on the road and a slip of one of the wheels occurs, the FWD system transfers motion to the wheel (axle) with the most grip (traction). The FWD is turned on by the driver (Braun, P., 2016). It should be also noted that the system can be turned on only in specific circumstances. It does not function permanently. Otherwise, when the FWD mode is not activated the system operates as two wheel drivetrain. Only when a loss of traction is identified, the FWD system can be started. At the beginning of the FWD introduction period the vehicles equipped with this technology were mainly SUVs as they were believed to move on inaccessible roads. However, as the automotive companies desired to upgrade the existing automobiles for mass production, the technology was embedded also in some volume passenger vehicles enhancing their qualities and performance (Ingram, A., 2016).

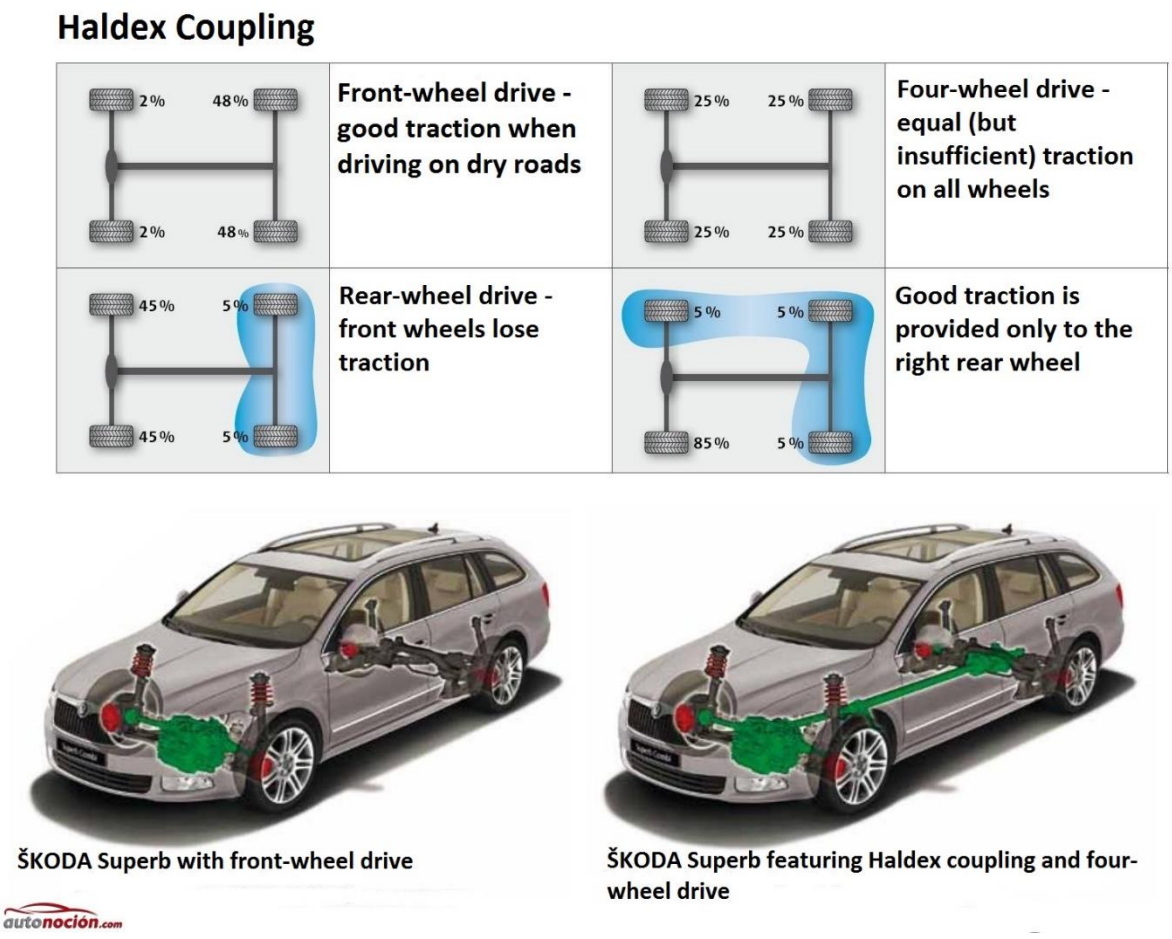
In contrast, the permanent all wheel drive (AWD) does not need to be electronically or manually activated. The system software uses its „predictive operating strategy" („All conditions are," 2016). It takes the weather/road conditions, the driving mode and driver's behaviour in consideration, and distributes the power accordingly. The system commands three differentials – front, central and rear. Electro-hydraulic clutches are embedded in the front and rear differentials, and within milliseconds they transfer the torque needed to the front and the rear wheels. The central differential is needed to split the torque properly between the front/ rear axles. Sensors integrated on every individual wheel continually monitor the speed of rotation of the wheels and the traction guaranteeing the best feasible traction (Ibid.). The permanent AWD features better performance and safer drive behaviour when the front or the rear wheels are on snow, during brisk acceleration or in situations where the vehicle corners at speed. In the first situations a considerable part of traction is retranslated to the rear axle. That ensures an effortless overcoming of unsafe roads or drive conditions. When the automobile corners at speed, the wheel-selective torque control, a feature of the electronic stability control, brakes the rotation of the wheels on the inside of the curve, whereas the larger part of the torque is redistributed to the outer wheels thus improving the vehicle's stability and neutral driving (Braun, P., 2016; „quattro®," 2016).

The way in which the engine has been mounted plays the main role for the incorporation of the permanent AWD or FWD. There are two options of engine mounting – transversely (side-to-side) and longitudinally (front to back). The manner of the engine mounting defines the way of the power flow. According to M. Barrett, the Vice President of Engineering, Product Development and Procurement at American Axle the "*transverse engine configuration means you have to go 90 degrees to transfer the torque to the rear*." Therefore vehicles with transverse engine feature front wheel drivetrain, a characteristic of the FWD. In contrast, the longitudinally positioned engine can be found conventionally in vehicles with permanent AWD (Cole, C., 2012).

Furthermore, we can differentiate between two main technologies – drivetrains with Torsen differential or Haldex coupling ("AWD System Dissected," 2015).

In the normal driving mode the Haldex coupling transmits around 90 percent of the power is to the front wheels and a minimum power to the rear wheels („4MOTION," 2016). Due to its sensors, it can analyse the conditions and deliver torque to the rear wheels. Therefore, the Haldex system is believed to function most of the time as front-wheel drivetrain and as four-wheel drive only if required. In result, the Haldex coupling is embedded in vehicles with non-permanent AWD ("AWD System Dissected," 2015; Ingram, A., 2016).

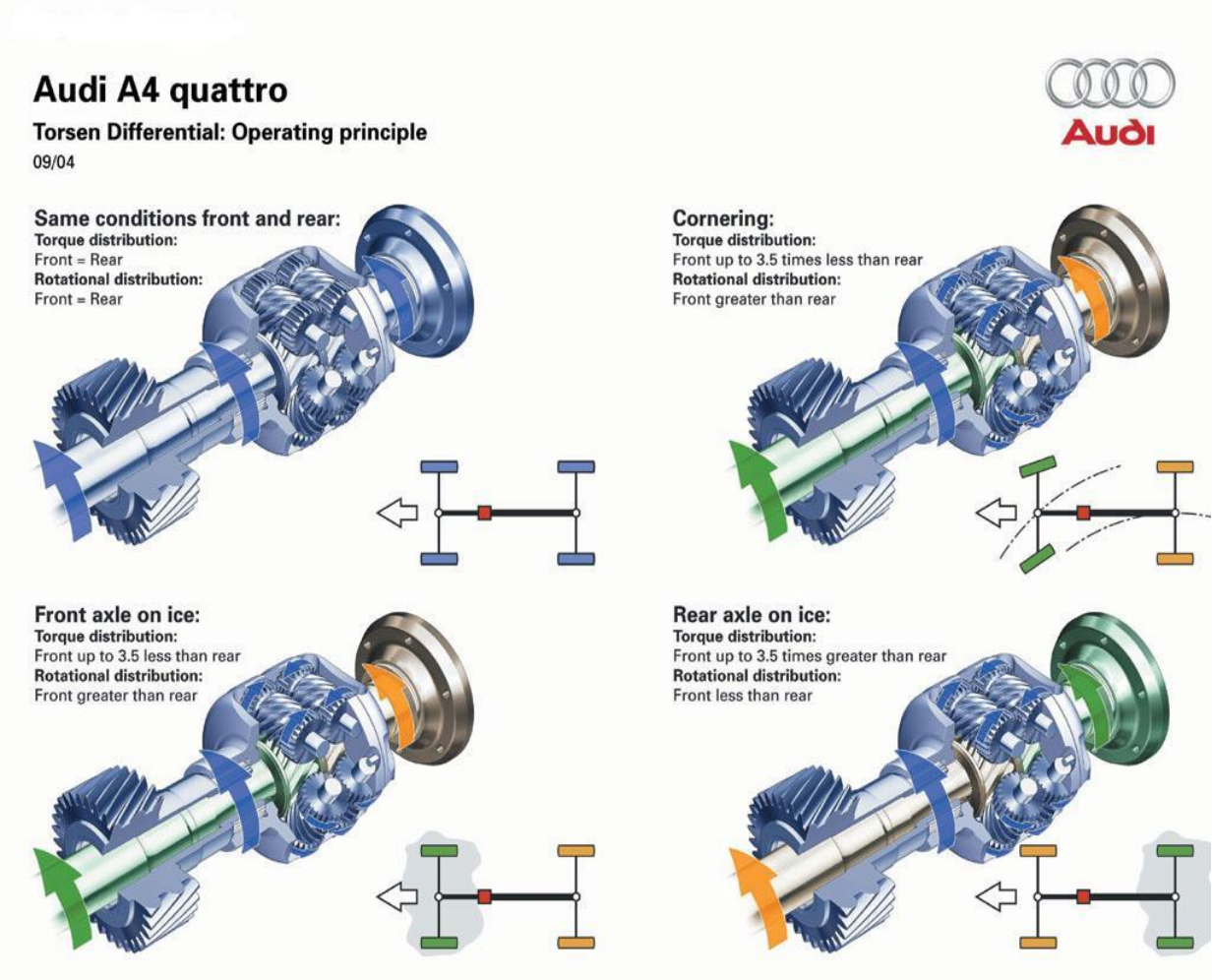
Image 8 Haldex Coupling



Note: Reprinted and adapted from Ferrer, A. (2015, May 11). Haldex vs Torsen: Todo lo que tienes que saber, incluidas sus ventajas e inconvenientes. Copyright (2011-2017) by Autonoción®.

The Torsen differential is a central differential that distributes the power/ torque between the front/rear wheels. Due to its sensing function, it regulates the torque according to the demand. It is capable to respond to the changing rotational forces of every wheel individually. Therefore it is incorporated in vehicles with permanent AWD (Ferrer, A., 2015; „4MOTION," 2016).

Image 9 Torsen Differential



Note: Reprinted from Audi-Sport.Net (2009). How do you drive a quattro in snow & ice? Copyright (2017) by Audi.

6.9.2. Drive Technology of Volkswagen Passenger Vehicles

The first automobile, which was equipped with the new AWD technology was Audi Quattro presented in 1980 (Audi quattro®, 2016). To become mass produced and to be fit in the passenger automobiles with the individual engine characteristics of the Volkswagen Group, the permanent AWD needed 15 years ("AWD System Dissected," 2016).

To understand which vehicles of the Volkswagen passenger automobiles possess a true permanent AWD we should examine the technical characteristics of the engine separately. Automobiles that command FWD technology are labelled as "4Motion" and claim to have

permanent four-wheel drive system (“4MOTION,” 2016). But are all of them in reality equipped with the full-time AWD?

The same holds true for Audi mass produced automobiles which have been presented as „quattro“ models. If we research deeper we can see that the permanent AWD technology is not compatible with the whole range of the passenger automobiles because of the engine positioning. However, Audi puts all of its FWD vehicles under the name „quattro“ standing for permanent AWD, which in fact can be slightly misleading.

Models with the emblem of Volkswagen equipped with FWD technology are the Phaeton, Touareg, the new Tiguan, fifth generation Passat, Golf 7 hatchback and CC as three of them being high volume produced („Enjoy 4MOTION,“ 2015). From the Škoda high volume product range the third generation of Octavia possesses FWD system, referred to as 4x4 model („ŠKODA 4x4 models,“ 2016). The quattro range of high volume produced Audi consists of A3, A4, A6, Q3, Q5 („quattro®,“ 2016). SEAT has introduced the new Leon powered by four-wheel drive system (“Leon Overview,” 2016).

According to the technical specifications the Tiguan has front mounted transverse engine (“Tiguan Technical Specifications,” 2016). The torque is delivered by the hydraulic multi-plate Haldex clutch (Self Study Program 861803, 2008, p. 9).

The Golf 7 hatchback features the same characteristics. It should be stated that Volkswagen commands a MQB platform for producing powertrains of different vehicles with equal characteristics. The MQB production platform implies „Modularer Querbaukasten" or Modular Transverse Matrix which is a strategy of the Group to standardise the components of the different brands and to produce them on the same assembly line (MQB Technology, 2016).

The engines that should be positioned transversely in the high volume vehicles produced within the MQB are the engines foreseen for the new Golf, Polo, Jetta, Tiguan, sixth generation Passat (B6), Audi A3, Audi Q3, the whole range of the high volume Škoda and SEAT automobiles (Horrell, P., 2014). All of the transversely positioned engines within volume passenger automobiles of the Volkswagen Group feature the Haldex clutch for their FWD systems. This can be seen by the Tiguan technical specifications as well (“AWD System Dissected,” 2015). Therefore, we can clearly state that the 4Motion Golf hatchback and Tiguan, the 4x4 Škoda Octavia, SEAT Leon, and the Audi A3, Q3 even described as „quattro models“ apply in their four-wheel drivetrain the Haldex clutch which functions in most of the time as front wheel drivetrain (two-wheel drive system) and the AWD system is activated only if required. That is why the four-wheel drive of these automobiles is definitely non-permanent.

In contrast, the first, second and fifth generation of the Passat (B1, B2, B5), produced until 2006 featured a longitudinally posinioned engine, sharing the same platform of standardised vehicle parts production with most of the Audi automobiles (Kraebber, S., 2016). For the power distribution is used Torsen central differential. It is completely equal with the differential applied in the quattro models where the differential splits the torque in a proportion of 50:50 to the front and rear axles (“AWD System Dissected,” 2015). For the production of standartised components and modules such as engines that should be installed longitudinally in the front section of the vehicles in the driving direction, the Group has created the modular longitudinal platform (Modularer Längsbaukasten). On the platform are

produced the engines for the high volume passenger automobiles A4, A6, Q5, etc. (Lemke, H., 2013).

Audi A4, A6 and Q5 used to be equipped with the Torsen central differential that splits the torque in proportion of 40:60 percent to the front and rear axles ("AWD System Dissected," 2015). In the new and last generation of those automobiles the Torsen differential is replaced by the "Crown Gear" differential which is a differential developed by Audi and functions in similar manner as its predecessor. ("Audi quattro – the next," 2011; "quattro® Crown Gear," 2016).

6.9.3. Drive Technology of Toyota Passenger Vehicles

The high volume passenger automobile of Toyota Motors that demonstrates the presence of AWD powertrain is only the RAV4. The category of the Toyota vehicles equipped with FWD are described as „4x4" and it is claimed to be equipped with AWD system („Model range," 2016). According to the technical specifications the engine of the RAV4 is transversely mounted („Toyota RAV4 Engine," 2016). The torque is distributed to the front/ rear wheels due to a control coupling system that functions in a similar way compared to the Haldex clutch. It is activated when the driver selects the "sport mode on" which implies that the drive force to all the four wheels is optional ("AWD System Dissected," 2015; "How does the Toyota RAV4," 2014). This in turn makes the FWD system of the Toyota RAV4 a system on demand or non-permanent AWD.

From the Lexus passenger automobiles range, the ES model features front wheel drivetrain and no configuration for AWD system ("ENGINE/ ES 350," 2016).

6.9.4. Drive Technology of Hyundai Kia Passenger Vehicles

In terms of the vehicles of Hyundai Kia which are powered by all-wheel drivetrain are Hyundai Santa Fe, Kia Sportage and Kia Sorento ("Safely Drive and Play," 2016; "The SUV/4x4 KIA," 2016).

The engine of Hyundai Santa Fe is transversely positioned. Under ordinary driving and weather conditions the AWD remains deactivated and the torque is transmitted only to the two front wheels. If the system detects difficulties on the road the AWD mode is turned on automatically via the Haldex clutch. It distributes 50 percent of the torque to rear wheels. There is also the option where the driver can press the "AWD Lock" button and activate the system manually. Therefore, we can state that Hyundai Santa Fe does not feature a permanent AWD system ("Hyundai Santa Fe," 2016; Simister, J., 2015).

The engine of the Kia Sportage has been transversely mounted in the front section of the vehicle. To activate the AWD mode the vehicle relies on the Magna Powertrain and its DynaMax system. Basically, the DynaMax AWD coupling, which responds to the hydraulic pressure, functions similarly to the Haldex clutch systems. In normal driving situations, the Kia Sportage features two wheel drivetrain. However, like mentioned above if the system determines obstacles on the road, the hydraulic pressure activates the clutch/ the DynaMax AWD coupling and torque is transferred to the rear axles. The AWD system can be activated manually as well, where the DynaMax AWD coupling splits the torque in proportion of 50:50 percent to the front and the rear wheels ("Magna's new AWD," 2010).

The first 4x4 vehicle that was equipped with DynaMax AWD coupling was the Kia Sportage. From 2015 Kia Sorento features the same AWD characteristics as the Sportage. The engine is positioned transversely („Engine Layout," 2016). The torque is distributed in the same manner and on demand. In normal circumstances the vehicle demonstates two-wheel powertrain („News Release – Magna," 2015).

Summary

Three generations of the Passat, Audi A4, A6 and Q5, as high volume passenger automobiles within the Volkswagen Group, prove a permanent all wheel drive system. In contrast, additional passenger vehicles with the emblem of Volkswagen – the Golf 7, Passat B6 and Tiguan; of Toyota – RAV4 and of Hyundai Kia – Santa Fe, Spotage and Sorento are equipped with non-permanent AWD. Their FWD system can be described as a conventional on-demand FWD powertrain.

6.10. New Injection Technology

6.10.1. New Technologies for Improvement of the Internal Combustion Engine

„*The Golden Age of Turbocharging is upon us***"** (Kulkarni, N., cited in Wayland, M., 2015)

The high volume passenger automobiles command in majority two types of engine – diesel and petrol engine. Both of the engines display equal injection system – the electronic direct injection system. As described in the research question, the character features of the electronic injection system used in the diesel engines did not change significantly since its introduction. The technology remains the same and only a couple of refinements have been launched – for example the engine noise has been reduced. A wider perspective for innovations gives the petrol engine. According to A. Bedwell – analyser of LMC Automotive, which is along with JATO Dynamics the largest provider of automotive powertrain forecasts, the total share of newly registered passenger automobiles with diesel engines demonstrates a slight decrease in the last years and is also expected to decline perceptibly in the coming years ("Global Light," 2016). The European market share of diesel engines is projected to decline to 35 percent in three years and to adjust to the global conditions where around 75 percent of the new light vehicles registrations possess a petrol engine (Madslien, J., 2015).

Furthermore, there is specific trend of direction of the development of the petrol engine that proved to offer a new perspective for automotive innovations – the turbocharged petrol engines. Turbochargers have been used mainly for the diesel engines and therefore most of the companies have concentrated their efforts on the turbocharged diesels and neglected the petrol ones. As the diesel engines face a serious backlash in the last decade, the automotive industry has confirmed its course towards embracing the turbocharging technology for the petrol engines. (Madslien, J., 2015; "Come back petrol," 2009; Wailand, M., 2015).

In order to investigate the development of the turbocharged petrol engines within the three companies, we shall focus on the injection system and figure out, if the embrace of the new technology is combined with new development or modifications of the injection system or it

relies on the conventional one. This is important because, a normally aspired engine can be turned into a turbocharged engine without any significant technological modifications and only by installing a turbine housing (a turbocharger) and increasing the pressure in the nozzles (Douglas, G., 2015).

The conventional technology of a petrol engine can be described in four stages. During the first stage, the piston in the combustion chamber of the engine moves downwards and clean air and petrol are flowing into the cylinder through the inlet valve. After that this mixture is compressed due to the upward movement of the piston. The mixture is ignited by a spark plug. The power of the ignition moves the piston downward again and the energy powers the crankshaft. The rotation of the crankshaft forces the wheels of the automobile to move. The piston moves upwards once again and the exhaus gases fly out through the exhaust valve of the engine ("Industrial Catalysis," 2016).

The petrol engine faces a couple of difficulties which hamper its better performance. In order to increase the engine power and thus its performance, the conventional petrol engines have been technologically upgraded to turbocharged engines. In general, the turbocharged engines are smaller and lighter and in principle they need less fuel while idling. Their size contributes to the better fuel economy. The turbochargers are air compressors that are powered by exhaust gas turbine. Therefore it requires the waste energy of the exhaust gases to run. The energy created by the exhaust gases is absolutely lost in a normally aspired engine. That is why the turbo engine is more efficient, the automobile displays better performance with the same quantity of fuel and reduced exhaust emissions ("Engineering Explained," 2014; "Turbo technology," 2014).

Nevertheless, the most serious disadvantage not only of turbocharged engines but also of petrol engines is the unburned fuel. In principle, the fuel bores of the injector that injects the fuel- air mixture in the combustion chamber are in the most cases one or two. This means that the mixture (that should be ignited) is not dispersed. The mixture cannot be ignited properly by the spark plugs because the fuel burns on its surface and in its middle layer remains liquid ("About Fuel Injectors," 2008). This could be perceived by the strong unpleasant petrol smell when starting the automobile.

Consequently, the turbocharged petrol engine has a capacity of better fuel economy and enhanced performance. The engine's limitation to achieve really outstanding results is the insufficient ignition of the fuel-air mixture.

6.10.2. Injection Technology of Turbocharged Petrol Engines of Volkswagen Group

Volkswagen Group has upgraded and modified the turbocharged petrol engine to an advanced level. We can see this in the TSI engine concept developed since 2005 ("TSI Maximum power," 2016). We should mention here that the Group elaborated various versions of an improved turbocharged petrol engine under different marketing labels – TSI, FSI, TFSI. However, the main technology in the core of the engine is equal and the master thesis will refer to the modified turbocharged petrol engine as TSI engine (Stubbs, V., 2010). In order to understand the modification we shall have a look inside the TSI engine technology.

In general, the TSI engine relies on the direct petrol injection system which is not only connected to a turbocharger but also to an additional supercharging unit in some variations

of the engine (e.g. TSI 1.4). The Group named the collaboration of both units “twincharging”. The petrol is injected directly into the combustion chamber by use of a very high pressure and is mixed with the air-flow. The turbocharger, which is powered by the exhaust gases energy, presses a supplementary flow of air in the combustion chamber. The supercharger is an air-compressor that presses additionally the air flowing trough the inlet valve. It is powered via a belt-drive and operates at the lower revolutions. When the automobile is accelerating the turbocharger comes into play as well. Therefore, the pressure and the temperature in the combustion chamber are significantly higher compared to the normally aspired engine and even to the turbocharged one. The important thing is that Volkswagen developed new four or six fuel bores injectors for the direct injection which is the main improvement of the conventional system. The bores of the injector disperse under high pressure the air-fuel mixture into the cylinder in droplets so there is no residue of the fuel-mixture. That is why, the fuel-mixture is ignited properly and the engine functions more effectively. Because of the higher temperature in the combustion chamber a water-cooled intercooler has been mounted in the turbocharger (“TSI Maximum power,” 2016; Stubbs, V., 2010).

The TSI engine has another character feature that contributes to its efficiency and fuel economy- the Active Cylinder Technology (ACT). The Group is a pioneer in equipping a high volume passenger automobile – the up! with four-cylinder engine with the Active Cylinder Technology. In general, the ACT is a technology that deactivates two of the four cylinders (second and third) in urban driving conditions (e.g. driving from a traffic light to the other). The ACT is activated at the lower revolutions per minute (RPM) during the acceleration. If the accelerator is pressed hardly both of the deactivated cylinders start to function again. The normal urban conditions do not demand high speed and therefore the work of the two cylinders can be spared. In this way the automobile consumes less fuel and produces less emissions (“Active Cylinder Technology (ACT),” 2016).

The TSI engine enjoyed wide acceptance and has been honoured by the automotive industry. The International Engine of the Year – an annual competition for internal combustion engines with an international jury consisting of motoring journalists, has priced the TSI engine to be the best engine every year in the category „1 litre to 1. 4 litre“ from 2006 to 2014. In 2016, the TSI engine gained the fifth place among the best engines in the same category. In the category „1.8 litre to 2 litre“ engine the crown from 2006 to 2009 has won Audi with the FSI version of the engine whose technology is the same. With its upgrade to 5 cylinder engine the TFSI version manages to be the best engine from 2010 to 2016 in the category „2 litre to 2.5 litre“ (“Engine of the Year Results,”; “Engine of the Year Archiv,” 2016).

High volume passenger automobiles, equipped mostly with 1.4 TSI ACT engine, are Volkswagen Golf, Beetle, Polo, Jetta, Audi A3, A4, Q3, SEAT Ibiza, Leon, Škoda Octavia and Superb (“Engine of the Year Results,” 2016).

6.10.3. Injection Technology of Turbocharged Petrol Engines of Toyota

Toyota Motors has developed turbocharged petrol engine in 2015. Before 2015 there is no Toyota vehicle equipped with a turbocharger. The company approaches the turbocharging technology with its 1.2T litre engine with four cylinders. The core technology has been described as direct injection system. Compared to the conventional turbocharged engines the 1.2T demonstrates a turbocharger powered by the exhaust gases. The temperature and the pressure in the combustion chamber are very high and therefore an intercooler has been

mounted. Additionally, in order to cool the components of the engine and to reduce the high temperature level in the combustion chamber which can lead to damages, the pistons and the cylinder head are separately cooled from the engine block. The injection systems creates multiple injections in each cycle. In terms of the injector bores, there is only one fuel bore that injects the fuel-air mixture in the cylinder in the form of a thin spray. However, the only automobile of the automotive company that embraces the turbocharged technology is Toyota Auris that is not a volume produced vehicle. According to press releases the company aims to enhance the production range of turbocharged petrol automobiles in the future and the development of new engines ("Toyota Unveils," 2015; "1.2T direct injection," 2015).

6.10.4. Injection Technology of Turbocharged Petrol Engines of Hyundai Kia

The turbocharging technology of Hyundai Kia focuses nowadays on small and compact engines –three-cylinder 1.0 litre as an enhancement of their four cylinder 1.4, 1.6 and 2.0 litre turbocharged engines. The new engine is part of the Kappa engine family which intends to equip not only Hyundai but also Kia automobiles in future. The development of the turbocharged engine range (Kappa, Gamma, Theta) dates back to 2010. The company puts now the emphasis on decreasing the size of the engine and making it lighter. Therefore it has cut out one cylinder. In this way, the fuel economy has been increased and the emissions while accelerating reduced. The turbo system relies on petrol direct injection. The turbocharger has been described as small and „single-scroll" ("Advanced Powertrain," 2016). Single-scroll turbocharger stays for a turbocharger with a single exhaust gas inlet manifold (Pratte, D., 2009).

In 2015 with the development of the last compact three-cylinder 1.0 litre turbocharged petrol engine the conventional injectors has been redesigned and they feature currently six bores in a pyramid form. Under a high pressure the injectors inject the fuel-air mixture in the cylinder in a manner it can be ignited properly without a residue of the product. However, with the upgraded injections technology are equipped only the new Kia cee'd vehicles that have been launched only on the European market in the beginning of 2016. According to press releases the company plans to enhance the range of automobiles powered by the new turbocharged petrol engine (López, A., 2015).

The other four-cylinder 1.6 and 2.0 litre turbo engines fall in the range of the Gamma T-GDI and Theta engine family. In general, the turbocharged petrol engines within the Gamma scope feature twin-scroll turbocharger ("Hyundai - Gamma 1.6 T-GDI," 2013). A twin-scroll turbocharger has a divided inlet manifold and is the conventional turbine housing for almost all turbo engines as it has showed an overall improvement of the powertrain technology after its introduction. The twin-scroll turbocharger's main function is to separate the cylinders whose exhaust gases vibrations mess with each other (Pratte, D., 2009). The turbocharger is cooled by an intercooler. The Theta version for four-cylinder 2.0 litre engines characterises with the same technology but features only one distinction – it commands in some cases a single-scroll turbine housing ("Theta TGDI," 2010).

It should be mentioned that there is a significant difference of the fuel injection system of the Kappa on the one side and Gamma and Theta engine families on the other. The latter two have been described as possessing "fuel direct injection system". But that is slightly misleading. In reality, they feature multi-port injection system (Winter, D. 2012). The multi-

port fuel injection system (MFIS) had been incorporated in the petrol engine prior to the development of the direct injection (around 1980) and after the carburettor. It is also believed to be an improvement of the carburettor technology (Artigue, B., 2004, p. 2). The MFIS injects the fuel-air mixture separately into intake ports that are near the intake valves of each cylinder. The MFIS does not inject the fuel directly in the combustion chamber. It uses intake tubes that are connected to the combustion chamber and transmit the mixture to it in order to be ignited ("How Electronic Fuel," 2016).

High volume passenger automobiles that are described by the company to be equipped with the turbocharged petrol engine are Sonata, i30 (Elantra), equipped with the Gamma turbocharged petrol engine (in reality MFIS) and the European Kia cee'd manufactured in 2016 powered by the new Kappa turbo technology (López, A., 2015, Winter, D., 2012).

6.11. Integration of IT Systems in High Volume Passenger Automobiles –ADAS

6.11.1. Proposals for Commercially Exploitable ADAS Technologies in the New Passenger Vehicles

The modern vehicles command a high range of interactive appliances that can distract the attention of the driver in some situations like the installment of an on-board phone, a tablet for entertainment of the children on the rear seat, etc. On the other hand, there are various hazards on the road that can have disastrous consequences once the driver's attention has been diverted. Additionally, there are other perils for the safety of the on-board passenger that are not directly connected to the driver's capabilities or concentration. Driving on monotonous motorways and long distances is one of them. Studies suggest that around 20 percent of the road accidents took place because of the driver fatigue (falling asleep at the wheel). The chance of these accidents to cause death is by 50 percent higher compared to the other crashes because of the high speed and the limited time for reaction. Young drivers without experience, professional truck drivers or workers with physically demanding jobs are frequently involved in accidents caused by tiredness or sleepiness. Principally affected are people whose main working activity is driving ("Driver Fatigue," 2016).

The driver fatigue is only one of the cases of the single vehicle accidents. The single vehicle accidents can be described as run-off-road collisions whereas the automobile divers the main way unintentionally due to internal or external factors. As to 2008 around 33 percent of the automobile accidents with fatal ending on the European Union's roads were reported to be road-off-collisions (Naing, C., et al., 2008, Introduction). The figure for the US in 2010 is by 4 percent higher (Liu, C. & Ye, T., 2011, p. 6).

There are no specific statistics for the single vehicle accidents' causes in Europe. Therefore we can rely on these studied in the US. According to data from National Motor Vehicle Crash Causation Survey the most frequent explanation for run-off-roads collisions were the following categories - driver performance errors, driver decision errors, and driver recognition errors. Furthermore, the main causes for the errors committed are reported to be internal

distraction, poor directional control, too fast for curve, and falling asleep at the wheel (Liu, C. & Ye, T., 2011, V).

Two decades ago, the driver was the only one who could estimate the road conditions, react to them, take the decisions and was able to maneuver. Now the safety of and within the passenger vehicles has been altered. The vehicle is being equipped with intelligent technologies which turn it into a cooperative driver assistant. The automotive industry has undertaken a commitment toward embracing innovative warning and safety solutions (Choi, S., et al., 2016).

The American National Highway Traffic Safety Administration has estimated that the crash damages occurred to an automobile involved in single vehicle collision without anti-lock braking system (ABS) and electronic stability control (ESC) are 2.1 times greater compared with automobiles equipped with these safety systems (Liu, C. & Ye, T., 2011, p. 25). That is why we can assume that the safety technology do play a significant role in the avoidance of collisions or the mitigation of additional damages. The ABS and ESC are considered by the manufacturers to be nowadays a basic safety equipment. The manufacturers have identified the development of more advanced warning and emergency systems and their incorporation as a crucial milestone on the way toward technological innovation and improvement of the overall vehicle performance in risky situations. Many automobile manufacturers have grasped the opportunity and have equipped their high class automobiles with state-of-the art ADAS (Choi, S., et al., 2016).

The Department for Transport and the Centre for Connected and Autonomous Vehicles in the United Kingdom has identified the regulatory framework of several existing and new safety technologies which are likely to be commercially exploitable. The master thesis shall rely on their identification as they are approved to meet the government safety and environmental requirements (“Pathway to Driverless Cars,” 2016, pp.12-13).

a. Adaptive (advanced) cruise control (ACC) – a technology that monitors the behaviour of the automobile and automatically adjusts its speed in accordance to the traffic and the vehicles ahead of it.
b. Automatic braking systems – a system that is designed to reduce automatically the speed of the vehicle and thus to mitigate possible damages. If the driver presses the brake pedal lightly the system can increase the pressure on it.
c. Automated parking (Park Assist) – assists the driver in parking. The system could be fully (autonomous vehicles) or semi-automated (passenger vehicles).
d. Blind spot detection – a system that informs the driver through sensitive sensors on objects or persons, located in the blind spot of the automobile and which otherwise are impossible to be seen.
e. Driver drowsiness detection – fatigue detection software - a technology that monitors the behavior of the driver, their maneuvers and the road signs, and can detect indications of tiredness.
f. Lane Keeping Assist Systems (LKAS) – monitors the direction of the automobile and maintains the position of the automobile within its lane while controlling the speed and the distance from other vehicles.
g. Satellite navigation systems and bird’s eye view– presenting a complete view of the road and the area in front of the driver and surrounding the automobile. In general, the information is provided due to four cameras, integrated in the automobile.

In order to evaluate the technological innovation in that area, the master thesis will investigate the incorporation of the single above-mentioned ADAS components in high volume passenger automobiles of the three manufacturers. Although many of the ADAS are still optional (because of price related issues), we can see to which extent they are compatible with the volume passenger vehicles. The investigation is important because according to the European Commission passenger automobiles are mainly involved in collisions ("Mobility And Transport, Road Safety", 2016).

6.11.2. Integration of ADAS in the High Volume Automobiles of Volkswagen Group

Active (adaptive) Cruise Control

The first high volume passenger automobile of Volkswagen Group that was equipped with ACC was is the Passat B6 in 2005. The technology was first activated in the speed range between 30 and 210 km/h. The Golf commands an ACC technology since 2007. The first Audi volume vehicle A6 features ACC since 2005. From 2007 and onwards the Group started to enhance the range of vehicles having the ACC technology installed. Furthermore, the technology itself has been developed and new characteristics have been added. The speed range of the activation has been enlarged and it starts now from 0 km/h and the speed and acceleration rate can be set by the driver ("Adaptive Cruise Control (ACC)," 2016). A new "stop and go" function is added whereas the vehicle automatically slows down in a traffic jam and after that continues to move monitoring the behaviour of the vehicle ahead of it (Chesterton, A., 2016).

All of the Audi volume vehicles feature the "pre-sense city" technology (introduced as optional in 2010) which supplements the ACC and is designed to "sense" vehicles and pedestrians around the vehicle and inform the driver about them. If the technology detects a danger for collision at a speed range up to 85 km/h it can apply the brakes. The A6 and A4 models demonstrate the ACC and the pre-sense technology as basic equipment since 2011/2012, the Q5 and Q3 since 2015, and A3 since 2016 ("The driver assistance systems from Audi," 2011; "Audi A4 pre sense city," 2016, "The new Audi A3; The driver assistance systems," 2015; "Driver assistance systems," 2013). For SEAT Leon it is still optional technology ("Technology switched on," 2016). We should consider that SEAT Ibiza features the conventional Cruise Control System that maintains the selected speed during the whole journey without monitoring the driver's and other participants' behaviour ("Stress-Free Safety," 2016).

In summary, as a standard equipment the ACC (plus Stop and Go) can be found in the whole range Škoda Octavia, the Passat since 2015 and the whole range Audi passenger automobiles ("Skoda Adaptive Cruise Control," 2016; "Volkswagen Democratizes," 2015;). For the automobiles of the whole Golf family and Jetta the ACC is available. The feature is optional and fully compatible with the Polo, the Tiguan, Škoda Superb, Fabia since 2014 and SEAT Leon since 2015 ("Skoda premieres," 2014; "Volkswagen Democratizes," 2015; "Škoda Adaptive Cruise," 2014; "Technology switched on," 2016).

Automatic braking systems

The Autonomous Emergency Braking is called in the Volkswagen Group „Front Assist". The technology is standard for the Passat launched in 2015 and the Golf ("Volkswagen Democratizes," 2015). In general, the Front Assist can be seen as a part of the ACC technology as it uses its front cameras and sensors ("Volkswagen's safe distance technology," 2016). The same can be seen by Audi –the new technology is called „Braking Guard", belongs to the „pre-sense" package and is integrated in the ACC as an optional configuration ("Description A4," 2013). The A6, A4 and Q5 command the Brake Assist since 2008 ("Safety Based on," 2008). Furthermore, the Brake Assist has been configured for the Q3 in 2010 and A3 in 2013. The emergency brake assist in the Q3 and A3 models has been further developed in 2013 and enhanced to a „secondary collision brake assist". If the vehicle has been hit from the backside the system automatically activates and prevents the vehicle from rolling uncontrollable and thus provoking a second collision. The secondary collision brake assist has been incorporated as a constant feature of the emergency brake assist since 2013 ("Im Audi Q3," 2011; "Die Fahrerassistenzsysteme," 2013; "Driver assistance systems," 2014; "A successful car," 2014).

The Front Assist is a standard feature of the new Škoda Octavia and the new Superb (2015) ("Inspiring safety technology," 2015).

Automated parking (Park Assist)

The park assist can evaluate if the vehicle can fit in a given parking space. The technology is present for the Volkswagen vehicles in the form of a button. It is a semi-automated parking assistance. By pressing the button once the technology will assist in parallel parking activity and by pressing twice in perpendicular ("Volkswagen Democratizes," 2015). The driver has to control the accelerator, shifter and brake, and the Park Assist operates the steering wheel autonomously. The Park Assist was optional feature for the Golf, Passat and Tiguan since 2008 ("Self-parking – Volkswagen," 2009). For the new model range of the three and new Škoda Octavia automobiles the technology is available on board and for the Superb it can be custom-built since 2011 ("Volkswagen Democratizes," 2015; "Inspiring safety technology," 2015). The new Audi volume vehicles – A3, A4, A6, Q3 and Q5 demonstrate the availability of the Park Assist if requested and the automated parking technology of Audi is being incorporated in vehicles since 2012 (Subbaraman, N., 2015; "Build your Audi," 2016).

The Park Assist has been offered by the SEAT Leon as a standard characteristic of the vehicle since 2014 (Morgan, T., 2014). SEAT Ibiza features only the conventional park distance control (Thomas, F., 2016).

Blind spot detection

As a standard equipment Volkswagen incorporates the Blind Spot Monitor in the Passat and Beetle model range from 2015. As an available feature it can be seen in the Golf, Jetta and Tiguan from 2015 as a new infotainment characteristic ("Volkswagen Democratizes," 2015). The blind spot detector is integrated in the „side-assist" technology of Audi that monitors the vehicles approaching from behind with the help of rear sensors. It is an optional technology designed for the whole range of volume passenger automobiles since 2010 ("Audi side assist,"

2011). The SEAT Leon commands a Blind Spot Monitor as an additional custom-built technology since 2014 (Auty, C., n/d). The new Škoda Superb presents the Blind sport detection as an additional feature of the Laurin & Klement (L&K) trims since 2015 (Keynes, M., 2015).

Driver drowsiness detection

The system monitors on the one side the driver's concentration and their maneuvers and on the other the road signs and speed limitation, and evaluates them. If it detects indication of distraction or irregularity it notifies the driver with sound signal. The Passat and Golf VII command the Driver Alert System as standard technology, the first since 2010 and the latter since 2012 (Janouch, S., 2012; "Assistenzsysteme im VW Golf," 2012). The technology is available for the Polo and Tiguan automobiles since 2011/2012 and it has become standard for the Jetta in 2014 (Evans, G., 2013; "Driver Alert System," 2016; "Vorverkaufsstart für den," 2014).

The Audi vehicles command a rest recommendation feature. It is a standard equipment in the Ambition and Ambiente product lines of the Audi A3 since 2013, in Audi A6 since 2012, and in Q5 since 2013 ("Driver assistance systems," 2013; "High-performance SUV," n/d). The new A4 from 2015 is equipped with the drowsiness detection as well ("Audi A4 (fifth generation)," n/d). The technology is standard for the latest Q3 as a part of the driver information system and it has to be enabled ("Model Overview," 2016; "Audi Q3 2.0 TFSI," 2015).

The new Superb from 2015 demonstrated the fatigue detection as a standard component ("Inspiring safety technology," 2015). The technology could be fitted into the Octavia since 2013. In the new models from Ambition and Style equipment lines of Octavia 2016 the fatigue detection is present as a regular feature ("Fatigue Detection," 2016).

The SEAT Leon model range from 2013 and onwards demonstrates the tiredness recognition as an optional element that can be configured to the vehicle ("Leon 2013 - 2017 Tiredness," 2016).

Lane Keeping Assist Systems

The Lane Departure Assist is on optional component of the ADAS incorporated in the Passat B6 since 2008, the Golf VII since 2012 and a standard only for the new Passat 2015 (Brandon, J., 2012; "VW Passat Spurhalteassistent," 2008; "Volkswagen Democratizes," 2015). The technology functions constantly during the whole ride and not only when it senses a problem (Brandon, J., 2012). Furthermore, the Lane Assist can be configured for the Tiguan since 2013 (Evans, G., 2013).

The Lane Assist could be configured for the A6, A4 and Q3 since 2011, and Q5 since 2012 ("Always on the road," 2012; "Audi A6 Zugpferd," 2011; "Der geliftete Audi," 2011;).

For the Octavia the technology is available since 2013 and for the Superb model it has been introduced in 2015 ("SKODA Octavia 2013," 2013; "Inspiring safety technology," 2015).

In comparison, SEAT Leon exhibits the Lane Assist as an optional ADAS since 2013 (Burnay, J., 2013).

Satellite navigation systems – Bird's eye perspective

The bird's eye perspective is provided to the cockpit due to the technology "Area View". It delivers to 12 individual "live views" of the surroundings or selected areas of the automobile in accordance to the traffic situation ("Area View: Keep an eye," 2016). Within the range of volume automobiles the new Tiguan 2016 and the Passat since 2014 can show the perspectives from a bird's eye view ("Volkswagen Passat – Area," 2014).

The bird's eye perspective has been integrated in the new navigation systems of Audi A6 since 2014 and Q5 since 2016 ("Assistenz Paket," 2016; "Audi A6 Test," 2014).

Moreover, the new Audi A4 will be optionally equipped with the "top view" system of Audi for providing a complete view of the area in 2017 (Paukert, C., 2015).

The innovative navigation technology is present on Octavia and Superb model year 2016 ("Assistenzsysteme im Praxis-Check," 2016).

6.11.3. Integration of ADAS in the High Volume Automobiles of Toyota Motors

Active (adaptive) Cruise Control

The active cruise control is called within Toyota Motors Dynamic Radar Cruise Control (DRCC). The vehicles that are equipped with that type of ADAS fall under the category "Toyota Safety Sense P" which are additional and optional safety packages for passenger automobiles ("Together we can," 2016). The Toyota Safety Sense is reported to become standard on vehicles whose manufacturing starts in 2017 (Sinek, J., 2016). The manufacturer uses the term "standard" that means actually "available". We can see that there are different prices for the safety packages that will become compatible with the vehicles in 2017 (Ramsey, J., 2015).

The DRCC is activated between 40 and 180 km/h. Moreover, the minimum speed of the automobile to activate the DRCC has to be above 45 km/h ("Together we can," 2016).

Toyota develops its own ACC since 2006 ("Safety Technology History," 2016;). In 2010 the optional safety package was introduced to limited Prius trims as the first volume passenger automobile that could be configured with ADAS ("New Safety Pack," 2010). In 2016, the RAV4 features for the first time the new technology as an optional component ("Toyota Car Safety," 2014). The ADAS technology will become available on models starting production in 2017, interestingly for the first time Corolla and some of the Yaris trims ("Toyota Safety Sense," 2016; Greimel, H., 2014; 2017 Yaris, 2016) . The ACC was enhanced to three Prius trim levels (out of four) in 2016 (Ibid.).

There is no indication in the individual technical specifications or the press releases of the company that the Corolla commanded previously the ACC.

To the Lexus ES the optional safety package with ACC was added in 2008 ("Lexus ES350," 2008). For the next generations the ACC remained an available feature. In comparison with the vehicles with the emblem of Toyota, the Lexus ES will be offered in 2017 with a safety

package where the ACC is included for additional trim levels (Popely, R., 2016; Ramsey, J., 2015).

Automatic braking systems

The automatic braking is called in Toyota's vehicles "Brake Assist". The Brake Assist has been launched as a supplementary ADAS to the Corolla generation 2006 and the Prius in 2012 ("Toyota Corolla generations," 2015; "Prius v How-To," 2012). As to 2016 the technology is still described as optional. For the high volume passenger automobiles whose manufacture beginning is scheduled for 2017 the "Brake Assist" is included in the "Pre-Collision System" ("Together we can," 2016). In 2017 the "Brake Assist" will become standard to almost all trim levels of volume automobiles which were in the past lacking in that ADAS (Ramsey, J., 2015). However, we should consider that the standardisation of the Brake Assist does not involve a standardisation of the whole "Pre-Collision" safety package.

In general, the Lexus ES applies the same "Pre-Collision" supplementary safety package since 2013. From 2017 and onward the Lexus ES will be equipped with new version of the automatic braking system. The models from 2017 will demonstrate the automatic braking as standard equipment. The manufacturer has recalled the Lexus ES with the automatic braking technology from 2013 to 2015 and additional vehicles because of failure in the automatic braking system which can increase the risk for a collision (Read, R., 2015). For the Lexus ES model year 2017 the "Brake Assist" will become a constant characteristic ("Lexus Safety System+," 2016).

Automated parking (Park Assist)

The „Park Assist" technology is available for the latest Toyota passenger vehicles whose production started in 2014, 2015, 2016 and is called IPA „Intelligent Parking Assist". Is has the form of a button. With the help of four cameras installed on the automobile the driver gets assistance in the parallel or perpendicular parking ("Parking Aids," 2016). First the Prius has been supplied with the Park Assist in 2010 (Toyota Prius Intelligent, 2010). In contrast, the technology has been enabled for the eleventh generation of Corolla starting in 2014, for the Yaris in 2015 and for RAV4 in 2016 (Tutu, A., 2013; "Toyota Yaris – Parking," 2015; "Toyota RAV4 Owners," 2016).

For the Lexus ES the „Park Assist" is an optional component since 2007 which relies only on the warning signals and since 2010 the actual „Park Assist" has been made available ("Manual 2007 Lexus," 2014; "Manual 2010 Lexus," 2014).

Blind Spot Detection

Toyota describes the blind spot monitoring technology as one of its latest technological achievements. However, the blind spot detection is available only for the new Prius as a representative of the high volume automobiles whose production began in 2016 ("2016 Prius – the next," 2016; "Toyota car safety," 2014). The new Corolla from 2016 is not offered with blind spot monitoring technology ("2016 Toyota Corolla," 2015). There is no information on

the future safety strategy regarding the incorporation of Blind Spot Monitor to further volume vehicles.

The Lexus ES model year 2014 has been introduced on the market with an optional blind spot monitor on board ("Lexus ES Lane," 2013).

Driver drowsiness detection

Toyota Motors is the first automotive manufacturer who initiated a research on new technologies for monitoring the driver attention to the road including also a software that follows carefully the eyes of the driver. The company devotes its efforts to the inquiry since 2006 ("Toyota Enhances," 2008). However, there are no high volume passenger automobiles of Toyota or the Lexus division equipped with a technology that can detect the driver drowsiness or tiredness. The company applies the new software rather to the new hybrid vehicles ("Unterwegs im Toyota Prius," 2016).

Lane Keeping Assist Systems

The first volume vehicle with the emblem of Toyota equipped with „Lane Departure Alert" as an optional configuration was the Prius produced in 2010 ("Prius How-To," 2009). There are controversial statements on the availability of the Lane Assist in the RAV4. The division of Toyota in the US presents a commercial on the Lane Assist technology in 2013 and we can recognise the vehicle as RAV4 ("RAV4 Lane Departure," 2013). On the other hand, we can see a comparison between the 2015 and 2016 models on an auto trading platform. The author claims that the model 2015 does not feature the availability of the Lane Departure Alert and the first one supplied with the new technology is the RAV4 manufactured in 2016 (DeMuro, D., 2016). For Toyota Yaris the ADAS is optional since 2016 ("Toyota Safety Sense," 2016). The first Corolla supplied with Lane Departure Alert as optional component will be manufactured in 2017 ("Together we can," 2016). We should consider, that the Lane Assist is not a standard equipment of the vehicles, and even for the automobiles coming in 2017 it will remain an optional safety element (Ibid.).

The first Lexus ES to whom the Lane Departure Alert could be configured is reported to be model year 2013 ("Lexus ES Lane Departure," 2012).

Satellite navigation systems – bird's eye perspective

The bird's eye perspective has been introduced to limited Toyota vehicles in 2016. The technology is almost the same as described for the Volkswagen Group. It presents a 360 degrees perspective of the vehicle and the area surrounding it but only delivering a single image ("Toyota How-To," 2016). The technology has made its debut on the RAV4 Hybrid and Highlander ("Toyota RAV4 Hybrid," 2015; "Toyota Bird's Eye," 2016). Within the high volume passenger automobiles' range no model features the birds's eye perspective as an optional component so far ("Toyota Bird's Eye," 2016).

- *The Case of the Unintended Acceleration*

In 2009 a collision in USA has revealed that a number of volume passenger automobiles of Toyota have an accelerator pedal that speeds up uncontrollably whereas passenger are put at high risk. There are different explanations about the accelarator's failure such as the floor mats, sticky pedal, a failure of the electronic throttle control system or of the anti-lock braking system. The issue has turned into the most serious crisis of the company and has lead to a noticeable decline in sales, as the number of complaints accounts for more than 6,000 involving 89 cases of death (Koopman, P., 2014; Szinkota, M.& Ronkainen, I., p. 536). However, researchers claim that the crisis management of the company failed and its global image has been hurt badly (Kalb. I., 2012). The confusion that has come from Toyota managers who were a long time incapable of declaring the reason for the sudden acceleration and taking responsibility influenced the customers to be afraid onboard (Ibid., Szinkota, M.& Ronkainen, I., p. 536). A further reply to the crisis is seen in the development of new safety technologies such as the embrace of ADAS that could be perceived as a solution „so the defects are unlikely to reoccur" (Kalb. I., 2012).

6.11.4. Integration of ADAS in the High Volume Automobiles of Hyundai Kia

Active (adaptive) Cruise Control

The first volume produced Hyundai vehicle supplied with ACC is the Sonata model year 2015. The ACC is optional component and can be activated in the speed range from 0 km/h to the driver's maximum selected speed (Howard, B., 2014). The Elantra and Santa Fe will apply the safety technology in models whose production starts in 2017 ("Elantra 2017," 2016; "The Latest Advancements," 2016).

With regard to the Kia brand, the first volume vehicle that commands an ACC is Kia Sorento since 2015 ("All New 2015," 2015). A year later Sportage (only one trim out of six) and Optima have been equipped with the new ADAS as an available configuration ("Trendsetting design," 2016; All-New Kia Sportage, 2016). The technical characteristics of the Kia ACC are equal of those of Hyundai ("Trendsetting design," 2016).

Automatic braking systems

The Sonata has added "the autonomous emergency braking" to its available safety features in 2016 ("Sonata Safety," 2016). The same holds true for the Santa Fe and the Elantra ("New Santa Fe," 2015; "All New 2016 Elantra," 2016). In case of a risky situation the technology notifies the driver via a sound signal and if required the brakes are applied autonomously to avoid collision (New Santa Fe, 2015).

The Optima features the emergency braking system since 2016 ("Trendsetting design," 2016). According to the manufacturer this kind of ADAS will be available on the Sorento, Sportage and Forte whose production is scheduled for 2017 ("Kia Vehicles," 2016).

Automated parking (Park Assist)

The automated parking is named within the Hyundai Group as „Smart Parking Assist System". Only the Santa Fe model year 2016 commands the Park Assist relying on front and rear sensors, a camera and intelligent guidance system ("New Santa Fe," 2016, p.11). However, we should make a distinction between the Smart Parking Assist System and the Park Assist Warning. The first is the new safety technology that helps the driver in the parallel or perpendicular parking due to its sensors and guidance software. The latter relies only on rear sensors and is in reality the well-known parktronic system that notifies the driver via a sound signal about the distance to a object located in the rear area of the automobile. In the brochures of the new Sonata and Elantra we can see that the park assist described is actually the Park Assist Warning System or the Parktronic ("Elantra 2017," 2016, p.11; "Sonata Safety," 2016).

The Kia Sportage and Optima have been supplied with the optional „Smart Parking Assist System" in 2012 ("Kia´s Smart Park," 2012; "Kia Sportage – Smart," 2012). The Sorento features that safety component since 2014 ("Smart Parking," 2014). The cee'd demonstrates the availability of the rear view sensors only ("The Sleek and Sporty," 2016).

Blind Spot Detection

The first volume vehicles that apply the Blind Spot Detection technology within Hyundai are the Santa Fe and Sonata model year 2016 ("New Santa Fe," 2015; "Sonata Safety," 2016). The equipment of the Elantra is envisaged in 2017 ("Elantra 2017," 2016).

The Blind Spot Detection technology can be configured to the Kia Sorento and Optima since 2016 ("Sorento 2016," 2016; "Trendsetting design," 2016). Now the Sportage and Forte do not command the new safety technology but they are expected to have it available on board in 2017 ("Sportage 2017," 2016; "Tech: Driver Assist," 2016).

Driver drowsiness detection

The first vehicle that will be supplied with the driver drowsiness detection called in Hyundai "Driver Attention Alert" will be the new i30 (renamed Elantra for the European market) in 2017 ("A Car for Everyone," 2016).

There is no statement of the manufacturer or third sources that Kia has developed or applied the driver drowsiness detection technology.

Lane Keeping Assist Systems

The Lane Departure Warning has been incorporated in the Sonata in 2016 ("Sonata Safety," 2016). It should not be confused with the „Lane Change Assist" which has been applied earlier. The Lane Change Assist is actually a Side-Assist that monitors the vehicles approaching from other lanes and notifies the driver.

The Lane Departure Warning is reported to be available for the Santa Fe and Elantra in 2017 (“Elantra 2017,” 2016; “The Latest Advancements,” 2016).

Kia started to incorporate the Lane Departure Warning technology prior to Hyundai. The first volume vehicle is the new Kia cee’d in 2013 (“New Kia cee'd,” 2012). After that in 2016 the range of the vehicles which feature that ADAS component has been enhanced with the Kia Optima and Sorento (“All New Kia Optima,” 2015; “Sorento 2016,” 2016). The Sportage will have the technology available in 2017 (“Sportage 2017,” 2016).

Navigation Bird’s Eye Perspective

The Santa Fe whose production starts in 2017 will be able to be optionally configured with a 360 degree camera that provides images of the automobile’s surroundings (“How To Use,” 2016).

Kia Sorento and Optima model year 2016 are the first two and only vehicles within the Kia production range featuring the bird’s eye perspective (Muller, D., 2016; “Sorento 2016,” 2016).

Summary: Incorporation of ADAS

*Figure 29 Period of incorporation of ADAS in volume automobiles and their availability on board **O**- optional equipment; **S**-standard equipment; **F**- available for future vehicles; **X** – not available on board*

	ACC	Year of Adoption	Automatic Braking	Year	Park Assist	Year	Blind Spot Detection	Year
Golf	O	2007	S	2015	O	2008	O	2015
Passat	O/S	2005/2014	S	2015	O	2008	S	2015
Jetta	O	2015	O	2015	O	2013	O	2014
Polo	O	2013	O	2014	O	2014	X	X
Up!	X	X	O	2012	X	X	X	X
Tiguan	O	2014	O	2015	O	2008	O	2015
Beetle	X	X	X	X	X	X	S	2015
A3	O/S	2010/2016	O	2013	O	2012	O	2010
A4	O/S	2010/2011	O	2008	O	2012	O	2010
A6	O/S	2010/2011	O	2008	O	2012	O	2010
Q3	O/S	2010/2015	O	2013	O	2012	O	2010
Q5	O/S	2010/2015	O	2008	O	2012	O	2010
Octavia	S	2016	S	2015	S	2015	O	2016
Fabia	O	2014	O	2014	O	2014	X	X
Superb	O	2014	S	2015	O	2011	O	2015
SEAT Leon	O	2015	O	2013	S	2014	O	2014
SEAT Ibiza	X	X	O	2015	X	X	X	X
Toyota Corolla	F	2017	O	2006	O	2014	X	X
Prius	O	2010	O	2012	O	2010	O	2016
Yaris	F	2017	F	2017	O	2015	X	X
RAV4	O	2015	F	2017	O	2016	X	X
Lexus ES	O	2008	O/S	2013/2017	O	2010	O	2014
Hyundai Elantra	F	2017	O	2016	X	X	F	2017
Sonata	O	2015	O	2016	X	X	O	2016
Santa Fe	F	2017	O	2016	O	2016	O	2016
KIA Cee'd	X	X	F	2017	X	X	F	2017
Sportage	O	2016	F	2017	O	2012	F	2017
Sorento	O	2015	F	2017	O	2014	O	2016
Optima	O	2016	O	2016	O	2012	O	2016

Note: Adapted from technical specifications, manuals, press releases, video materials of volume automobiles of Volkswagen, Toyota and Hyundai Kia, different years.

*Figure 30 Period of incorporation of ADAS in volume automobiles and their availability on board. **O**- optional equipment; **S**-standard equipment; **F**- available for future vehicles; **X** – not available on board*

	Driver Drowsiness Detection	Year of Adoption	Lane Assist	Year	Bird's Eye Perspective	Year
Golf	S	2012	O	2012	X	X
Passat	S	2010	O/S	2008/2015	O	2014
Jetta	S	2014	X	X	X	X
Polo	O	2011	O	2014	X	X
Up!	X	X	X	X	X	X
Tiguan	O	2011	O	2011	O	2016
Beetle	O	2016	X	X	X	X
A3	S	2013	O	2012	X	X
A4	S	2015	O	2011	F	2017
A6	S	2012	O	2011	O	2014
Q3	S	2015	O	2011	X	X
Q5	S	2013	O	2012	O	2016
Octavia	O/S	2013/2016	O/S	2013/2016	O	2016
Fabia	O	2014	O	2014	X	X
Superb	S	2015	O/S	2016	O	2016
SEAT Leon	O	2013	O	2013	X	X
SEAT Ibiza	O	2016	O	2016	X	X
Toyota Corolla	X	X	F	2017	X	X
Prius	X	X	O	2010	X	X
Yaris	X	X	O	2016	X	X
RAV4	X	X	O	2016	X	X
Lexus ES	X	X	O	2013	X	X
Hyundai Elantra	F	2017	F	2017	X	X
Sonata	X	X	O	2016	X	X
Santa Fe	X	X	F	2017	F	2017
KIA Cee'd	X	X	O	2013	X	X
Sportage	X	X	F	2017	X	X
Sorento	X	X	O	2016	O	2016
Optima	X	X	O	2016	O	2016

Note: Adapted from technical specifications, manuals, video materials of volume automobiles of Volkswagen, Toyota and Hyundai Kia, different years.

7. Analysis and Discussion of the Findings

7.1. R&D Expenditure – the Budget of Science

Referring to the first criterion and considering the data on the „budget of science“ that the three companies command, we can clearly see that nowadays Volkswagen Group invests the largest amount of financial means (13,612 billion euro) in the R&D operations. The figure is higher compared to the investment of Toyota Motors with 8,9 billion euro. Toyota's expenditure accounts for 65 percent of the total investment of Volkswagen. In contrast, Hyundai Kia spent 10 times less compared to Volkswagen and around 3 times less compared to Toyota.

In 1998 Volkswagen Group devoted 2,2 billion euro to R&D operations. The figure achieved for 17 years a sixfold increase, reaching in 2015 13,612 billion euro, surpassing Toyota noticeably and making the Group the most generous R&D spender.

Toyota invested in the late 90's heavier in R&D activities compared to Volkswagen (or 4 billion euro). We can notice that the company has increased its R&D spending through the years as well. The highest investment that Toyota has reached (in 2009) is only doubling the initial figure.

The available information on the combined expenditure of Hyundai Kia starts from 2003 with 1,61 billion euro, which is the smallest amount of investment among the three automotive companies but also similar to a degree with the Volkswagen's initial expenditure from 1998. However, we can see that the company did not experience such a sharp increase of R&D expenses and gradually enhanced its efforts toward innovative research and development by almost doubling the initial figure reaching 3,1 billion euro in 2015. A possible reason for this could be the focus of attention placed by Hyundai Kia Group on the improvement of technical facilities, extension of its subsidiaries and the building of new factories which we can notice by the wide difference between the financial means devoted to R&D operations and those to tangible fixed and current assets. The latter is twice larger compared to the former.

However, the R&D operations are part of the innovation activities of a company (Dachs, et al., 2012, p. 12). Therefore, it is not surprising that Maclaurin defines the R&D expenditure as the „budget of science“. He assumes that a discovery could be possible without any extensive financial means, but future improvements and developments toward perfection include complex testing procedures and advanced machine tool technology. As Maclaurin claims:

„Great contributions are rarely made today in a garret“ and the amount of the financial support to the pure science is „likely to have some effect on“ the results and achievements (Maclaurin, 1953, p. 101).

Therefore, the research of the first criterion leads us to the assumption that Volkswagen Group due to its extensive R&D spending is more likely to reach new solutions and better technological achievements for its products and in our field of interest, for the high volume passenger automobiles. Toyota is ranked by PwC to be the second largest R&D automotive spender. In regard to this criterion this makes it the strongest automotive rival to the Volkswagen Group. Even occupying the second place, Toyota stays next to Volkswagen

regarding the opportunity to produce technological innovation. On the other side, Hyundai Kia increases its R&D spending rather in a humble way. The fifth largest automotive manufacturer is not present in the twenty companies studied by PwC regarding their R&D budgets. And the figures on the companies' combined budget of science confirm the considerable margin between Toyota and Volkswagen on the one side, and Hyundai Kia on the other. Compared to them, the South-Korean manufacturer was and is less likely to develop new technological improvements in its passenger vehicles. Considering the budget of science Volkswagen and Toyota possess „an inherent advantage over small rivals" such as Hyundai Kia (Sedgwick, D., 2016).

7.2. Capabilities in Research

All of the three companies command highly specialised and well equipped laboratories where the research and development operations are carried out. We can see that the main facilities of the three rivals to conduct research are rather centralised – Wolfsburg in Germany, Nagakute in Japan and Hwaseong City in Korea. In comparison to the other two companies Volkswagen commands more research centers located overseas that are coordinated via the headquarter in Germany. Furthermore, one can notice that Volkswagen has not invested in separate research centers devoted only to the conduct of fundamental research. On the contrary, the data on the numerous long-term partnership establishments of joint programmes with other companies and universities, suggests that the Volkswagen Group cooperates closely in the area of the applied research. The manufacturer supports especially the knowledge transfer between academics and university graduates, and the automotive industry by engaging students or PhD candidates in research projects and supporting them on their future career path. The universities are considered to be of immense importance for the transition from pure science to economic development in Maclaurin's theory (Maclaurin, 1953, p. 99). They give the scientists enough freedom and encouragement to "ask original and important questions which have far-reaching practical implications" and "to explore the unknown" (Ibid.). The close collaboration between educational institutions and the industry is especially important for the industry to create innovation as the new, young and well-educated talent coming from the universities has the potential to overwhelm "the mental block resulting from long established habits of thinking" of the regular employees who are used to the company's workplace practices and culture (Ibid., p.100). On the other side, the company's facilities - research and development centers, with their respective specialist departments and technological equipment provide the tools and environment needed to answer these original and important questions.

Volkswagen partners closely with 280 universities worldwide. Available data on Toyota suggests that the company cooperates with four universities, whereas Hyundai has established partnerships with five educational institutes. Hyundai Kia has showed an interest in strengthening their collaboration with universities due to the creation of the "Hyundai NGV" platform where academics have the chance to carry out research with industry players. However, the data does not indicate the persistence and the result of these cooperations. There is no indication that researchers from the R&D departments of Hyundai Kia or Toyota are willing to support master theses or PhD candidatures.

Regarding the focus of the research activities we can clearly see that Volkswagen puts the emphasis of the research centers on the practical application. The company concentrates its research efforts on the technological improvements of their hybrid and volume passenger automobiles.

On the other site, Toyota aims its attention rather to the fundamental research. There are two R&D facilities engaged only in the conduct of basic research. Significant efforts are put in the human-robot collaboration, the development of artificial intelligence that will assist disabled individuals in their daily routine – areas of research that do not have a direct impact on the automotive industry and the passenger automobiles. In this regard Maclaurin states "Pure science rarely leads directly to… immediate technological change." (Maclaurin, 1953, p. 99). Therefore, we can assume that considering the second criterion and because of the limited focus on applied research and close collaboration with industrial partners and universities, the technological innovation in the Toyota's volume passenger vehicles can emerge with delay compared to the innovation introduced to Volkswagen's automobiles.

Hyundai Kia puts the attention of its R&D operations on the applied research and the commercial applications of the automotive innovation. It initiated a platform for "intelectual interchange" (as described by Maclaurin, 1953, p. 100) between academic researchers and students, and industrial stakeholders. Nevertheless, to deepen its own collaboration with universities and to integrate young PhD candidates in its departaments, as Volkswagen does, the budget of science of Hyundai Kia is seriously limited.

7.2.1. Number of Scientists Employed

The number of qualified professionals employed in the laboratories of Volkswagen AG, Toyota Motors and Hyundai Kia accounts for 8, 7 and 11 percent respectively. However, if we see them according to their number, Volkswagen's R&D operations have at their disposal the largest figure of researchers– 48,731 individuals, followed by Toyota with approx. 25,000 researchers and Hyundai Kia with 11, 000 professionals.

Nevertheless, there is no considerable distinction between the three companies in the recruitment policy for their R&D departments. Hyundai Kia places great importance on the contemporary extension of the number of R&D employees in order to overwhelm their slowdown from the early 90s. Thirty percent of the new employees are appointed in the R&D division (Hyung, J., 2010).

However, there are no precise statistics on the professional qualifications (scientists, engineers, professionals with advanced training or laboratory assistants) of the employees engaged in similar tasks in all three companies. Maclaurin remarks that usually the large enterprises with centralised laboratories do not make "an adequate distinction" in their reports between the professional qualification of the researchers active in specific R&D operations (Maclaurin, 1953, p. 104). Therefore, we should answer the question whether 48,731 researchers are more likely to be more productive in the area of the technological innovation than 25,000 and 11,000 researcher. We shall take in consideration the fact that the researchers at the Volkswagen's R&D facilities command also more financial means as the budget of science provided by the Group is the most generous one.

As Maclaurin mentions one talented scientist may have the potential to outperform in productivity many researchers. However, geniuses are still exceptions (Ibid.). Acknowledging these disadvantages we can make an overall comparison between the three automotive companies. Relying on Maclaurin's opinion that our industry has come to a moment where novelties "are almost made to order", the master thesis like Maclaurin assumes that "there *can* be a definite correlation between the numbers of applied scientists employed (and the funds at their disposal) and the inventive results" (Ibid.).

Considering the whole labour force at Volkswagen, Toyota and Hyundai Kia, the number of R&D employees and the budget at their disposal, we can see that the three companies have a similar strategy of employees positioning in the R&D operations. However, referring to the theory Volkswagen still commands more professionals (as single individuals and scientists) devoted to its R&D activities and larger budget. Therefore, we can make a supposition that the higher number of professionals engaged in R&D operations of Volkswagen could produce more "inventive results" in pursuing technological innovation in volume automobiles. The research activities of Toyota could be more productive and could achieve better results compared to Hyundai Kia. Both of the assumptions are made with a shade of speculation because of the mentioned limitations of the theory.

7.2.2. The Number of Patents

In regard to the fulfilment of the criterion "number of patents" we can undoubtedly claim that Toyota Motors is the strongest player among the three rivals. Granting all the limitations and the criticism coming from many researchers on the credibility of that criterion to influence the innovation of a company, we could rely on the statement of Maclaurin that the number of patents can be analyzed "but they have to be used with care" (Maclaurin, 1953, p. 103). However, it was not possible to find what part of the patents issued are basic or improvement patents. Toyota concentrates its efforts on the development of alternative drive-train using fuel-cell technologies. Hyundai Kia follows that trend as well. So does Volkswagen whereas the company aims its attention in its patenting activities to the conventional power-train as well. As stated in the framework, the thesis considers the number of patents as a component that measures the "propensity to invent". Therefore, one can state that Toyota presents the strongest propensity to invent. Nevertheless, the invention does not lead automatically to innovation. According to Maclaurin a commercially launched invention (in the shape of a new or improved product) becomes an innovation (Maclaurin, p. 105). We should also look back at Schumpeter's assumption: "*Innovation is possible without anything we should identify as invention*." (cited in Maclaurin, 1953, p. 105)

Volkswagen and Hyundai Kia are placed on the fourth and fifth position among the 18 largest automobile manufacturers regarding their patenting activities. Apparently, Hyundai Kia has strengthen its efforts towards patents filing, despite the lower budget of science compared to its competitors.

On the one side, if we rely on the patents as a measurement of the propensity to invent, we can say that Toyota has the greatest potential outperforming Volkswagen and it will rely on its future strategy, what part of it would be commercially introduced as a new or improved process or product.

On the other side, Maclaurin mentions that two separate companies that operate in the same field may put different level of importance on the patents. The company that is more eager to get revenue from the patent royalties have stronger interest in patenting activities (Ibid., p. 103).

According to the expert in patent litigation W. Waldeck, the noticeable increase of patent filings from the automotive industry presents the attempt of the companies to "protect their technological edge". The automotive industry is the third active industry in regard to patent filings. In the era of technological advancements, the technological innovation has turned into a value-adding component of the vehicles. As the manufacturers go up fiercely agains each other developing new technologies and alternative powertrains, and technology companies like Bosch or Apple enter the automotive business, more patents have been filed in order the companies to protect their current position. Furthermore, the companies invest more financial funds into developing new technologies and the licensing revenues are now seen as a partial compensation for the investment (Waldeck, W. & Watts, J., 2015).

Considering this assumption we can say that Toyota Motors focuses its efforts strongly on the patent filings in the area of the new and alternative drivetrain concepts and due to its exceptional high number of patents (14,000 patent applications in 2014) aims to protect its position on the market of the hydrogen fuel-cell technologies. In this way the company will ensure an additional „revenue stream" during the „confrontational war on wheels" (Waldeck, W. & Watts, J., 2015).

7.3. Number of New Plants Built

The number of the new plants build by a company is believed to be an additional stream to finance innovation. The company uses the new constructions to produce the new or improved goods and the production of the old ones remains in the existing facilities. The period from 1995 to 2016 has been marked by a strategy of global expansion of the three companies and decentralisation of the production. The new production facilities of Volkswagen in the period under observation account for 86 plants and 3 additional are in construction. Toyota Motors added to its manufacturing facilities 40 new plants and one is in construction. Hyundai-KIA have built 14 new production factories. Based on the practices of the American companies, Maclaurin claims that because it is considerably hard for a company to finance the new production factories solely from their earnings, an increasing number of new factories is a clear signal that fresh capital is put in the hands of innovation activities (Maclaurin, 1953, p. 109). That is why based on the figure of the new factories built, one can expect that Volkswagen Group has the highest propensity to finance innovation. Toyota arrives second and Hyundai-KIA third regarding the propensity to "obtain financial support for innovations" (Ibid.).

7.4. Annual Sales Volume of the Improved Products

The annual sales volume of the new/ improved products contains a significant information about the presence of technological advancements in a product and is also a signal "when particular innovations have run their course" (Maclaurin, 1953, p. 108). In order to compare all of the improved passenger vehicles and correlate them with their sales figures, one should

have the information on every single component of the vehicle, its body structure, engine, transmission and even on every minute detail and their change over the generations. Such a comparison between 29 automobiles over approx. 5 generations of vehicle's development is constrained by the feasible volume of a single written paper. Furthermore, the acquisition of such a specific information on the vehicles' structure and components throughout the years requires a fine-grained and intimate inquiry about every of the three companies and permission to archived information on vehicles produced in the past, because comprehensive technical specifications in the brochures are available only for the newer generations.

The experts in patent litigation W. Waldeck and J. Watts assert, the technological innovation has become more significant to the value of the automobile. According to an analysis of McKinsey, the innovation in the connectivity among European high-class vehicles amounts to 4 percent of the value of the automobile and because of the advancements in the connected technology this figure is projected to increase (Waldeck, W. & Watts, J., 2015). Furthermore, C. L. From claims that the increasing annual sales of Volkswagen automobiles in China is mainly due to the introduction of technological innovation into the passenger vehicles which raised the confidence among the consumers (Lee From, C., 2016). Therefore, the vehicles' annual sales on the most important markets shall help us identify which models have gained the most trust of the customers. The embedment of innovative technologies may be a possible reason for that increase in sales.

The annual sales of Volkswagen on the three markets present a pattern on the most purchased automobiles. The most popular passenger automobiles among the European, U.S. and Chinese consumers were the new Golf (since 2008/ 2010), the Tiguan, Passat, the new A3 (2012), A4, A6, Q3, Q5, the new range of Škoda Octavia and Superb (2013), and SEAT Leon. Therefore, based on these results we should trace the highest rate of embedment of technological innovation into these passenger vehicles.

To draw a pattern for the Toyota's annual sales is more complicated. The three markets do not exhibit any considerable similarities. Overall, we can say that the most purchased models among the passenger automobiles are definitely RAV4 and Lexus ES, the Corolla in the USA and China, Yaris (2010) in Europe and China, and the Prius only in the US. Only the RAV4 and Lexus ES were very popular with all the customers of the three markets. Regarding the sales figures, one can assume that RAV4 and Lexus ES were praised mostly by the customers potentially because of the introduction of advanced technological improvements.

Hyundai Kia vehicles demonstrate a considerable decrease in sales on the Chinese market. According to researchers a couple of reasons is responsible for the sharp decline – the failure of the analysts group to introduce technological advancements into their passenger vehicles, the efforts invested in the lowering of prices to undercut the competition, and the focus on "simultaneously pushing" multiple generations of the automobile which leads to an extended model range of the same automobile and a confusion among consumers (From, C. L., 2016; Min-hee, J., 2016). Vehicles that relished the most customers' confidence were Elantra, Sonata, Sportage and Sorento.

In comparison to the combined Volkswagen's sales, the performance of the Toyota and Hyundai Kia volume passenger vehicles were clearly weaker. Toyota achieved higher sales of passenger automobiles compared to Hyundai Kia on the three markets.

7.5. New Production Method

The manufacture of high-volume passenger automobiles is scheduled mainly for automated assembly. Regarding the number of robots engaged in the production of the volume vehicles of the Volkswagen, Toyota and Hyundai Kia, the research has found out that the three rivals command advanced industrial robots that function in cells developed by robotics companies or by the enterprise itself. The actual number of industrial robots engaged cannot be stated precisely because the deliveries are a matter of private information. The three competitors have established automated assembly lines, body and paint shops, engaging an extensive number of world-renowned robotic intelligence like KUKA, Kawasaki and Fanuc. However, there is a significant difference in the emphasis placed on the level of automation of the automobile's assembly. The automation level of the final assembly is accounted for 80 percent at the Volkswagen Wolfsburg and Puebla plant, for 15 percent on average at Toyota plants and 10 percent at Hyundai manufacturing facility. Hyundai and Volkswagen operate body shops with automation level between 80 and 100 percent. Explicit information on the automation level of the Toyota's body shops is not available. The researchers U. and M. Krzywdzinski describe it as lower compared with the tendency of Volkswagen (Jürgens, U.& Krzywdzinski, M., 2016, p.19). We shall see that there are different automation levels across the companies. Volkswagen and Hyundai Kia are in push toward increased automation and engagement of robotic intelligence. On the other hand, Toyota is more restrained toward future automation. Toyota has defined its strategy with engaging more human labour force and reducing the level of automation. The company devotes its efforts rather to the creation of robots assisting in the household.Toyota has taken the decision not to build further manufacturing facilities.

However, it should be stated that because of the increase of the automation processes Volkswagen developed special vocational training for its employees as their operations require expert's surveillance. According to J. Laker, the success of the Toyota's strategy will depend on its flexibility in the relocation of employees and the investment in their training because in this way the company becomes more dependent on factory professionals (cited in Srinivasan, S., 2012).

Volkswagen has at its command several collaborative robotic arms that are capable of operating with human counterparts and performing precise operations. In comparison, Toyota engages only one collaborative intelligence in the automobile's assembly. There is no indication for Hyundai Kia. The involvement of collaborative robots is seen as the step toward reduction of industrial robots functioning in cells and engaging new movable collaborative artificial intelligence ("Gemeinsam schraubt," 2016). For the realisation of this vision, the manufacturer has to restructure its assembly line and change its conventional production method.

The new production method of Audi, which is being applied in several Volkswagen manufacturing plants as well, the modular assembly has changed the conventional automobile manufacture. Because of the new methods of collaboration (e.g. the virtual reality and connectivity) between engineers across the world, the factory has made the production more flexible regarding the assembly of different variants and the increased individualisation of vehicles. The production process can be controlled from any geographical point which implies that new professionals such as network architects have been integrated and other employees retrained (Hard, A., 2015). Maclaurin suggests that the introduction of

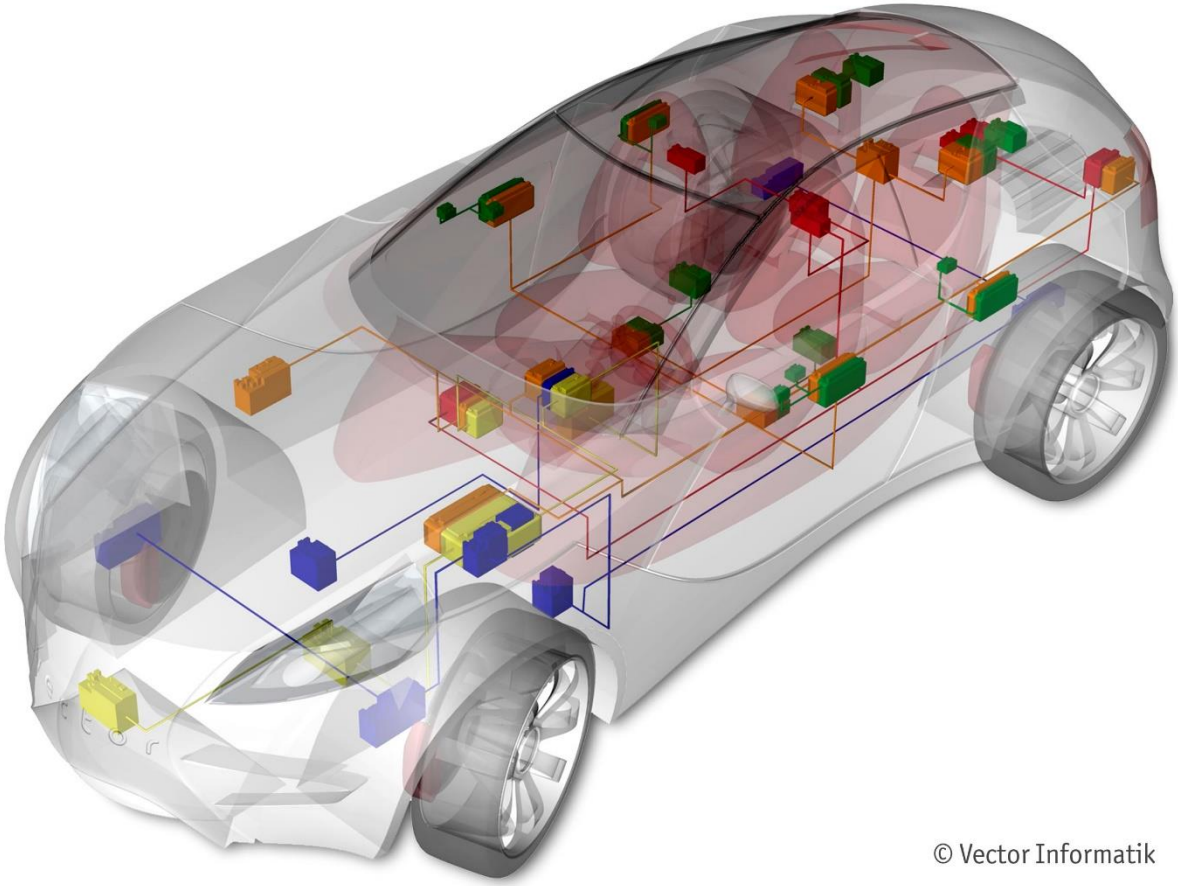
a new method of production of an old product could be more important for an industry than the „commercialization of a new invention“ (Maclaurin, 1953, p. 105).

Hyundai Kia and Toyota stay still reserved to any restructuring of the conventional assembly lines and reorganisation of well-established production practices.

7.6. Maintenance

A special attention should be devoted to the diagnostic equipment or the robots without a body and their significance for the automobile nowadays. We should note that Toyota and Hyundai Kia lack a comprehensive portfolio of diagnostic tools. Comprehensive and homogeneous diagnostic equipment is highly required especially for the interaction with the new automobiles because of the advanced technology and numerous components embedded besides the traditional parts. The presence of electronic components and their complexity have increased noticeably. The older automobiles did not require any specialised software to diagnose their condition as their disassembly was rather simple and the fault could be easily detected. The development of the automobile requires advancement of the diagnostic concepts. In 2002 the underlying software of a volume automobile has accounted for around 10 millions of lines of program code, easy to measure but almost impossible to interpret. Experts claim that the elaboration of comprehensive diagnostic equipment is a substantial challenge in front of every automobile manufacturer. It demands research and efforts in multiple fields. The diagnostic equipment has to be complete and powerful and meanwhile sufficiently individual for every model range. This is so because the path of the fault removal is individual regarding the technical specifications of the automobile. Furthermore, the diagnostic systems have to be compatible with the users‘ abilities. Despite the tendency of standartisation and universalisation of the diagnostic systems, it is rather unlikely that a single tester could perform all the required procedures accurately and not superficially for all the automobiles of an automotive group (Frank, H. & Schmidts, U., 2007).

Image 10 Advancement of the electronic networking in the automobile.



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According to H. Frank and U. Schmidts comprehensive diagnostic equipment and systems "*offer significant potential to automotive OEMs and suppliers for realizing efficiency gains and quality improvement*." (2007, p. 1).

7.8. New Materials

According to the E. Wimmer "*light-weight materials are becoming a central part of the battle for automotive technology*" ("Motoring the Future," 2012). The statement reflects the recent endeavour of the global automobile manufacturers to reduce the weight of their vehicles in order to make them more efficient, reliable and environmentally responsible. Behind this aim the automotive rivals compete in terms of devoloping advanced technology for the application of the new materials, experimenting with the new forms of ferrous and non-ferrous materials, their optimization and embedment in mass-produced automobiles.

Many automotive researchers confirm the promising future of the application of aluminum, magnesium, and MMCs in the automotive manufacturing. However, the employment of aluminum in the body structure of the automobile is considered as a highly innovative approach which only a few companies were able to realise. Small components as screws,

suspension elements, cylinder head covers, etc., do not contribute to the overall reduction of the automobile's weight or to its better collision resistance. The challenge that the key automotive manufacturers face is the successful integration of the lightweight materials in the body structure of the volume automobiles.

Volkswagen has applied aluminum and magnesium to a major component such as the vehicle's frame of a mass-produced automobile (Lupo 3 L) first in 1998. The Passat generation 2014 exhibits the first body structure of a volume automobile where aluminum has been employed. Golf VII demonstrates further refinement and optimisation of the application technology of the new materials, as elements conventionally produced of steel - front bulkheads and the floor panels, have been fashioned from aluminum.

Magnesium is even lighter but more expensive than aluminum. As its structures display serious disadvantages regarding their mechanical properties, specific procedures are needed in order to be applied to a vehicle. Volkswagen has developed techniques to overcome some of its drawbacks and has employed it in the gearbox housing, intake manifold, cylinder head covers (conventionally made of steel or aluminum) of three high-volume automobiles. Furthermore, the company has developed a strategy to start to apply magnesium to the chassis and body structure of the automobile in an era where even the application of aluminum is considered as noticeable innovation.

The Volkswagen division Audi experiments with the application of aluminum since 1994 and carries out extensive research in the sphere of the weight reducing constructions, long before any other automobile manufacturer. The new frame concept of Audi A6 presents the most extensive usage and application of lightweight materials in the body structure of a volume passenger automobile within the Volkswagen Group – 20 percent share of aluminum.

If we refer to Toyota and Hyundai-KIA we shall see that both of the companies do not employ either aluminum or magnesium in the body structures of their volume automobiles. As to aluminum, Toyota applied it to a limited number of cylinder blocks of the Corolla. Hyundai-KIA employs aluminum to more components as the manufacturer created an aluminum engine and focuses its application solely in the power-train area despite the aluminum casting facility at its disposal.

One can see that the body structure and the chassis of the volume passenger automobiles with the emblem of Toyota and Hyundai-KIA remain steel intensive as none of them uses non-ferrous materials.

Within Volkswagen Group 5 automobiles with different technical specifications demonstrate the application of aluminum in their body structure. The integration of non-ferrous materials in the chassis and body structure of the automobiles involves much more reorganization of the vehicle's assembly than just shift from steel and iron to aluminum and magnesium. As it is about high-volume manufacturing, the production method should be reorganised in a way to overcome the cost burden as aluminum and magnesium are still a privilege for high-class automobiles (This is beauty, 2016). Furthermore, the volume production requires alternative joining and spot welding techniques of the lightweight materials according to their characteristics - resistance spot welding, gas shielded arc fusion welding, adhesive bonding, the implementation of laser or friction stir welding, etc. (Powell, H. & Wiemer, K., 1996). The application of the lightweight materials in the body assemblies of high-volume vehicles presents a real challenge in front of the traditional production method, joining techniques

and long established experience in the manufacturing process. It requires further research and relating tests, training of the employees and reorganisation of suppliers network.

The available information on the application of MMCs of the three companies is scarce. Toyota employed successfully MMCs in small elements and devices whose employment improved the quality of the specific components. Volkswagen uses them for disc brakes. However, their employment is still limited. Therefore, the three companies need to concentrate on desirable advancements in the sphere of the metal matrix composites to achieve considerable weight reduction and increase fuel efficiency (Macke, et al., 2012, p. 22). The distinction between the companies can be made in the field of the application of non-ferrous materials.

Because of the successful integration of the new lightweight materials in the body structures and chassis of its volume automobiles, Volkswagen demonstrates a strong upside in the adoption and development of new joining and welding techniques and other requirements needed for the creation of the lightweight structures. The five vehicles are potentially lighter, more reliable, fuel efficient and thus more environmentally friendly. The application of the new materials gives Volkswagen the advantage to benefit from the experience over time. Besides their research or patent applications in the lightweight materials, Toyota and Hyundai-KIA are not able so far to realise an advancement of their production methods in order to make apply lightweight materials to their volume vehicles.

7.9. New Technology

7.9.1. New Drive Technology

The innovative driving technology – the permanent AWD, is on its way to capture the volume passenger vehicles. In this field, the automotive companies struggle with the dilemma to embed the new technology in the mass-produced automobiles without making the automobile too costly within their price range, to keep the affordability as an advantage for the average customer, but in the same time to offer them an improved automobile. We can see that the most purchased compact automobiles like the Golf still demonstrate the Haldex clutch which suggests that the company places the emphasis on its mass-production features.

Volkswagen has integrated the permanent AWD in four (Passat B1, B2, B5, Audi A4, A6 and Q5) of its volume passenger automobiles. Three generations of Passat present a long-term specialisation in the drivetrain upgrade of mass-produced middle-class vehicles. As it comes to Audi, the division has the richest experience with the equipment of standard automobiles with the permanent AWD. The fact that Audi is concentrated on this area for more than 30 years gives the Group an added advantage in terms of specialisation.

In contrast, Toyota and Hyundai Kia did not supply anyone of their volume automobiles with the permanent AWD even their luxury or SUV models. Their FWD is a conventional intermittent FWD. It should be activated by the driver.

The permanent AWD characterises with an advanced control over the vehicle. As not all of the driving conditions are perfect conditions, the AWD improves the behaviour of the automobile on the road. With the engagement of all the wheels the technology enables supplementary points of contact on the road (Callahan, R., 2016). With its introduction, the

vehicles with AWD have become more reliable and safer. The AWD demonstrates better grip not only on snowy and hardly accessible terrains, but also better control by fast acceleration and compensation by speeding up on curves.

With respect to that criterion Toyota and Hyundai Kia's vehicles do not offer a concept of permanent AWD integration in their vehicles. An often described disadvantage of the continuous AWD system is its higher cost (Choksey, J., 2014; DeMuro, D., 2013). Toyota and Hyundai Kia concentrate further on their „aggressive price wars" and logically their mass-produced automobiles are engaged in the front line (Dowling, J., 2016; Hirsch, J., 2010). Therefore, we can assume that Toyota and Hyundai Kia keep distance to the embedment of permanent AWD because of the willingness to maintain the low selling prices of their volume automobiles (Thomson, A., 2016).

7.9.2. New injection technology

Because of the increased production of particulate matter and nitrogen oxides of diesel engines, the master thesis sees in the embracement of turbocharged petrol engine a promising future direction. The three rivals differ in the level of uptaking the new turbocharged technology. We can see that Volkswagen managed to foresee the future and has designed their concept of petrol engine using a turbocharger in 2005, overwhelming the most noticeable drawback of the turbocharging – the unburned fuel through the development of the four/ six fuel bores of the injector that disperse the air-fuel mixture into the cylinder in tiny droplets. The Group made further advancements of the turbocharged engine especially important for volume automobiles in urban areas. The ACT technology deactivates two of the cylinders and thus increases the fuel efficiency and lessens the emissions.

Toyota started to develop a concept of a turbocharged engine in 2015. However, the research found out that the injector possesses only one fuel bore. There is no solution for the residue of the fuel-air mixture.

Hyundai Kia designed three types of engines described as turbocharged. Their new concept designed in 2015 – Kappa engine features an advanced technology of the injector that eliminates the residue of the mixture. Unfortunately, only one passenger automobile the Kia C'eed 2016 has adopted the new turbocharged technology. However, Hyundai-KIA still has very different engines under one roof claiming they all are turbocharged and in reality two of them feature the multi-port fuel injection system which is not a direct injection system.

In the cases of transforming a normally aspired engine in a turbocharged or using the conventional direct injection system where a residue of the air-fuel mixture is still demonstrable, the turbocharged petrol engine would be only a product differentiation of the conventional petrol engine (Oslo Manual, p. 39).

If we refer to the Maclaurin's theory, we can make a parallel between the improved direct injection system without residue and the creation of the lamp without bulb darkening which is considered to be a substantial progress. Improvements of the lamp such as the inside frosting lamp did not change the line of inquiry and exhibited just a slight change that resembles the venture of the turbocharged petrol engine relying on the conventional technology (Maclaurin, 1953, p. 102).

7.10. Integration of ADAS

The advanced driving assistance systems contribute to the escalation of the autonomy of the vehicle's decisions. They are capable of preventing or mitigating a collision assisting the driver and reducing human errors. The ADAS are considered to be the most rapidly growing segment in the automotive sector and their integration one of the most important lines of interest of the automotive companies and therefore a sphere of high competition("ADAS 2017:Overview," 2017). The safety technology is considered to be the most significant area for the automotive science nowadays ("Trends and outlook," 2013, p. 11). The integration of the ADAS was believed to be a privilege for the high-class automobiles as it not only increases the cost of the vehicle but also needs a special technological environment to integrate the complexity of the ADAS features. However, the new tendency in the mass produced automobiles has changed this conventionality. Many of the ADAS has become an optional equipment in the volume vehicles. This trend is projected to grow in the coming years as the European, Japanese and North American market demonstrate distinct demand for them (Leggett, D., 2015).

Furthermore, the integration of ADAS is inevitable, because the most influential driving regulations- the European ECE/EEC and the American FMVSS safety requirements insist that specific range of automobiles should be equipped with ACC, Lane Keeping Assist Systems and Brake Assist ("Trends and outlook," 2013, p. 7). To reply to the tensions regarding those international requirements and the high competition, and to supply their mass automobiles with the new ADAS, the automotive companies face a considerable challenge. The embedment of ADAS in the volume automobiles is more difficult compared to that in a luxury vehicle, because of the complexity of the vast range of sensors and functions that have to be integrated into rather a simpler automobile. The process demands collaboration between the auto manufacturers, software architectures companies, new parts manufacturers. The integration of ADAS requires further investment in the development of electronic control unit platforms (the system that controls the electrical subsystems), navigation technologies, etc. To improve the efficiency in this endeavour the companies put more efforts in the standartisation and modularisation of the components, parts, and sensors (Ibid., p. 8).

The most commonly integrated ADAS in the volume vehicles are ACC, Lane Keeping Assist, Automatic Braking and Park Assist (Leggett, D., 2015).

Regarding Volkswagen we can see that the Passat, Tiguan, Audi A6, Q5, Škoda Octavia and Superb can be designed with all the possible ADAS explored in the thesis. Within this range, there are vehicles from two different modular construction platforms (MQB and MLB). All of them with exception of Superb feature the ACC and the Driver Drowsiness Detection (exception the Tiguan) as standard components. The Passat has at its command since 2014 almost all the ADAS as standard equipment on board. Among the three rivals, Volkswagen grasped at the ACC back in 2007 overtaking the middle-class vehicles of the other two and the started to enhance the range of vehicles featuring ADAS since 2010.

The most purchased automobile in the world – the Corolla features only Automatic Braking and Park Assist. Generally speaking, Toyota did not embrace any ADAS as standard equipment of its volume automobiles. Moreover, there is not a volume passenger automobile of Toyota that can be equipped optionally with all of the ADAS features explored in the master thesis. The compatibility of many of them is still envisaged for vehicles, whose manufacture starts in 2017. The automobiles where the majority of the ADAS have been made optional for, are the Prius and the Lexus ES.

The integration of the ADAS in Toyota volume passenger vehicles is seen as a possible solution of the crisis involving sudden acceleration. The embedment of the new safety technology grew since 2012. However, some Toyota models lack important components as the ACC, Automatic Braking and Blind Spot Detection. No vehicle is equipped with Driver Drowsiness Detection and Bird‘s Eye Perspective.

To the majority of the Hyundai Kia vehicles, ADAS have been integrated all in a breath – in 2015 and 2016. There is not a single automobile offering the Driver Drowsiness Detection. But the Sorento and Optima can be custom-made with one of the latest navigation concepts- Bird’s Eye Perspective. Compared to Toyota there are mass-produced models not supplied with ACC, Park Assist, and Blind Spot Detection. Hyundai Kia is the only one company whose most vehicles do not feature Automatic Braking. Both of the companies envisage increased ADAS embedment in their volume vehicles in 2017. But in terms of the integration period of the most ADAS, Toyota has a precedence over Hyundai.

Most of the automotive companies consider the safety technologies as a key factor for differentiation that will deliver competitive advantage („Trends and outlook,“ 2013, p. 11). A part of the technologies- Drowsiness Detection, Bird’s Eye Perspective and Blind Spot Detection successfully integrated into Volkswagen volume vehicles, did not achieve to be moved from the luxury to the mass-produced segment of Toyota and Hyundai-KIA.

8. Conclusion

Volkswagen, Hyundai Kia and Toyota differ in the integration level of new and advanced technologies into their passenger vehicles. Volkswagen focuses on the cost leadership and sustaining competitive differentiation of its volume vehicles. Multiple factors explain Volkswagen cost leadership: they rely on shared modular construction platforms and standard components to build their automobiles. The Group prioritises both its differentiation strategy and the improvement of the technical specifications of its volume automobiles during the period under review (Or, W., et al., 2015, p. 4). The first, second and third criterion- the R&D spending, the capabilities in research and new plants built demonstrate a noticeable strengthening over time. The company has not only the highest propensity to finance innovation, but also commands the most generous budget of science and its research is highly devoted to the advancement of their automotive concepts. Volkswagen supports vigorously the knowledge transfer between academics and its internal automotive needs.

On the other hand, Toyota and Hyundai Kia show their preferences in the area of the fundamental research and patenting activities. Through the patenting activities we can see that Toyota places an emphasis on the development of alternative drive-train using fuel-cell technologies. The company is ardently preparing to target the electric vehicle segment. It has also aimed its attention to the hydrogen fuel movement and intends to protect its leading position (Cobb, J., 2016).

Toyota pursues a return to a manufacture, which engages more manual labour in order to detect inefficiencies. The company does not offer a new method for production processes despite its large R&D expenditure. Toyota relies heavily on its traditional values at the core of the organisation – kaizen, jidoka, etc. and its concept for "perfection" and social responsibility (Szinkota, M. & Ronkainen, I., p. 538). Therefore, the company invests also in the development of domestic robots, to make the life of society easier- lines of interest that are not connected to the volume automobiles (Guizzo, E. & Ackerman, E., 2015).

Hyundai Kia has also reduced the number of construction platforms after the acquisition of Kia in order to achieve cost leadership. However, the company is rather on its way to find a stable position on the automotive market in Korea. The Korean auto market has been marked by a reconfiguring since 2000 and the restructuring of Hyundai (merging with KIA) is only a part of that process (Cho, S. & Lee, B., p. 10). The company managed during the investigation to double its R&D expenses. It also puts priority on the improvement and extension of technical facilities, subsidiaries and new factories.

In regard to the fourth criterion - annual sales volume of improved products, the master thesis cannot arrive at an unbiased conclusion. The annual sales do not reveal whether the models most purchased take advantage of all the technical specifications which the thesis considers as innovative attributes. Furthermore, it does not disclose whether these advanced technologies remained "homogenous" over time because of the large quantity of possible variations of a single passenger automobile (Maclaurin, 1953, p. 108). Moreover, one can claim that customers highly appreciate the embedment of advanced technologies into vehicles, but there is no reliable indication that their decision-making process is influenced solely by the level of innovation.

The last four criteria – development of comprehensive diagnostic systems, new materials, new drive or injection technology, and integration of ADAS unveil actual physical characteristics of the volume automobiles. The diagnostic equipment of Hyundai Kia and Toyota, applied during the maintenance phase of the automobile, does not demonstrate a development toward a comprehensive and powerful system. Automotive researchers claim that the field of vehicle diagnostics is highly open to innovation and evolution. This in turn would require additional efforts of companies to restructure their collaboration with rivals and suppliers (Frank, H. & Schmidts, U., 2007, p. 3). Toyota Motors and Hyundai Kia remain rather passive in the progress toward the creation of multiple and specialised diagnostic tools within a consistent system.

The resistance to the application of aluminium and light-weight materials for the body structure and chassis of their volume automobiles indicates a reluctance of both

manufacturers to invest in the reorganisation of the production method and the development of alternative joining and spot welding techniques. Furthermore, the cost of aluminium is considered as an impediment that can harm the affordable price of their mass-produced vehicles (Cho, M. & Jin, H., 2014).

The absence of permanent AWD and advanced technology of turbocharged petrol engine in the volume vehicles proves the hesitation of both Toyota and Hyundai Kia to upgrade their mass-market concept. The companies are more willing to maintain the low selling prices as an advantage.

On the one side, the volume vehicles of Hyundai Kia and Toyota remain under the investigation period steel-intensive and with restricted potential for enhanced reliability by fast acceleration, fuel efficiency and environmental responsibility. On the other side, they stand unprepared for the downward migration of advanced driveline concepts and attributes from the high-class vehicles to the mass-produced ones, and not ready to react to the global pressure on the automotive industry in regard to the weight reduction and the decline of diesel engines in mainstream models (Cho, M. & Jin, H., 2014).

Toyota and Hyundai Kia started to embed ADAS into their volume vehicles consistently during the last two years and some components are envisaged for vehicles, whose manufacture begins in 2017. As we can see, the premium volume automobile Lexus ES has had priority in regard to the period of ADAS integration. The Toyota models Corolla and Yaris lack the key safety technology - ACC. The most popular Hyundai model Elantra demonstrates only Automatic Braking which is an additional indication from the company for its reluctance to integrate costly technologies into best- selling mass automobiles. The same holds true for the Corolla. It proves the possibility for integration only of Automatic Braking and Park Assist. Three of the Hyunai Kia volume vehicles (Kia C'eed, Sportage, Sorento) do not feature the automatic emergency braking. There is not a volume automobile of Toyota or Hyundai Kia that can be equipped optionally with all of the ADAS, explored in the master thesis. No ADAS feature has been integrated as standard during the period under observation. Therefore, one can conclude that Toyota and its rival Hyundai Kia did not put an emphasis on the standartisation and modularisation of the components and sensors (that involve ADAS) of their volume vehicles until recently.

According to a research in the automotive industry, the level of integration of the new safety requirements is one of four influential factors, along with fuel efficiency, turbocharged engines and in-vehicle communication systems, for the automobile purchase decision of customers („Steady Demand from Developing," 2015).

The continual insistence on the lower selling prices of their volume segment since 1990, reveals that Hyundai Kia and Toyota do not consider the brand of the mass-produced automobiles as a field, where innovative technical solutions can be embraced, and is still restricted by the boundaries of conventional manufacturing processes and architecture. The progressive technologies are rather embed in their luxury and prototype vehicles which with the exception of Lexus ES are not volume produced. The innovation power within the range of mainstream vehicles of both companies in the period under investigation is limited.

However, there is a signal coming from the swift (and projected) integration of ADAS in the majority of the Toyota and Hyundai Kia's vehicles within the last years, indicating an incipient embrace of innovative solutions into their volume vehicles. We can trace in their future volume models, if Toyota and Hyundai Kia will identify the volume segment as a key field for innovation development. According to Maclaurin large companies, despite their power are not able to develop all fields „with equal vigor" (Maclaurin, 1953, p. 107) . Therefore, they form lines of main interest (Ibid.). The technological advancement and the integration of innovative concepts in their volume automobiles was a line that both companies have tended to neclect over the period under investigation.

In closing, a more profound and explicit investigation is suggested. The concept of the automobile has been refined and upgraded due to its technological advancement. The complexity of its systems and subsystems and their development over time should be atomised and addressed in depth. A separate comparison between every group of similar models (e.g. Toyota Corolla vs. Volkswagen Golf vs. Hyundai Elantra vs. Kia C'eed) may enrich the exploration, adding more factual and individual results for every automobile. The Center of the Automotive Management has identified in 2014 more than 250 novelties and 30 world premieres introduced to the automobile, whose presence can be traced in the different manufacturers ("Ranking list," 2015). The volume of the master thesis cannot respond to the requirements of a comprehensive industry research and to the access to confidential company information or data.

Appendix I List of Abbreviations

ACC	Active (adaptive) Cruise Control
ACT	Active Cylinder Technology
ADAS	Advanced Driver Assistance Systems
AG	Automotive Group
AWD	All Wheel Drive technology
CAM	Center of Automotive Management
DRCC	Dynamic Radar Cruise Control
FWD	Four Wheel Drive technology
MMC	Metal Matrix Composites
SUV	Sport Utility Vehicle
TSI	Twincharged Stratified Injection/ Turbocharged Stratified Injection
VW	Volkswagen AG

Appendix II

Zusammenfassung

Die Thematik der Masterarbeit wurde von der abwechslungsreichen Entwicklung des Kraftfahrzeuges und seiner Rolle in unserem Alltag inspiriert. Dank der Durchführung einzelner Innovationsideen, die seine Massenproduktion ermöglicht haben, hat sich das Fahrzeug von einer Luxusleistung der Reichen in eine Gewohnheit verwandelt, die das Gefühl von Freiheit verheißt.

Die Einführung macht einen Rundgang durch mehrere einflussreiche Wendepunkte in der Evolutionsgeschichte des Personenwagens, die von Bedeutung für die Einsicht seines vielschichtigen Wesens sind. Seine technische Weiterentwicklung weist wellenartiges Muster auf – Zeitspannen gekennzeichnet durch wesentlichen Fortschritt, gefolgt von jahrelangem Stillstand. Die Automobilindustrie bestätigt, dass das Fahrzeug eine neue Ära seiner Laufbahn eingeläutet hat - die Eröffnung der Tür zum autonomen und vernetzten Fahren. Dadurch ist eine neue Phase der Mobilität angebrochen, für die bislang nur die Prototyp- und Hybridfahrzeuge reif gewesen sind. Der Trend der zunehmenden Verbreitung neuer Funktionen und Dienstleistungen hat sogar die Mittelklasse beeinflusst. Die Beantwortung der Forschungsfrage wird die nach unten neigende Übersiedlung innovativer, technischer Lösungen in einem bestimmten Zeitraum darstellen, die bisher als Kennzeichen der Oberklasse angenommen wurden und die auf die Mittel- und Kompaktklasse schrittweise übertragen werden – wie z.B. die Anwendung neuer Leichtbauwerkstoffe auf die Ausfertigung der Karosserie, die Verbesserung der Antriebsart und die Einführung des permanenten Allradantriebs, der die Motorenleistung zu allen vier Rädern übermittelt, und der Einbau innovativer Fahrassistenzsysteme, die die Fahrt sicherer machen. Die Verwirklichung dieser Konzepte ist jedoch durchführbar, wenn die Kernkomponenten des Triebwerkes umgestaltet und nachgerüstet werden. Der empirische Teil der Forschung untersucht diese Umgestaltung und innovative Ausrüstung der Fahrzeuge in Großserie von Toyota Motor Corp. und Hyundai Kia Automotive Group, im Bezug auf die eingeführten in Serienfertigung technischen Neuerungen von Volkswagen AG. Damit man die Innovation bei den Fahrzeugen als ein messbares und bewertbares Konstrukt verarbeiten kann, vertraut sich die Forschung auf die Theorie der technologischen Innovation, elaboriert von dem Wissenschaftler R. Maclaurin.

References

About fuel Injectors & Injector cleaning. (2008). Retrieved January 11, 2017, from Injectortune, http://injectortune.co.uk/About.html#Function

About us. History. (2007). Retrieved January 29, 2017, from Hyundai Motor, http://www.hyundai.co.uk/about-us/think-you-know-hyundai/history

Abuelsamid, S. (2009, November 3). Hyundai opens Indian R&D facility to develop small cars. Retrieved October 11, 2016, from Autoblog, http://www.autoblog.com/2009/11/03/hyundai-opens-indian-randd-facility-to-develop-small-cars/

Ackerman, E. & Guizzo, E. (2015, November 6). Toyota Invests $1 Billion in AI and Robots, Will Open R&D Lab in Silicon Valley. Retrieved January 30, 2017, from IEEE Spectrum, http://spectrum.ieee.org/automaton/robotics/industrial-robots/toyota-to-invest-1-billion-in-ai-and-robotics-rd

Active Cylinder Technology (ACT): Fuel saving cylinder deactivation technology (2016). Retrieved January 11, 2017, from Volkswagen Technology, http://www.volkswagen.co.uk/technology/petrol/active-cylinder-technology-act

ADAS 2017: Overview. (2017). Retrieved January 10, 2017, from Institution of Mechanical Engineers, http://events.imeche.org/ViewEvent?code=CMP6467

Adaptive Cruise Control (ACC), Volkswagen's safe distance technology. (2016). Retrieved January 25, 2017, from Volkswagen, http://www.volkswagen.co.uk/technology/adaptive-cruise-control-acc

Advanced Powertrain Technologies For Greater Efficiency And Driving Dynamics. (2016). Retrieved January 22, 2017, from Hyundai, http://www.hyundai.co.uk/about-us/news-and-events/hyundai-motor-reveals-passion-for-high-performance-with-n-sub-brand-at-frankfurt-motor-show?page=2

Aktuelle CAM-Studien (2016). Retrieved October 25, 2016, from Center of Automotive Management, http://www.auto-institut.de/pm_studien.htm

All conditions are perfect conditions with quattro. (2016). Retrieved December 11, 2016, from Audi, http://www.audi.com.au/au/brand/en/models/r8/r8/technology/quattro_all_wheel_drive.html

All-new seventh generation Volkswagen Golf breaks cover in Berlin. (2012, September 4). Retrieved January 28, 2017, from Volkswagen, http://www.volkswagen.co.uk/about-us/news/425

All New 2015 Kia Sorento/ Adaptive Cruise Control. (2015, June 24). Retrieved January 16, 2017, from Kia, https://www.youtube.com/watch?v=Q4k-YQ-xTY8

All New 2016 Elantra. (2016). Retrieved January 16, 2017, from Hyundai, https://www.youtube.com/watch?v=bS19g7Va6jg

All New Kia Optima - Lane Departure Warning System (LDWS). (2015, December 30). Retrieved January 17, 2017, from Kia Oman, https://www.youtube.com/watch?v=GE71aUUi-Rw

All-New Kia Sportage. (2016). Retrieved January 16, 2017, from Kia, http://www.kia.co.uk/new-cars/range/suvs-4x4-cars/new-sportage/profile.aspx

All Wheel Drive (AWD) transfer mode selection. (2016). Hyundai Santa Fe. Retrieved December 10, 2016, from http://www.hyundaisantafemanual.com/santafe-194-all_wheel_drive_awd_transfer_mode_selection.html

Allen, J. (2014, August 1). How world war One changed the car you drive today. Retrieved June 15, 2016, from https://www.carwow.co.uk/blog/Car-Companies-World-War-One-027

The Aluminium Automotive Manual. (2013). European Aluminium Association. Retrieved December 8, 2016, from http://european-aluminium.eu/media/1543/1_aam_body-structures.pdf

Aluminium-Hybrid-Bauweise. (2016). Retrieved December 6, 2016, from Audi, https://www.audi.de/de/brand/de/neuwagen/layer/technologien/aluminium-hybrid-bauweise.html

Alvis, J. (2006). Developments in the Korean Auto Industry. Retrieved August 30, 2016, from http://www.keia.org/sites/default/files/publications/april%2006.pdf

Always on the road. (2012). Retrieved January 28, 2017, from Audi, http://adsoftheworld.com/media/print/audi_lane_assist

Anandan, T. (2013, June 6). The End of Separation: Man and Robot as Collaborative Coworkers on the Factory Floor. Retrieved November 30, 2016, from Robotics Online, http://www.robotics.org/content-detail.cfm/Industrial-Robotics-Industry-Insights/The-End-of-Separation-Man-and-Robot-as-Collaborative-Coworkers-on-the-Factory-Floor/content_id/4140

Anker, S. (2014, September 4). Auch einen VW und Audi gibt es nicht edler. Retrieved January 20, 2017, from WELT, https://www.welt.de/motor/article131896360/Auch-einen-VW-und-Audi-gibt-es-nicht-edler.html

Annual Report 1999. (2000) Retrieved August 28, 2016, from Volkswagen AG, http://www.volkswagenag.com/content/vwcorp/info_center/de/publications/2000/03/Annual_Report_1999.bin.html/binarystorageitem/file/VW_GB_1999_d.pdf

Annual Report 2000. (2001) Retrieved August 28, 2016, from Volkswagen AG, http://www.volkswagenag.com/content/vwcorp/info_center/de/publications/2001/03/Annual_Report_2000.bin.html/binarystorageitem/file/VW_GB_2000_d.pdf

Annual Report 2005. Retrieved August 29, 2016, from Volkswagen, https://www.vwfsag.de/en/home/investor_relations/geschaeftsberichte/archiv_2002-1997.html

Annual Report 2005 Hyundai Sublime Drive (n.d). Retrieved August 15, 2017, from Hyundai, http://worldwide.hyundai.com/wcm/idc/groups/sggeneralcontent/@hmc/documents/sitecontent/mdaw/mdi2/~edisp/hw026558.pdf

Annual Report 2010: Experience D(r)iversity. (2011). Retrieved August 28, 2016, from Volkswagen AG.

Annual Report 2010 Hyundai Motor Company. (n.d). Retrieved August 29, 2016, from http://worldwide.hyundai.com/wcm/idc/groups/sggeneralcontent/@hmc/documents/sitecontent/mdaw/mdi2/~edisp/hw026553.pdf 2000

Annual Report 2013 Hyundai Motor Company (n.d.). Retrieved October 11, 2016, from Hyundai, http://worldwide.hyundai.com/wcm/idc/groups/sggeneralcontent/@hmc/documents/sitecontent/mdaw/mdg1/~edisp/hw085130.pdf

Annual Report 2012 Hyundai Motor Company. (2016). Retrieved August 20, 2016, from Hyundai Motor Company, http://worldwide.hyundai.com/wcm/idc/groups/sggeneralcontent/@hmc/documents/sitecontent/mdaw/mdcz/~edisp/hw073495.pdf

Annual Report 2002 Kia Motors. (n.d) Retrieved August 29, 2017, from Kia, http://www.kiapressoffice.com/Company/Media/Kia/uploads/annual-reports/Kia%20Annual%20Report%202002.pdf

Anzahl der Patente der 18 globalen Automobilkonzerne 2006/2013-14**. Retrieved October 25, 2017, from Auto-Institut, http://www.auto-institut.de/index_htm_files/patente.png

Area View: Keep an eye on everything from the driver's seat. (2016). Retrieved January 25, 2017, from Volkswagen, http://www.volkswagen.co.uk/technology/proximity-sensing/area-view

Armstrong, J. (2004, August 23). Electronic fuel injection: A history lesson. Retrieved May 31, 2016, from http://www.autonews.com/article/20040823/SUB/408230807/electronic-fuel-injection:-a-history-lesson

Arild, E. (2014, May 9). Audi A6 Avant Test: Der 3.0 TDI darf auf die Bahn. Retrieved January 25, 2017, from http://www.autorild.de/neuwagen-blog/viertuerer/691-der-audi-a6-avant-3-0-tdi-quattro-ist-ein-reisewagen-par-excellence

Artigue, B. (2004, July). Bosch L-Jetronic Fuel Injection Guide: FIAT Fuel Injected Engines. Retrieved January 22, 2017, from https://www.mirafiori.com/faq/fiatFI_may2002.pdf

Assistenzsysteme im Praxis-Check: Skoda geht auf Nummer Sicher. (2016, July 15). Retrieved January 25, 2017, from http://www.auto.de/magazin/assistenzsysteme-im-praxis-check-skoda-geht-auf-nummer-sicher/

Assistenzsysteme im VW Golf VII. (2012, September 6). Retrieved January 20, 2017, from http://www.autokiste.de/psg/1209/10273_2.htm?subid=14

Audi Annual Report 2014: We Create Tomorrow. (2015). Retrieved August 28, 2016, from Audi AG.

Audi A4 (fifth generation). (2016). Retrieved January 29, 2017, from http://www.carjourno.co.uk/a4/

Audi A4 pre sense city. (2016). Retrieved January 25, 2017, from Audi Technology Portal, http://www.audi-technology-portal.de/en/electrics-electronics/driver-assistant-systems/audi-a4-pe-sense-city-en

Audi A6 Zugpferd. (2011, May 19). Retrieved January 15, 2017, from Süddeutsche Zeitung, http://www.sueddeutsche.de/auto/audi-a-avant-zugpferd-1.1099286-13

Audi A3: Design story. (2012, May 8). Retrieved December 8, 2016, from Car Body Design, http://www.carbodydesign.com/2012/05/audi-a3-design-story/

Audi's automobile production from FY 2013 to FY 2015, by model (in units). (2016). Retrieved August 20, 2016, from statista, https://www.statista.com/statistics/267262/automobile-production-of-audi-by-model-since-2009/

Audi side assist. (2011). Retrieved January 28, 2017, from Audi Technology Portal, http://www.audi-technology-portal.de/en/electrics-electronics/driver-assistant-systems/audi-side-assist_en

Audi Smart Factory. (2016, November 17). Retrieved December 9, 2016, from Audi, https://www.audi-mediacenter.com/en/audi-techday-smart-factory-7076

Audi Q3 2.0 TFSI sport-quattro-s-tronic. (2015). Retrieved January 20, 2017, from ADAC, https://www.adac.de/infotestrat/fahrzeugkauf-und-verkauf/neuwagenberater/autokatalog/detail.aspx?mid=243720&bezeichnung=audi-q3-2-0-tfsi-sport-quattro-s-tronic-7-gang

Audi quattro®. (2016). December 11, 2016, from Audi, https://www.audiusa.com/technology/performance/quattro

Audi quattro – the next generation. (2011, December 12). Retrieved December 5, 2016, from http://www.audiworld.com/articles/audi-quattro-the-next-generation/

Auty, C. (n.d.). SEAT Leon FR TDI – Full Test. Retrieved January 28, 2017, from Driving Spirit, http://drivingspirit.com/seat-leon-fr-tdi-2014-full-test/

Automate 2015: New Era of Industrial Robots. Retrieved November 13, 2016, from Robotics Tomorrow, http://www.roboticstomorrow.com/article/2015/04/automate-2015-new-era-of-industrial-robots/5840/

The Automotive Industry Is Entering a New Golden Era of Innovation. (2014, January 13). Retrieved June 5, 2016, from The Boston Consulting Group, http://www.prnewswire.com/news-releases/automotive-industry-is-entering-a-new-golden-era-of-innovation-239861611.html

AutomotiveINNOVATIONS award. (2012, November 21). Retrieved July 15, 2016, from PricewaterhouseCoopers http://www.pwc.de/de/initiativen/automotive-innovations-award.html

AutomotiveINNOVATIONS award 2016: Volkswagen is the most innovative high-volume brand. (2016). Retrieved June 20, 2016, from Volkswagen, https://www.volkswagen-media-services.com/en/detailpage/-/detail/AutomotiveINNOVATIONS-Award-2016-Volkswagen-is-the-most-innovative-high-volume-brand/view/3470435/7227fa995ef711551e7c4741077ed756?p_p_auth=1ULOsevB

AutomotiveINNOVATIONS – Studien (2016). Retrieved October 28, 2016, from Center of Automotive Management, http://www.auto-institut.de/innovations_studien.htm

Automotive News Data Center (2016). Retrieved December 6, 2016, from Automotive News, http://www.autonews.com/section/datalist46

Automotive News Data Center Data Tables and Lists. Retrieved December 15, 2016 from Automotive News Data Center, http://www.autonews.com/section/datalist

Auyang, S. (2004). Leaders who are engineers. In *Engineering—An Endless Frontier* (pp. 256-300). Cambridge: Harvard University Press. Retrieved June 8, 2016, from http://web.a.ebscohost.com.uaccess.univie.ac.at/ehost/ebookviewer/ebook/ZTAwMHhhdF9fMjgyMjY4X19BTg2?sid=8808a99f-caa7-4f95-a1ab-77ce9fa92afd@sessionmgr4006&vid=0&format=EB&lpid=lp_256&rid=0

AWD SYSTEM DISSECTED: AUDI QUATTRO VS. VOLKSWAGEN 4MOTION. (2016). Retrieved December 5, 2016, from You Wheel, http://blogs.youwheel.com/2015/02/25/awd-system-dissected-audi-quattro-vs-volkswagen-4motion/

Ballard Inks US$80M+ Deal With Volkswagen. (2015, February 11). Retrieved August 30, 2016, from Ballard, http://ballard.com/about-ballard/newsroom/news-releases/news02111501.aspx

Bayley, S. (2008). *Cars: Freedom, Style, Sex, Power, Motion, Colour, Everything*. London: Conran Octopus Ltd. Retrieved June 8, 2016, from https://books.google.co.uk/books?id=Ce_4UTP97ZIC&printsec=frontcover#v=onepage&q&f=false

Beginnings of the automobile: The predecessor companies (1886 - 1920). (2016). Retrieved June 20, 2016, from Daimler AG, https://www.daimler.com/company/tradition/company-history/1886-1920.html

Benz patent motor car, the first automobile (1885 – 1886). (2016). Retrieved May 20, 2016, from Daimler AG, https://www.daimler.com/company/tradition/company-history/1885-1886.html

Bernier, C. (2016). Case study: Universal robots in Volkswagen facilities. Retrieved November 29, 2016, from Robotiq, http://blog.robotiq.com/bid/67739/Case-Study-Universal-Robots-in-Volkswagen-Facilities

Blawert, C., Hort, N. & Kainer, K. (2004). Automotive applications of magnesium and its alloys. *Trans indian Inst Met 57*(4), 397–408. Retrieved December 8, 2016, from http://www.igcar.ernet.in/transiim/2004/vol57-4overview2.pdf

Bosch Workshop World (2016). OEM Infos & Downloads. Retrieved November 13, 2016, from Bosch, http://de-ww.bosch-automotive.com/en/euro5_products_workshopworld_1/oem_info_downloads_euro5_ww_1/audi_1/audi_1

Bowler, T. (2015, October 2). Volkswagen: From the Third Reich to emissions scandal. BBC Business. Retrieved May 30, 2016, from http://www.bbc.com/news/business-34358783

Boyle, G. & Mitelka, L. (2008). Making Choices about Hydrogen: Transport Issues for Developing Countries. Paris: United Nations University Press. Retrieved June 29, 2016, from https://books.google.co.uk/books?id=VpeYdv82bNYC&pg=PA195&lpg=PA195&dq=toyota+patents+19

90&source=bl&ots=GNk1KD9xbd&sig=dc0TaZrzblFP0j7D88B_NfGWdy0&hl=en&sa=X&ved=0ahUKEwi0wKj57_3PAhXMXhoKHalnAgEQ6AEIHDAA#v=onepage&q=toyota%20patents%201990&f=false

Brandon, J. (2012, October 15). 10 tech-tastic features inside the new VW golf 7. Retrieved January 28, 2017, from http://www.techradar.com/news/car-tech/10-tech-tastic-features-inside-the-new-vw-golf-7-1103700

Braun, P. (2016, July 19). So, what's the difference between '4-wheel drive' and 'all-wheel drive?'. Retrieved December 5, 2016, from Digital Trends, http://www.digitaltrends.com/cars/whats-the-difference-between-four-wheel-drive-and-all-wheel-drive/2/

Buescher, J. (2011, December 14). The auto industry goes to war. Retrieved January 29, 2017, from teachinghistory, http://teachinghistory.org/history-content/ask-a-historian/24088

Build your Audi. (2016). Retrieved January 26, 2017, from Audi, https://www.audi.co.uk/audi-innovation/advanced-technologies/technologies.html

Burnay, J. (2013, October 9). SEAT Leon review: What's it like to live with? Retrieved January 25, 2017, from http://www.carbuyer.co.uk/news/116181/seat-leon-review-what%E2%80%99s-it-live

Cain, T. (2015, August 5). Automaker Market Share in America - July 2015. Retrieved December 5, 2016, from http://www.thetruthaboutcars.com/2015/08/chart-day-automaker-market-share-america-july-2015/#more-1132857

Cain, T. (2016, June 1). U.S. Auto sales brand-by-brand results: May 2016 YTD. Retrieved December 6, 2016, from Industry, http://www.thetruthaboutcars.com/2016/06/u-s-auto-sales-brand-brand-results-may-2016-ytd/

A Car for Everyone: The New Generation Hyundai i30 Product Information 2016. (2016, September 7). Retrieved January 16, 2017, from Hyundai, http://worldwide.hyundai.com/WW/Corporate/News/News/DF_WW_GLOBALNEWS_160907_2.html?testValue=DF_WW_RD_GLOBALNEWS&title=DF_WW_GLOBALNEWS_160907_2&Row=500&totalRow=500&selx2=

Callahan, R. (2016). The Advantages & Disadvantages of All Wheel Drive. Retrieved January 31, 2017, from http://www.ehow.com/list_6318640_advantages-_amp_-disadvantages-wheel-drive.html

CARNET Research and Innovation. (2016). Retrieved August 30, 2016, from CARNET, http://www.carnetbarcelona.com/

CES 2015: Toyota opens up hydrogen patents. (2015, January 6). Retrieved October 28, 2016, from BBC News, http://www.bbc.com/news/technology-30691393

Chalupová, M., Gärtnerová, V., Trojanová, Z., Jäger, A., Námešný, A., Palček, P., & Lukáč, P. (2004). *Mechanical and fracture properties of an AZ91 Magnesium alloy reinforced by Si and SiC particles. Composites Science and Technology, 69*(13), 2256-2264. http://dx.doi.org/10.1016/j.compscitech.2009.06.016

Changes in R&D Expenditures. Retrieved August 25, 2016, from Toyota, http://www.toyota-global.com/company/history_of_toyota/75years/data/company_information/management_and_finances/finances/r_and_d_expenditures/index.html

Chanlat, J. & Clarke, T. (2009). *European Corporate Governance: Readings and Perspectives*. New York: Routledge. Retrieved November 29, 2016, from https://books.google.co.uk/books?id=GSB9AgAAQBAJ&printsec=frontcover#v=onepage&q&f=false

Chappell, L. (2005, June 13). Hyundai focuses on automation. Retrieved December 3, 2016, from Automotive News, http://www.autonews.com/article/20050613/SUB/506130711/hyundai-focuses-on-automation

Chesterton, A. (2016, September 14). Adaptive cruise control explained. Retrieved January 26, 2017, from http://www.carsguide.com.au/car-advice/adaptive-cruise-control-explained-45905

Chinese English Pinyin Dictionary. (2016). Retrieved June 20, 2016, from https://chinese.yabla.com/chinese-english-pinyin-dictionary.php?define=kia

Cho, J. (2015, September 29). Hyundai-Kia motor group falls behind in patent competition for hydrogen-powered vehicles. Retrieved October 17, 2016, from Business Korea, http://www.businesskorea.co.kr/english/news/industry/8880-patent-competition-hyundai-kia-motor-group-falls-behind-patent-competition

Choi, S., Hansson, F., Kaas, H.-W., & Newman, J. (2016, January). Capturing the advanced driver-assistance systems opportunity. Retrieved January 31, 2017, from McKinsey&Company Automotive & Assembly, http://www.mckinsey.com/industries/automotive-and-assembly/our-insights/capturing-the-advanced-driver-assistance-systems-opportunity

Choi, S., & Lee, B. (n.d.). Merger and Reconfiguring of Hyundai-Kia. Retrieved August 29, 2016, from http://gerpisa.org/rencontre/9.rencontre/S13Lee-Cho.pdf

Choksey, J. (2014, January). AWD Rundown: The Top All-Wheel-Drive Systems. Retrieved January 31, 2017, from Autotrader, http://www.autotrader.com/car-tech/awd-rundown-the-top-all-wheel-drive-systems-219711

Cobb, J. (2016, November 7). Is Toyota thinking twice about fuel cell vehicles? Retrieved January 30, 2017, from Toyota, http://www.hybridcars.com/is-toyota-thinking-twice-about-fuel-cell-vehicles/

Cole, G. & Sherman, A. (1995). Lightweight Materials for Automotive Applications. *MATERIALS CHARACTERIZATION, 35*, 3-9.

Cole, C. (2012, December 17). What's the best all-wheel-drive system for you? Retrieved December 5, 2016, from Auto Guide, http://www.autoguide.com/auto-news/2012/12/whats-the-best-all-wheel-drive-system-for-you.html

Come back petrol, all is forgiven. (2009, August 3). Retrieved December 11, 2016, from Autocar, http://www.autocar.co.uk/opinion/confidential/come-back-petrol-all-forgiven

Company History. (2016). Retrieved December 6, 2016, from Toyota, http://corporatenews.pressroom.toyota.com/corporate/company+history/

Company Profile. (2016). Retrieved October 26, 2016, from Toyota Central R&D Labs., Inc., http://www.tytlabs.com/comp/outline01.html

Corday, R. (2014, September 21). The evolution of assembly lines: A brief history. Retrieved November 30, 2016, from Robohub, http://robohub.org/the-evolution-of-assembly-lines-a-brief-history/

Cromer, G., Foster, C.& Purdy, K.. Automobile. (2016). In *Encyclopædia Britannica*. Retrieved from https://www.britannica.com/technology/automobile/History-of-the-automobile

Crowe, S. (2016, February 16). Top 50 robotics companies of 2016. Retrieved December 1, 2016, from Robotic Trends, http://www.roboticstrends.com/article/top_50_robotics_companies_of_2016

Cummins, K. (2012, June 25). Lightening the load: New materials for automotive. Retrieved August 29, 2016, from https://www.theengineer.co.uk/issues/25-june-2012/lightening-the-load-new-materials-for-automotive/

Dachs, B., Hanzl-Weiss, D., Hunya, G., Kampik, F., Scherngell, T., Zahradnik, G. & Urban, W. (2012). Internationalisation of business investments in R&D and analysis of their economic impact. *European Commission*. Retrieved 25 August 2016, from https://ec.europa.eu/research/innovation-union/pdf/internationalisation_business-rd_final-report.pdf

Davis, M. (2010, October 1). What you need to know about mechanical fuel injection - hot Rod Magazine. Retrieved June 10, 2016, from Hotrod, http://www.hotrod.com/articles/hrdp-1010-what-you-need-to-know-about-mechanical-fuel-injection/

DeBord, M. (2016, October 13). Toyota could be making a big change to its china strategy. Retrieved December 5, 2016, from Business Insider, http://www.businessinsider.de/toyota-market-share-china-2016-10?r=UK&IR=T

Deffree, S. (2016, July 3). Karl Benz drives the first automobile, July 3, 1886. Retrieved January 29, 2017, from http://www.edn.com/electronics-blogs/edn-moments/4376656/Karl-Benz-drives-the-first-automobile--July-3--1886

Delayne Stroud, J. (n/d). Understanding the Purpose and Use of Benchmarking. Retrieved June 29, 2016, from https://www.isixsigma.com/methodology/benchmarking/understanding-purpose-and-use-benchmarking/

DeMuro, D. (2013, June). All-Wheel Drive: Do You Really Need It? Retrieved January 31, 2017, from Autotrader, https://www.autotrader.com/car-tips/all-wheel-drive-do-you-really-need-it-210670

DeMuro, D. (2016, February). 2015 vs. 2016 Toyota RAV4: What's the difference? Retrieved January 30, 2017, from http://www.autotrader.com/car-reviews/2015-vs-2016-toyota-rav4-whats-the-difference-249812

Den Beetle gibt es in 8 Ausstattungsvarianten. (2016). Retrieved January 20, 2017, from Volkswagen, http://www.volkswagen.de/de/models/beetle/ausstattungsvarianten.html

Der geliftete Audi A4 Avant im Fahrbericht. (2011, December 1). Retrieved January 15, 2017, from https://www.heise.de/autos/artikel/Der-geliftete-Audi-A4-Avant-im-Fahrbericht-1387933.html?artikelseite=3

Der Roboter, dein Freund und Helfer. (2016) Retrieved November 26, 2016, from Volkswagen Inside, http://www.industrie-forum.net/de/ncfertigungde/oktober062003/2809104/

Der Polo mit Müdigkeitserkennung. (2016). Retrieved January 22, 2017, from Volkswagen, http://polo.volkswagen.de/

Description A4. (2013) . Retrieved January 19, 2017, from Audi Tech, http://www.auditech.org/acont-917.html

Die Fahrerassistenzsysteme. (2013, June 16). Retrieved January 20, 2017, from Audi, https://www.audi-mediacenter.com/de/start-ins-weltweit-groesste-marktsegment-die-audi-a3-limousine-und-s3-limousine-3249/die-fahrerassistenzsysteme-3350

Difference between a Two Wheel Drive and Four Wheel Drive. (2015, July 3). Retrieved December 11, 2016, from http://theydiffer.com/difference-between-a-two-wheel-drive-and-four-wheel-drive/

Dowling, J., 2016 http://www.news.com.au/technology/innovation/motoring/small-car-price-war-toyota-corolla-tops-sales-in-july-2016-but-hyundai-i30-hatchback-still-leads-the-race-yeartodate/news-story/232eadc54a3da9ed4a5fa50443764574

Driver Assistance. (2016). Retrieved January 25, 2017, from Volkswagen, https://www.vw.com/models/driver-assistance/

Driver assistance systems. (2013, November 6). Retrieved January 29, 2017, from Audi, https://www.audi-mediacenter.com/en/foray-into-the-worlds-largest-market-segment-the-audi-a3-sedan-and-s3-sedan-3249/driver-assistance-systems-3350

Driver assistance systems. (2014, June 11). Retrieved January 20, 2017, from Audi, https://www.audi-mediacenter.com/en/the-audi-q3-a-winner-with-many-new-strengths-2955/driver-assistance-systems-3014

The driver assistance systems and integrated safety. (2015, June 26). Retrieved January 29, 2017, from Audi, https://www.audi-mediacenter.com/en/high-tech-all-the-way-the-new-audi-a4-and-a4-avant-4328/the-driver-assistance-systems-and-integrated-safety-4332

The driver assistance systems from Audi: New concepts for safety, convenience and light. (2011, November 21). Retrieved January 25, 2017, from Audi USA, https://www.audiusa.com/newsroom/news/press-releases/2011/11/driver-assistance-systems-from-audi-new-concepts-safety

Driver Fatigue and Road Accidents. (2016). Retrieved January 22, 2017, from ROSPA, http://www.rospa.com/road-safety/advice/drivers/fatigue/road-accidents/

Dynamic Radar Cruise Control (DRCC). (2016). Retrieved January 31, 2017, from Toyota, http://www.toyota-global.com/innovation/safety_technology/safety_technology/technology_file/active/radar.html

EACH LEXUS MODEL AND ITS FACILITY. Retrieved November 1, 2016, from Lexus, http://www.lexus.com/about/manufacturing

Edwards, D. (2016, March 3). Industrial robots can now do their work uninterrupted thanks to the cloud and offline programming. Retrieved November 29, 2016, from Robotic & Automation News, https://roboticsandautomationnews.com/2016/03/03/industrial-robots-can-now-do-their-work-uninterrupted-thanks-to-the-cloud-and-offline-programming/3143/

Elantra 2017. (2016). Retrieved January 30, 2017, from Hyundai, https://www.hyundaicanada.com/Content/PDF/allnewelantra_en.pdf

Electric Vehicles, Hybrids & IP. (2011). Retrieved October 29, 2016, from Clear View IP, http://www.clearviewip.com/wp-content/uploads/2015/05/ClearViewIP-Electric-Vehicle-IP.pdf

Encyclopædia Britannica (2010). Toyota motor corporation | Japanese corporation. *Encyclopædia Britannica*. Retrieved from https://www.britannica.com/topic/Toyota-Motor-Corporation

ENGINE/ ES 350. (2016). Retrieved December 5, 2016, from Lexus, http://www.lexus.com/models/ES/specifications

Engine of the Year Archiv. (2016). Retrieved January 11, 2017, from International Engine of the Year Awards 2016, http://www.ukipme.com/engineoftheyear/archive.php

Engine Layout. (2016). Kia Sorento. Retrieved December 10, 2016, from https://www.carleasingmadesimple.com/data/kia/sorento/engine-layout/

Engineering Explained: The Pros And Cons Of Turbochargers Vs Superchargers. (2015). Retrieved January 11, 2017, from https://www.carthrottle.com/post/engineering-explained-the-pros-and-cons-of-turbochargers-vs-superchargers/

Engineering Explained: Turbo technology – the differences between petrol and diesel turbos. (2014, November). Retrieved January 11, 2017, from http://www.aet-turbos.co.uk/blog/story/turbo-technology-the-differences-between-petrol-and-diesel-turbos

Enjoy 4MOTION All-Wheel Drive Capabilities on Many 2016 Volkswagen Models. (2015, September 29). Retrieved December 5, 2016, from Douglas Volkswagen, http://www.douglasvw.com/blog/which-volkswagen-models-have-all-wheel-drive/

Enright, A. (2006, October 4). Audi Quattro (1981 - 1990) used car review. Retrieved January 31, 2017, from http://www.rac.co.uk/drive/car-reviews/audi/quattro/207987/

Enright, M. (2016). *Developing China: The Remarkable Impact of Foreign Direct Investment*. Routledge. Retrieved June 26, 2016, from https://books.google.co.uk/books?id=skXUDAAAQBAJ&printsec=frontcover#v=onepage&q&f=false

Employee Status. (2016). Retrieved October 17, 2016, from Hyundai, https://csr.hyundai.com/ta_400_01.do?CSR_LOCALE_PARAM=en

Erste Seat Leon erreichen China. (2012, February 24). Retrieved January 25, 2017, from https://www.auto-medienportal.net/artikel/detail/14404

Esterdahl, T. (2014, December 1). VW data lab opens in Munich, Germany. Retrieved August 28, 2016, from Articles, http://motrolix.com/2014/12/new-vw-data-lab-munich-aims-improve-technology-software-future-products/

Europe Retail Sales. (2016). Retrieved December 6, 2016, from Hyundai, http://worldwide.hyundai.com/WW/Corporate/InvestorRelations/IRActivities/SalesPerformance/EuropeRetailSales/index.html?NextRow=1&selx2=

European New Car Registrations Grew by 9.3% in 2015, with Sales Exceeding 14 million units. Retrieved December 2, 2016, from JATO, http://www.jato.com/european-new-car-registrations-grew-9-3-2015-sales-exceeding-14-million-units/

Evans, A., Mortensen, A. & San Marchi, Ch. (2003). *Metal Matrix Composites in Industry: An Introduction and a Survey*. Springer Science + Business Media New York. Retrieved July 15, 2016, from https://books.google.de/books?id=zlvmBwAAQBAJ&printsec=frontcover&hl=de#v=onepage&q&f=false

Evans, G. (2013, April 5). Volkswagen Tiguan: Secret safety systems. Retrieved January 29, 2017, from http://www.parkers.co.uk/volkswagen/tiguan/estate-2008/long-term-reviews/april---secret-safety-systems/

Export by Region. (2016). Retrieved December 19, 2016, from http://worldwide.hyundai.com/WW/Corporate/InvestorRelations/IRActivities/SalesPerformance/ExportbyRegion/index.html

FACTS ABOUT HMETC. (2016). Retrieved October 11, 2016, from Hyundai, http://www.hmetc.com/facts-about-hmetc/

Fanuc Robot R-2000*i*B series. Retrieved December 1, 2016, from Fanuc America, http://www.fanucamerica.com/cmsmedia/datasheets/R-2000iB%20Series_177.pdf

Fatigue Detection. (2016). Retrieved January 29, 2017, from Škoda, http://www.skoda.com.au/models/hotspotdetail?HotspotName=AU-OCT-fatigue&Page=technology&WebID=309a52a8-ed96-46dd-a5e4-280553817507

Ferrer, A. (2015, May 11). Haldex vs Torsen: Todo lo que tienes que saber, incluidas sus ventajas e inconvenientes. Retrieved January 11, 2017, from https://www.autonocion.com/diferenciales-haldex-vs-torsen/

F&E-Kennzahlen. (2016). Retrieved August 28, 2016, from Volkswagen AG, http://geschaeftsbericht2015.volkswagenag.com/konzernlagebericht/nachhaltige-wertsteigerung/forschung-und-entwicklung/f-e-kennzahlen.html

Financial Statements. (n.d). Retrieved August 25, 2016, from Hyundai http://worldwide.hyundai.com/WW/Corporate/InvestorRelations/FinancialInformation/FinancialStatements/index.html

490 young scientists studying for a PhD in the Volkswagen Group. (2014, October 30). Retrieved August 28, 2016, from Volkswagen, http://media.vw.com/doc/1214/490_young_scientists_studying_for_a_phd_in_the_volkswagen_group-press_relase-585202255452708199da8.pdf

4MOTION. Keeps you safely on track. (2016). Retrieved December 5, 2016, from Volkswagen, http://www.volkswagen.co.uk/technology/transmissions-and-drivetrains/4motion

Fourth consecutive year of sales growth for Toyota Motor Europe in 2014. (2015, January 14). Retrieved December 3, 2016, from Toyota, http://newsroom.toyota.eu/pressrelease/4183//fourth-consecutive-year-sales-growth-toyota-motor-europe

Francis, S. (2016, October 8). Smart factory: Audi opens advanced manufacturing plant in Mexico. Retrieved December 10, 2016, from https://roboticsandautomationnews.com/2016/10/08/smart-factory-audi-opens-advanced-manufacturing-plant-in-mexico/7725/

Frank, H. & Schmidts, U. (2007). Vehicle Diagnostics – The whole Story. *Vector Informatik*. Retrieved January 31, 2017, from https://vector.com/portal/medien/cmc/press/PDG/Diagnostics_Congress_ElektronikAutomotive_200703_PressArticle_EN.pdf

Friedrich, H. & Mordike, B. (2006). *Magnesium Technology: Metallurgy, Design Data, Automotive Application*s. Berlin: Springer Verlag. Retrieved December 8, 2016, from https://books.google.co.uk/books?id=uuQA1cdh78AC&printsec=frontcover#v=onepage&q&f=false

The future of mobility promises to bring comfort, safety and convenience to our lives. (2016). Retrieved October 26, 2016, from Toyota Research Institute, http://www.tri.global/research/

Fujimoto, T. (1999). *The Evolution of a Manufacturing System at Toyota*. New York: Oxford University Press. Retrieved November 29, 2016, from https://books.google.co.uk/books?id=KBm8F9cI8OYC&pg=PA252&lpg=PA252&dq=robot+windshield+toyota&source=bl&ots=Sh_bsKlw7W&sig=YEdpYkBFPxoHeRze05keVeiWx28&hl=en&sa=X&ved=0ahUKEwiCkd-jppLQAhVMVRoKHTlfCt4Q6AEIKjAF#v=onepage&q=robot%20windshield%20toyota&f=false

George, A. (2014, July 28). The Iconic WWI Vehicle That Paved the Way for Modern Cars. Retrieved June 20, 2016, from Wired, http://www.wired.com/2014/07/world-war-one-automobile/#slide-1

Gemeinsam schraubt es sich schneller: KUKA flexFELLOW unterstützt bei Triebsatzvormontage. (2016, September). Retrieved January 30, 2017, from KUKA, https://www.kuka.com/de-de/presse/news/2016/09/vw-setzt-auf-mensch-roboter-kollaboration

German Automotive DNA. (2016). Retrieved August 30, 2016, from Volkswagen Group of America, http://www.vwerl.com/

Geschäftsbericht 1998. Bericht über das fünfte Geschäftsjahr. (n.d). Retrieved October 20, 2016, from Volkswagen, https://www.vwfsag.de/de/home/investor_relations/geschaeftsberichte/archiv_2002-1997.html

Geschäftsbericht 1999. Bericht über das sechste Geschäftsjahr. (n.d). Retrieved October 20, 2016, from Volkswagen, https://www.vwfsag.de/de/home/investor_relations/geschaeftsberichte/archiv_2002-1997.html

Geschäftsbericht 2000. Financial Services AG. Retrieved October 20, 2016, from Volkswagen, https://www.vwfsag.de/de/home/investor_relations/geschaeftsberichte/archiv_2002-1997.html

Geschäftsbericht 2005. Bericht über das zwölfte Geschäftsjahr. (n.d). Retrieved October 20, 2016, from Volkswagen AG.

Ghassemieh, E. (2011). Materials in Automotive Application, State of the Art and Prospects, New Trends and Developments in Automotive Industry, Prof. Marcello Chiaberge (Ed.), *InTech*. Retrieved May 29, 2017, from: http://www.intechopen.com/books/new-trends-and-developments-in-automotiveindustry/materials-in-automotive-application-state-of-the-art-and-prospects

Gibbs, N. (2013, November 1). Closer to the machines. Retrieved November 24, 2016, from Automotive Manufacturing Solutions, http://www.automotivemanufacturingsolutions.com/technology/closer-to-the-machines

Gilfillan, S.C. (1960). An Attempt to Measure the Rise of American Inventing and the Decline of Patenting. *Technology and Culture, 1*(3), 201-214. doi: 10.2307/3101388. Retrieved July 29, 2016, from http://www.jstor.org.uaccess.univie.ac.at/stable/3101388?seq=10#page_scan_tab_contents

Glad, D. (2015, May 21). Turbocharged engine guide - how to install turbo any engine. Retrieved December 11, 2016, from Hotrod, http://www.hotrod.com/articles/ccrp-0907-turbocharged-engine-guide/

Global Car market: New-car Sales 2016-Q1. Retrieved December 2, 2016, from JATO, http://www.jato.com/wp-content/uploads/2016/06/JATO-Global-Car-Sales-2016-Q1.pdf

Global demand for passenger cars reaches new high. (2015). Retrieved August 20, 2016, from Volkswagen, http://annualreport2014.volkswagenag.com/group-management-report/business-development/global-demand.html

Global Diagnostic System (2016). Retrieved December 3, 2016, fromhttp://www.m2kinc.com/pdf/105-brochure.pdf

GLOBAL LIGHT VEHICLE SALES FORECAST. (2016). Retrieved January 11, 2017, from JATO & LMC Automotive, from http://www.lmc-auto.com/services/global-light-vehicle-sales-forecast/

Global networks. Hyundai motor Europe. (2016). Retrieved September 30, 2016, from Hyundai, http://www.hyundai.com/eu/en/Corporate/Network/GlobalNetworks/index.html

Global Plant. (2016). Retrieved November 1, 2016, from Hyundai, http://www.hyundaimotorgroup.com/About-Us/Global-Plant/International.hub

Godin, B. (2008). In the Shadow of Schumpeter: W. Rupert Maclaurin and the Study of Technological Innovation. *Minerva*, *46*, 343–360. doi: 10.1007/s11024-008-9100-4

Godin, B. (2015). Technological Change What do Technology and Change stand for? Retrieved July 29, 2016, from http://www.csiic.ca/wp-content/uploads/2015/12/Paper24_TC.pdf

THE GOLDEN AGE OF TURBOCHARGERS IS UPON US! Retrieved December 11, 2016, from Turbotech, http://www.turbotech.com.au/blog/the-golden-age-of-turbochargers-is-upon-us/

Good Performance In Europe: Hyundai, Kia Reach Highest Market Share in Europe in 1 Year. (2014, September 19). Retrieved December 6, 2016, from Business Korea, http://www.businesskorea.co.kr/english/news/industry/6412-good-performance-europe-hyundai-kia-reach-highest-market-share-europe-1-year

The Grand Challenge. (2005). Retrieved August 28, 2016, from Stanford Racing, https://cs.stanford.edu/group/roadrunner/old/presskit/about_erl.pdf

Greif, S. (1996/1997). Strukturen und Entwicklungen im Patentgeschehen. In *Wissenschaftsforschung, 40*, 97-136. Retrieved August 28, 2016, from http://www.wissenschaftsforschung.de/JB96-97_97-136.pdf

Greimel, H. (2013, October 12). Toyota's high-tech safety push. Retrieved January 26, 2017, from http://www.autonews.com/article/20131012/OEM11/310149961/toyotas-high-tech-safety-push

Greimel, H. (2014, April 10). Toyota unveils new generation of fuel-efficient gasoline engines. Retrieved December 11, 2016, from http://www.autonews.com/article/20140410/COPY01/304109963/toyota-unveils-new-generation-of-fuel-efficient-gasoline-engines

GTS Diagnostic Tools. (2016). Retrieved November 30, 2016, from Toyota, https://www.toyota-tech.eu/GTS/Wizard/step2-intro.aspx

Gudorf, P. (2007). Der Wachstumsmarkt für Robotertechnologie in Japan. In A. Moerke & A. Walke (Eds.), *Japans Zukunftsindustrien*. Berlin: Springer. Retrieved November 29, 2016, from https://books.google.co.uk/books?id=U6EkBAAAQBAJ&pg=PA190&lpg=PA190&dq=automatisierung+toyota+roboter&source=bl&ots=EvLthaXgjc&sig=yVr95VrIPdQoc8ZzZhvJ2ADtlf0&hl=en&sa=X&ved=0a

hUKEwjhz-bWn5LQAhWQhRoKHZuPD-YQ6AEIRjAF#v=onepage&q=automatisierung%20toyota%20roboter&f=false

Guillot, C. (2016, August 2). Toyota's Innovative Manufacturing Facility in Mexico Offers Many Lessons. Retrieved January 27, 2017, from Chief Executive, http://chiefexecutive.net/toyota-build-innovative-manufacturing-facility-mexico/

Hall, B. (2004, October). Patent Data as Indicators. Retrieved July 29, 2016, from http://www.oecd.org/science/inno/33835392.pdf

Hard, A. (2015, May 25). With 3D printing and drone transport, Audi's 'smart factory' is the workshop of the future. Retrieved January 5, 2017, from Cars, http://www.digitaltrends.com/cars/audi-smart-factory-pictures-specs-details-news/

Hård, M. & Knie, A. (2001). The Cultural Dimension of Technology Management: Lessons from the History of the Automobile, *Technology Analysis & Strategic Management*, 13(1), 91-103, DOI: 10.1080/09537320120040464

Harrison, D. (2014, June 10). VOLKSWAGEN GROUP OF AMERICA APPOINTS EWALD GOESSMANN TO LEAD ELECTRONICS RESEARCH LAB. Retrieved August 28, 2016, from Volkswagen, http://media.vw.com/release/771/

Healey, D. (2016, October 11). Revitalising a veteran. Retrieved November 13, 2016, from Automotive Manufacturing Solutions, http://www.automotivemanufacturingsolutions.com/focus/revitalising-a-veteran

Heat dissipation plate for IGBT. (2016). Retrieved December 8, 2016, from Toyota, http://www.toyota-global.com/company/history_of_toyota/75years/data/automotive_business/products_technology/technology_development/materials/details_window.html#supplement08

Henry, I. (2015, February 4). Hyundai-Kia: Moving on up. Retrieved November 18, 2016, from Automotive Manufacturing Solutions, http://www.automotivemanufacturingsolutions.com/focus/moving-on-up

Henry, I. (2015, June 1). Audible progress. Retrieved November 14, 2016, from Automotive Manufacturing Solutions, http://www.automotivemanufacturingsolutions.com/focus/audible-progress

Herwig, J. (2015, January 25). The Volkswagen Group –"Forschungsweltmeister". Retrieved October 20, 2016, from Volkswagen AG.

Hessler, M. (2014). Die Halle 54 bei Volkswagen und die Grenzen der Automatisierung. Retrieved November 23, 2016, from Zeithistorische Forschungen, http://www.zeithistorische-forschungen.de/1-2014/id%3D4996

High-performance SUV with many talents – the updated Audi Q5. Retrieved January 29, 2017, from http://www.conceptcarz.com/z21466/Audi-Q5.aspx

The highway to growth. (2013). *PricewaterhouseCoopers*. Retrieved from https://www.pwc.com/gx/en/automotive/industry-publications-and-thought-leadership/assets/pwc-highway-to-growth-strategies-for-automotive-innovation.pdf

Hirsch, J. (2010, March 25). Honda joins Toyota in price war. Retrieved January 31, 2017, from Tribune Newspapers, http://articles.chicagotribune.com/2010-03-25/news/sc-biz-0326-incentives--20100325_1_toyota-motor-corp-corporate-credit-research-firm-price-war

HISTORIE SCHWARZENBERG (2016). Retrieved November 23, 2016, from KUKA, http://www.kuka-systems.com/de/company/organisation/history_schwarzenberg/

History. (2016). Volkswagen. Retrieved June 29, 2016, from http://www.volkswagenag.com/content/vwcorp/content/de/the_group/history.html

History 2000-2009. (2016). Retrieved December 2, 2016, from Hyundai Heavy Industries CO. LTD., http://www.hhiir.com/EN/company/history.asp?tab_code=4

History of Toyota 1960-1969. Retrieved May 29, 2016, from TOYOTA MOTOR CORPORATION, http://www.toyota-global.com/company/history_of_toyota/1960-1969.html

Hooper, J. (2004, April 24). Leonardo's car brought to life. The Guardian. Retrieved May 29, 2016, from https://www.theguardian.com/world/2004/apr/24/italy.arts

Holt, N. (2009, May 1). Korea's flexible carmakers. Retrieved December 2, 2016, from Automotive Manufacturing Solutions, http://www.automotivemanufacturingsolutions.com/focus/koreas-flexible-carmakers

Hold, N. (2010, March 1). Ultimate flexibility. Retrieved December 2, 2016, from Automotive Manufacturing Solutions, http://www.automotivemanufacturingsolutions.com/focus/ultimate-flexibility

Holt, N. (2015, January 21). T Sarangarajan, Hyundai Chennai. Retrieved December 9, 2016, from Automotive Manufacturing Solutions, http://www.automotivemanufacturingsolutions.com/people/interview-t-sarangarajan-hyundai-chennai

Holloway, J., Hinton, M., & Mayle, D. (1998). WHY BENCHMARK? UNDERSTANDING THE PROCESSES OF BEST PRACTICE BENCHMARKING. *Centre for the Development and Financial Management of Organizations*, 1-3. Retrieved 15 June 2016, from http://www7.open.ac.uk/oubs/research/pdf/WP97_8.pdf

Holweg, M. (2008). The Evolution of Competition in the Automotive Industry. In *Build To Order*, pp. 13-34.

Horrell, P. (2014, March 21). Explained: The VW group's MQB platform. Retrieved December 5, 2016, from Top Gear, http://www.topgear.com/car-news/insider/explained-vw-groups-mqb-platform

How a fuel injection system works. (2016). Retrieved June 20, 2017, from How a Car Works, http://www.howacarworks.com/basics/how-a-fuel-injection-system-works

How do you drive a quattro in snow & ice? (2009). Retrieved January 15, 2017, from Audi-Sport.Net, http://www.audi-sport.net/xf/threads/how-do-you-drive-a-quattro-in-snow-ice.85564/page-2

How does the Toyota RAV4 four-wheel drive system work? (2014, December 9). Retrieved December 5, 2016, from Toyota, http://blog.toyota.co.uk/toyota-rav4-four-wheel-drive-system-work

How Electronic Fuel Injection Works (2016). Retrieved January 22, 2017, from AA1Car, http://www.aa1car.com/library/fuel_injection_basics.htm

How To Use the 360 Camera in 2017 Hyundai Santa Fe Sport Ultimate. (2016, April 13). Retrieved January 18, 2017, from https://www.youtube.com/watch?v=gXlrumDHNiI

HOW TOYOTA USES AUTOMATION TO IMPROVE PROCESSES. Retrieved November 13, 2016, from Robot Worx, https://www.robots.com/articles/viewing/how-toyota-uses-automation-to-improve-processes

Howard, B. (2014, July 2). 2015 Hyundai sonata review: Driver assistance makes this the best midsize sedan made today. Retrieved January 16, 2017, from Extreme, https://www.extremetech.com/extreme/185492-2015-hyundai-sonata-review-driver-assistance-makes-this-the-best-midsize-sedan-made-today

Hunt, D. (1983). *Industrial Robotics Handbook*. New York: Industrial Press Inc. Retrieved July 29, 2016, from https://books.google.co.uk/books?id=fHZTIZ8K-lUC&printsec=frontcover#v=onepage&q&f=false

Hussein, R., & Northwood, D. (2014). Improving the performance of magnesium alloys for automotive application. In *High Performance and Optimum Design of Structures and Materials* (pp. 531-545). Southampton: WIT Press. Retrieved December 10, 2016 from https://books.google.de/books?id=0qZvAwAAQBAJ&printsec=frontcover&hl=de#v=onepage&q&f=false

Hwaseong R&D Center. (2016). Retrieved October 11, 2016, from Hyundai WIA, http://en.hyundai-wia.com/rnd/namyang_institute.asp

Hyundai achieve 'Six million' sales in Europe. (2014, March 25). Retrieved December 6, 2016, from http://www.motoring.co.uk/car-news/hyundai-achieve-six-million-sales-in-europe_62397

Hyundai and Kia Report 10% growth in R&D spending last year. (2015, April 3). Retrieved September 15, 2016, from http://english.hankyung.com/news/apps/news.view?c1=04&nkey=201504031757061

Hyundai - Gamma 1.6 T-GDI Engine. (2013, March 13). Retrieved January 22, 2017, from Hyundai Singapore, https://www.youtube.com/watch?v=0vviID1kxhk

Hyundai Heavy Industries, the world's biggest shipbuilder, today completed a new 4,000-unit capacity industrial robot factory in Ulsan, Korea. Retrieved December 2, 2016, from Hyndai Heavy Industries CO. LTD., http://www.hhiir.com/en/news/report_view.asp?insNo=1285&sGubun=

Hyundai-Kia aims for 10% market share in US. (2007). Retrieved December 6, 2016, from Kia-World, http://www.kia-world.net/hyundai-kia-aims-for-10-market-share-in-us/

Hyundai & Kia Automotive group spent US$2.97 Billion on R&D in 2013. (2014, April 24). Retrieved August 21, 2016, from The Korean Car, http://thekoreancarblog.com/2014/04/24/hyundai-kia-automotive-group-spent-us2-97-billion-on-rd-in-2013/

Hyundai Kia Diagnostic Tools (2016). Retrieved December 3, 2016, from UK Diagnostics, http://www.scantool-direct.co.uk/hyundai-kia-diagnostic-tools.html

Hyundai NGV. (2016). Retrieved October 11, 2016, from Hyundai, http://www.hyundaimotorgroup.com/Affiliates/OTHERS/Hyundai-NGV.hub

Hyundai Motor CIS and the Moscow Polytechnic University announced results of the contest of student engineering projects "New thinking with Hyundai – 2016". (2016, June 7). Retrieved October 11, 2016, from Moscow Polytech, http://mospolytech.ru/news_new.php?id=8786

Hyundai motor group plans to invest $73 billion by 2018. (2015, January 7). Retrieved August 18, 2016, from Automotive News, http://www.autonews.com/article/20150107/OEM01/150109937/hyundai-motor-group-plans-to-invest-$73-billion-by-2018

Hyundai Motor India. (2014, January 6). Retrieved December 2, 2016, from Automotive Manufacturing Solutions, http://www.automotivemanufacturingsolutions.com/focus/hyundai-motor-india

Hyundai Motor Manufacturing Alabama Reaches Production Milestone In Celebration of the 3 Millionth Alabama-Built Hyundai (2015, June 30). Retrieved August 20, 2016, from Hyundai, http://www.hmmausa.com/3-millionth-vehicle/

Hyundai motor to invest 73 bln USD in R&D, production line by 2018 - Xinhua. (2015, January 6). Retrieved September 30, 2016, from Asia & Pacific Edition, http://news.xinhuanet.com/english/2015-01/06/c_133900568.htm

Hyundai Robotics. (2016). Retrieved December 2, 2016, from AA Robotics, http://www.aarobotics.co.uk/ABOUT-US/Hyundai-Robot

Hyundai Sonata 2004-2008. (2016). Retrieved December 9, 2016, from http://www.autoevolution.com/cars/hyundai-sonata-2004.html#aeng_hyundai-sonata-2005-20

Hyung, J. (2010). The Hyundai Way: The Evolution of a Production Model. Global Asia, 5(2), 102-107. Retrieved December 3, 2016, from https://www.globalasia.org/wp-content/uploads/2010/06/343.pdf

Ian, H. (2015, February 4). Hyundai-Kia: Moving on up. Retrieved August 20, 2016, from Focus, http://www.automotivemanufacturingsolutions.com/focus/moving-on-up

IFI CLAIMS Patent Services (2007). Processing of Single-Walled Carbon Nanotube Metal-Matrix Composites Manufactured by an Induction Heating Method. Retrieved June 10, 2016, from https://www.google.com/patents/US20100015002

Im Audi Q3 von Peking nach Schanghai. (2011, October 19). Retrieved January 19, 2017, from Focus, http://www.focus.de/auto/news/das-taegliche-chaos-im-audi-q3-von-peking-nach-schanghai_aid_676068.html

Industrial Research and Innovation (2016). Retrieved August 29, 2017, from European Commission, http://iri.jrc.ec.europa.eu/home

Industrial Robot Statistics (2016). 2015: By far the highest volume ever recorded. Retrieved November 19, 2016, from International Federation of Robotics, http://www.ifr.org/industrial-robots/statistics/

Ingram, A. (2016, February 7). Audi's quattro system explained. Retrieved December 11, 2016, from https://www.carwow.co.uk/guides/glossary/audi-quattro-system-explained

Inspiring safety technology: New ŠKODA Superb with innovative assistance systems for improved safety and comfort. (2015, April 27). Retrieved January 29, 2017, from Škoda, https://media.skoda-auto.com/en/_layouts/Skoda.PRPortal/pressrelease.aspx?ID=827

International Engine of the Year Results. (2016). Retrieved January 11, 2017, from International Engine of the Year Awards 2016, http://www.ukipme.com/engineoftheyear/results.php?id=2

Itasse, S. (2012, November 7). Kuka kann Gewinn verdoppeln. Retrieved November 3, 2016, from Maschinen Markt, http://www.maschinenmarkt.vogel.de/kuka-kann-gewinn-verdoppeln-a-384811/

Jääskeläinen, H. (2013). Variable geometry Turbochargers. Retrieved May 30, 2016, from https://www.dieselnet.com/tech/air_turbo_vgt.php

Janouch, S. (2012, April 5). Bosch-Müdigkeitserkennung auch im VW Passat Alltrack. Retrieved January 20, 2017, from http://www.elektroniknet.de/elektronik-automotive/sonstiges/bosch-muedigkeitserkennung-auch-im-vw-passat-alltrack-87362.html

Japanese Production Sites (2016, March 2). Retrieved November 1, 2016, from Toyota, http://newsroom.toyota.co.jp/en/corporate/companyinformation/manufacturing

Jeschke, S. (2015, Octover 2015). *Robotics in Automobile Industry*. Retrieved November 19, 2016, from http://www.ima-zlw-ifu.rwth-aachen.de/fileadmin/user_upload/INSTITUTSCLUSTER/Publikation_Medien/Vortraege/download//Robotics_automotive_industry_27Oct2015.pdf

Jetta Park Assist. (2013, December 13). Retrieved January 21, 2017, from https://www.youtube.com/watch?v=S6MbDPoWX04

Jidoka. (2016). Retrieved November 30, 2016, from Lean Enterprise Institute, http://www.lean.org/lexicon/jidoka

Jidoka – Toyota Production System guide (2016). Retrieved November 27, 2016, from Toyota, http://blog.toyota.co.uk/jidoka-toyota-production-system

Jin, H. (2016, January 4). Hyundai, Kia see 2016 sales lagging auto industry growth. Retrieved December 6, 2016, from Reuters, http://www.reuters.com/article/us-hyundai-motor-outlook-idUSKBN0UH0RU20160104

Jin, H., & Cho, M. (2014, June 19). As western automakers embrace aluminum, Asia still welded to steel. Retrieved December 9, 2016, from Reuters, http://www.reuters.com/article/us-asia-autos-aluminium-insight-idUSKBN0EU2M120140620

Jin, H., & Lienert, P. (2015, January 19). Hyundai posts biggest gain in global patent filings, report says. Retrieved September 30, 2016, from Automotive News, http://www.autonews.com/article/20150119/OEM06/150119736/hyundai-posts-biggest-gain-in-global-patent-filings-report-says

Johnson, M. (2003, May 7). GW RECEIVES $410, 000 GRANT FROM HYUNDAI-KIA FOR SAFETY RESEARCH LAB. Retrieved October 10, 2016, from Hyundai, http://www.hyundainews.com/us/en/media/pressreleases/28810

Johnson, M. (2012, January 12). HYUNDAI TECHNICAL CENTER INVESTS $15 MILLION AND STIMULATES EMPLOYMENT IN SUPERIOR TOWNSHIP, MICHIGAN. Retrieved October 15, 2016, from Hyundai, http://www.hyundainews.com/us/en/media/pressreleases/35054/hyundai-technical-center-invests-15-million-and-stimulates-employment-in-superior-township-michigan

Johnson, M. (2016). Industrial Catalysis. Retrieved January 11, 2017, from http://resources.schoolscience.co.uk/JohnsonMatthey/page13.htm

Jürgens, U. & Krzywdzinski, M. (2016). *The New Worlds of Work: Varieties of Work in Car Factories in the BRIC Countries*. New York: Oxford University Press. Retrieved January 30, 2017, from https://books.google.co.uk/books?id=-nrnCwAAQBAJ&printsec=frontcover#v=onepage&q&f=false

Kalb, I. (2012, December 28). How Toyota's crisis management failures added to the Billion-Dollar settlement. Retrieved December 28, 2016, from Business Insider, http://www.businessinsider.com/toyota-paying-billions-because-of-marketing-failures-2012-12?IR=T

Kanellos, M. (2011, August 22). Will the car of the future be aluminum? Retrieved December 7, 2016, from https://www.greentechmedia.com/articles/read/will-the-car-of-the-future-be-aluminum

Kelessidis, V. (2000). Benchmarking. *INNOREGIO: dissemination of innovation management and knowledge techniques*. Retrieved 15 June 2016, from http://www.adi.pt/docs/innoregio_benchmarking-en.pdf

Key R&D figures. (2015). Retrieved August 20, 2016, from Volkswagen, http://annualreport2014.volkswagenag.com/group-management-report/sustainable-value-enhancement/research-and-development/key-r-d-figures.html

Keynes, M. (2015, March 9). Full pricing and specification announced for the new ŠKODA Superb. Retrieved January 28, 2017, from Škoda, http://www.skoda.co.uk/news/pricing-and-specification-announced-for-new-superb

Kia enhances cooperation with schools. (2006, October 12). Retrieved October 11, 2016, from Kia, http://eng.kia.sk/news/index.php?news&data_id=184

Kia factory in Slovakia, the home of Sportage, Venga, Cee'd. (2012). Retrieved December 2, 2016, from Kia-World, http://www.kia-world.net/kia-factory-in-slovakia-the-home-of-kia-ceed-sportage-and-venga/

Kia investment in R&D underpins commitment to environmental responsibility. (2016). Retrieved November 1, 2016, from Hyundai, http://www.hyundaimotorgroup.com/MediaCenter/News/Press-Releases/Press-release-1865-2012-0911.hub#.WBcdMC197Dc

Kia Sportage – Smart Park Assist. (2012, March 13). Retrieved January 17, 2017, from Kia, https://www.youtube.com/watch?v=JM9RpH4JWog

Kia´s Smart Park System. (2012, March 13). Retrieved January 17, 2017, from https://www.youtube.com/watch?v=bzi95wKXCzo

Kia Vehicles With Autonomous Emergency Braking – AEB System. (2016). Retrieved January 16, 2017, from Kia-World, http://www.kia-world.net/kia-aeb/

Kim, J. J., & Han, D. S. (2008). Recent Development and Applications of Magnesium Alloys in the Hyundai and Kia Motors Corporation. *Materials Transactions, 49*(5), 894–897. Retrieved December 10, 2016 from https://www.jstage.jst.go.jp/article/matertrans/49/5/49_MC200731/_pdf

Knie, A. & Hård, M. (2001) The Cultural Dimension of Technology Management: Lessons from the History of the Automobile. *Technology Analysis & Strategic Management, 13*(1), 91-103, DOI: 10.1080/09537320120040464 Retrieved from http://dx.doi.org/10.1080/09537320120040464

Knorr, B. (1998). VW History. Retrieved May 20, 2017, from http://people.westminstercollege.edu/staff/bknorr/html/history.htm

Kochan, A. (2005, June 27). Toyota meets, exceeds high standards in Kolin. Retrieved November 30, 2016, from Automotive News, http://www.autonews.com/article/20050627/SUB/506270802/toyota-meets-exceeds-high-standards-in-kolin

Kohlbacher, Florian (2006). Erfolgsmaschine Toyota. Retrieved October 28, 2016, from Japan Markt, https://www.dijtokyo.org/wp-content/uploads/2016/09/Erfolgsmaschine-Toyota_JM092006.pdf

Koopman, P., (2014). A Case Study of Toyota Unintended Acceleration and Software Safety. Retrieved January 11, 2017, from https://users.ece.cmu.edu/~koopman/pubs/koopman14_toyota_ua_slides.pdf

Korosec, K. (2016, April 7). Toyota Expands AI, Robotics Research to Third Facility. Retrieved October 26, 2016, from Fortune, http://fortune.com/2016/04/07/toyota-ai-robotics-cars/

Koster, A., Ahlemann, D., Hirsh, E., & Viereckl, R. (2016, September 27). Connected car report 2016: Opportunities, risk, and turmoil on the road to autonomous vehicles. Retrieved July 29, 2016, from http://www.strategyand.pwc.com/reports/connected-car-2016-study

KR 90 R2900 HIGH ACCURACY. (n.d.). Retrieved December 1, 2016, from KC Robotics, https://www.kcrobotics.com/industrial-robots/kuka/small/kr90-r2900-high-accuracy

Kraebber, S. (2016, January 19). Best Automobiles: Volkswagen Passat. Retrieved December 5, 2016, from http://www.bestautomobilesforus.tk/2016/01/volkswagen-passat.html

Kroh, R. (2011, May 13). Bis Ende dieses Jahres werden wir über 2000 Roboter an VW liefern. Retrieved November 23, 2016, from Maschinen Markt, http://www.maschinenmarkt.vogel.de/bis-ende-dieses-jahres-werden-wir-ueber-2000-roboter-an-vw-liefern-a-315716/

Kruschke, G. (2012, November 7). Kuka erhält Großauftrag von Volkswagen. Retrieved November 26, 2016, from Automobil Produktion, https://www.automobil-produktion.de/hersteller/wirtschaft/kuka-erhaelt-grossauftrag-von-volkswagen-118.html

KUKA flexFELLOW-bolt in der Serienproduktion des VW Golf im Werk Wolfsburg. (2016, August 16). Retrieved November 3, 2016, from Kuka, http://www.flexfellow.de/2016/07/05/kuka-flexfellow-bolt-in-der-serienproduktion-des-vw-golfs-im-werk-wolfsburg/

Kuznets, S. (1971, December 11). Modern Economic Growth: Findings and Reflections. Retrieved July 29, 2016, from Nobel Prizes and Laureates, http://www.nobelprize.org/nobel_prizes/economic-sciences/laureates/1971/kuznets-lecture.html

Lansbury, R., Kwon, S. & Suh, C. (2007). *The Global Korean Motor Industry: The Hyundai Motor Company's Global Strategy*. Oxon: Routledge. Retrieved July 14, 2016, from https://books.google.co.uk/books?id=dZV9AgAAQBAJ&pg=PA79&lpg=PA79&dq=Ulsan+Plant+robots&source=bl&ots=qOI6n5eGYZ&sig=PIxiLtEGpkSPtLG62euuT3zjjVY&hl=en&sa=X&ved=0ahUKEwj184Wx5JnQAhVIcRQKHdN_Ar4Q6AEINzAH#v=onepage&q=Ulsan%20Plant%20robots&f=false

The Latest Advancements in Safety. (2016). Retrieved January 16, 2017, from Hyundai, https://www.hyundaiusa.com/santa-fe/safety.aspx

Lee, B.-H., & Cho, S.-J. (2001). MERGER AND RECONFIGURING OF HYUNDAI-KIA. Retrieved July 16, 2016, from http://gerpisa.org/rencontre/9.rencontre/S13Lee-Cho.pdfHyundai Motor Company Success Story. (n.d.). Retrieved July 16, 2016, from http://successstory.com/companies/hyundai-motor-company

Lee, E. (2012, December 30). Hyundai plans record spending, recruitment. Retrieved August 29, 2016, from Korea Joongang Daily, http://koreajoongangdaily.joins.com/news/article/Article.aspx?aid=2946356

Lee From, C. (2016, September 28).Analysis: Hyundai Kia's lackluster performance in the Chinese auto market. Retrieved December 6, 2016, from Gasgoo.com, http://autonews.gasgoo.com/6/70000329.html

Leggett, D. (2015, October 8). UK: Driver assistance systems seeing 'unprecedented growth'. Retrieved January 10, 2017, from News, http://www.just-auto.com/news/driver-assistance-systems-seeing-unprecedented-growth_id163760.aspx

Leggett, D. (2016, August 30). Diesel share of European car market falling. Retrieved January 11, 2017, from Just Auto, http://www.just-auto.com/analysis/diesel-share-of-european-car-market-falling_id171598.aspx

Lemke, H.. (2013, November). Die Modul-Baukasten-Strategie des Volkswagen-Konzerns im Zusammenspiel mit globalen Systemlieferanten. *Technische Projektleitung*. Retrieved December 5, 2016, from Volkswagen AG, http://www.rkw-bw.de/rde/pdf/RKW-Organisation-2013/Vortrag-Lemke-VW.pdf

Leon Overview. (2016). Retrieved December 5, 2016, from SEAT, http://www.seat.co.uk/new-cars/leon-x-perience/design.html

Leon 2013 - 2017 Tiredness Recognition System. (2016). Retrieved January 29, 2017, from Petch, http://seat-leon.sgpetch.co.uk/pages/accessories/detail/model=450/category=ROOT-safety/accessory=Tiredness+Recognition+System/id=14586

Lexus ES Among Best Selling Luxury Cars in China. (2011, May 19). Retrieved December 5, 2016, from Lexus Enthusiast, https://lexusenthusiast.com/2011/05/19/lexus-es-among-best-selling-luxury-cars-in-china/

Lexus ES Lane Change Assist. (2013, November 29). Retrieved January 20, 2017, from Lexus, https://www.youtube.com/watch?v=Lzy029K_8YY

Lexus ES Lane Departure Alert. (2012, May 13). Retrieved January 20, 2017, from Lexus, https://www.youtube.com/watch?v=ftJURK0QqgQ

Lexus ES350. (2008). Retrieved January 31, 2017, from Car and Drive, http://www.caranddriver.com/reviews/2008-lexus-es350-review-options-and-safety-features-page-2

Lexus Safety System+. (2016). Retrieved January 31, 2017, from Lexus, http://www.lexus.com/models/ES/safety

Lexus Sales Climbing in China. (2016, April 27). Retrieved December 5, 2016, from Lexus Enthusiast, https://lexusenthusiast.com/2016/04/27/lexus-sales-climbing-in-china/

Li, Z., Ding, D., Liu, Q., Ning, C., & Wang, X. (2014). Ni-doped TiO2 nanotubes for wide-range hydrogen sensing. *Nanoscale Res Lett., 9*(1). Retrieved December 11, 2016, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3984682/

LINC(Leaders in Industry/university Cooperation). (2016). Retrieved October 11, 2016, from Kookmin University, http://english.kookmin.ac.kr/site/about_kmu/project/linc.htm

Liu, C., & Ye, T. J. (2011, June). Run-Off-Road Crashes: An On-Scene Perspective. U.S. Department of Transportation, National Highway Traffic Safety Administration. Retrieved January 22, 2017, from https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/811500

Lüttgemann, M. (2015). can we have a little bit less? Retrieved December 6, 2016, from Volkswagen Magazine, http://magazine.volkswagen.co.uk/passat-model-change.html

Macke, A., Rohatgi, P. & Schultz, B. (2012, March). Metal Matrix Composites Offer the Automotive Industry an Opportunity to Reduce Vehicle Weight, Improve Performance. *ADVANCED MATERIALS & PROCESSES*, 19-22. Retrieved December 3, 2016, from http://www.asminternational.org/documents/10192/1902912/amp_17003p19.pdf/84deabbd-eae3-47a8-9c39-c1783d1414f8/AMP17003P19

Madslien, J. (2013, March 7). Hyundai and Kia gain from European crisis. BBC Business. Retrieved from http://www.bbc.com/news/business-21686822

Madslien, J. (2015, November 10). Turbo gives petrol cars a boost as diesel faces backlash. BBC Business. Retrieved from http://www.bbc.com/news/business-34731463

Magna's new AWD system powers 2011 Kia Sportage. (2010, August 20). Retrieved December 10, 2016, from SAE International, http://articles.sae.org/8707/

Manufacturing Plants. (2016). Retrieved November 1, 2016, from Kia, http://www.kiapressoffice.com/Info/10

Manual 2007 Lexus. (2014). Retrieved February 1, 2017, from Car Manuals, https://carmanuals2.com/get/lexus-es350-2007-intuitive-parking-assist-20266

Manual 2010 Lexus. (2014). Retrieved February 1, 2017, from Car Manuals, https://carmanuals2.com/lexus/es350-2010-intuitive-parking-assist-20438

Maclaurin, W. R. (1953, February). The Sequence from Invention to Innovation and its Relation to Economic Growth. *The Quarterly Journal of Economics, 67*(1), 97-111.

Maclaurin, W. R. (1955). Innovation and Capital Formation in Some American Industries. In *Capital Formation and Economic Growth,* 549 – 578*.*

Massey, R. (2015, May 25). Life-saving automatic braking systems to slash insurance claims. *Daily Mail*. Retrieved from http://www.dailymail.co.uk/motoring/article-3095201/Golf-Match-one-latest-VW-cars-fitted-auto-emergency-brakes-said-slash-insurance-claims.html

Metal Trades Committee (1994). Recent developments in the metal trades. *International Labour Organization.* Retrieved November 30, 2016, from https://books.google.co.uk/books?id=y5vUkyFeqzkC&pg=PA19&lpg=PA19&dq=level+automation+at+Toyota+plant&source=bl&ots=xqzJ6OCp8W&sig=61mghmYsc5BMUKxdattAcAVkDwY&hl=en&sa=X&ved=0ahUKEwjGzKD80JbQAhWF0hoKHcMgDPYQ6AEIUjAJ#v=onepage&q=level%20automation%20at%20Toyota%20plant&f=false

Microbatteries –innovative energy. (n.d.). Retrieved August 30, 2016, from http://www.microbattery.com/microbat/tech-habmain/power-one-varta-company.pdf

Miller, W., Zhuang, L., Bottema, J., Wittebrood, A., De Smet, P., Haszler, A., & Vieregge, A. (2000). Recent development in aluminium alloys for the automotive industry. *Materials Science and Engineering*, *A280*, 37-49.

Min-hee, J., 2016 http://businesskorea.co.kr/english/news/industry/13965-poor-sales-china-hyundai-kia-motor-group-sees-car-sales-china-plunge-21-jan

Miracle, D. (2005). Metal matrix composites – From science to technological significance. *Composites Science and Technology*, *65*, 2526-2540. Retrieved July 15, 2016, from http://opac.vimaru.edu.vn/edata/E-Journal/2005/Composite%20science%20and%20technology/Vol65is15-16/bai%2021.pdf

Mission & Role. (2016). Retrieved October 11, 2016, from Hyundai Venture Plaza, http://venture.hyundai.com/En/Introduction/Foundation.aspx

Mobility And Transport, Road Safety. (2016). Retrieved January 26, 2017, from European Commission, http://ec.europa.eu/transport/road_safety/specialist/knowledge/pedestrians/crash_characteristics_where_and_how/data_considerations_en

Model Overview: Driver Information System (DIS). (2016). Retrieved January 29, 2017, from Audi, http://www.uk.audi.com/uk/web/en/models/q3/q3.mediathek_infolayer.MMFA9Q7.html

Model range. Discover our 4x4 cars. (2016). Retrieved December 5, 2016, from Toyota, https://www.toyota.co.uk/car-categories/4x4-cars.json

Moldaschl, M. (2010, July). Why Innovation Theories Make no Sense. *Papers and Preprints of the Department of Innovation Research and Sustainable Resource Management, 9*.

Monthly and annual sales figures for Audi in China. (2016). Retrieved December 11, 2016, from Carsalesbase, http://carsalesbase.com/china-car-sales-data/audi/audi-a6l/

Monthly and annual sales figures for Audi in Europe. (2016). Retrieved December 11, 2016, from Carsalesbase, http://carsalesbase.com/european-car-sales-data/audi/audi-a6/

Monthly and annual sales figures for Audi in the US. (2016). Retrieved December 11, 2016, from Carsalesbase, http://carsalesbase.com/us-car-sales-data/audi/audi-a6/

Monthly and annual sales figures for Hyundai in Europe. (2016). Retrieved December 11, 2016, from Carsalesbase, http://carsalesbase.com/european-car-sales-data/hyundai/

Monthly and annual sales figures for Hyundai in China. (2016). Retrieved December 11, 2016, from Carsalesbase, http://carsalesbase.com/china-car-sales-data/hyundai/

Monthly and annual sales figures for Hyundai in the US. (2016). Retrieved December 11, 2016, from Carsalesbase, http://carsalesbase.com/us-car-sales-data/hyundai/

Monthly and annual sales figures for Kia in China. (2016). Retrieved December 11, 2016, from Carsalesbase, http://carsalesbase.com/china-car-sales-data/kia/

Monthly and annual sales figures for Kia in Europe. (2016). Retrieved December 11, 2016, from Carsalesbase, http://carsalesbase.com/european-car-sales-data/kia/

Monthly and annual sales figures for Kia in the US. (2016). Retrieved December 11, 2016, from Carsalesbase, http://carsalesbase.com/us-car-sales-data/kia/

Monthly and annual sales figures for SEAT in Europe. (2016). Retrieved December 11, 2016, from Carsalesbase, http://carsalesbase.com/european-car-sales-data/seat/

Monthly and annual sales figures for Skoda in China. (2016). Retrieved December 11, 2016, from Carsalesbase, http://carsalesbase.com/china-car-sales-data/skoda/

Monthly and annual sales figures for Skoda in Europe. (2016). Retrieved December 11, 2016, from Carsalesbase, http://carsalesbase.com/european-car-sales-data/skoda/

Monthly and annual sales figures for Toyota in China. (2016). Retrieved December 11, 2016, from Carsalesbase, http://carsalesbase.com/china-car-sales-data/toyota/

Monthly and annual sales figures for Toyota in Europe. (2016). Retrieved December 11, 2016, from Carsalesbase, http://carsalesbase.com/european-car-sales-data/toyota/

Monthly and annual sales figures for Toyota in the US. (2016). Retrieved December 11, 2016, from Carsalesbase, http://carsalesbase.com/us-car-sales-data/toyota/

Monthly and annual sales figures for Volkswagen in China. (2016). Retrieved December 11, 2016, from Carsalesbase, http://carsalesbase.com/china-car-sales-data/volkswagen/volkswagen-passat/

Monthly and annual sales figures for Volkswagen in Europe. (2016). Retrieved December 11, 2016, from Carsalesbase, http://carsalesbase.com/european-car-sales-data/volkswagen/volkswagen-passat/

Monthly and annual sales figures for Volkswagen in the US. (2016). Retrieved December 11, 2016, from Carsalesbase, http://carsalesbase.com/us-car-sales-data/volkswagen/volkswagen-passat/

Moody, S. (2016, May 16). Volkswagen clings on to top sales spot in Europe. Retrieved December 4, 2016, from http://www.carmagazine.co.uk/car-news/industry-news/volkswagen/volkswagen-clings-on-to-top-sales-spot-in-europe/

Moon, H., (2016). *The Strategy for Korea's Economic Success*. New York: Oxford University Press. Retrieved July 11, 2016, from https://books.google.co.uk/books?id=Vy_cCwAAQBAJ&printsec=frontcover#v=onepage&q&f=false

Morgan, T. (2014, July 1). Seat Leon SC FR 2.0 TDi (2014) technology and in-car entertainment review. Retrieved January 28, 2017, from http://www.expertreviews.co.uk/cars/1401858/seat-leon-sc-fr-20-tdi-2014-technology-and-in-car-entertainment-review

Motomachi Plant. (2016). Retrieved November 27, 2016, from Toyota, http://www.toyota-global.com/company/history_of_toyota/75years/data/automotive_business/production/production/japan/general_status/motomachi.html

Mounting for RAV4. (2016). Retrieved December 5, 2016, from Toyota, http://toyota-general.epc-data.com/rav4/aca21r/4440/engine/1107/12372A/

MQB Technology. (2016). Modular Transverse Matrix. Retrieved December 5, 2016, from Volkswagen, http://www.volkswagen.co.uk/technology/modular-transverse-matrix-mqb

Multimaterial Space Frame. (2016). Retrieved December 6, 2016, from Audi, http://www.audi-technology-portal.de/en/body/steel-bodies/multimaterial-space-frame_en

Murphy, A. (2015, September 10). The Largest Auto Companies in The World 2015. *Forbes*. Retrieved from http://www.forbes.com/pictures/eggh45eiki/9-hyundai-motor/#1e5d73bb2ba7

Naing, C., Hill, J., Thomson, R., Fagerlind, H., Kelkka, M., Klootwijk, C., … Bisson, O. (2008). Single Vehicle Collisions in Europe: Analysis Using Real World and Crash Test Data. *International Journal of Crash-worthiness, 13*(2), 219–229.

Namyang R&D center. (2016). Retrieved October 11, 2016, from Kia Motors Corporation, http://www.hyundaimotorgroup.com/MediaCenter/Library/11649.hub

Neuer Audi A3 2012: Active Lane Assist. (2012, March 9). Retrieved January 15, 2017, from https://www.youtube.com/watch?v=dBgB8QbjwLA

Neuer ŠKODA Fabia erzielt Bestwertung von fünf Sternen im Euro NCAP Crashtest. (2014, November 5). Retrieved January 20, 2017, from https://autoskauftmanbeikoch.de/skoda-fabia-ncap/

Neumann, H. (2015, October). Gute Arbeit in der Fabrik 4.0 –Der Weg von Volkswagen. In *Future Tracks*, pp. 8-11. Retrieved November 3, 2016, from Volkswagen, http://files.messe.de/299/media/02informationenfuerbesucher/robotationacademy_2/150414_future_tracks/sonstiges/VWAG_FutureTracks_Konferenz_April_2015.pdf

New Kia cee'd - Lane Departure Warning System. (2012, May 31). Retrieved January 16, 2017, from Kia, https://www.youtube.com/watch?v=Pf3egBsmit8

New Safety Pack option for Prius including Adaptive Cruise Control (2010, July 16). Retrieved January 30, 2017, from Toyota, http://blog.toyota.co.uk/new-safety-pack-option-for-prius-including-adaptive-cruise-control

New Santa Fe. (2016, April). Retrieved December 10, 2016, from Hyundai, www.hyundai.co.uk/models/santa_fe-2012/brochures/santa_fe_0416.pdf

New Santa Fe: Safety, comfort and convenience. (2015, September 15). Retrieved January 16, 2017, from Hyundai, https://www.hyundai.news/eu/models/new-santa-fe-safety-comfort-and-convenience/

New Toyota 1.2T engine in detail. (2015, March 2). Retrieved December 10, 2016, from Toyota, http://blog.toyota.co.uk/new-toyota-1-2t-engine

News Release - Magna Expands All-Wheel-Drive Leadership by Supplying Dynamax on New Kia Sorento. (2015, May 19). Retrieved December 10, 2016, from MAGNA, http://www.magna.com/mobile/news/2015/05/19/news-release---magna-expands-all-wheel-drive-leadership-by-supplying-dynamax-on-new-kia-sorento

Newton, B. (2015, November 26). Toyota's Australian tech centre to close. Retrieved September 26, 2016, from Motoring, http://www.motoring.com.au/toyotas-australian-tech-centre-to-close-54663/

Number of Vehicles Produced in Japan by Model. Retrieved September 20, 2016, from TOYOTA MOTOR CORPORATION http://www.toyota-global.com/company/profile/figures/production_en.html

1.2T direct injection. (2015, June 26). Retrieved January 11, 2017, from Toyota Europe, https://www.youtube.com/watch?v=GR-k5UbHI8o

Or, W., Xiang Hu, Q., Zhao, M. & Zhang, T. (2015, March 18). STRATEGIC ANALYSIS FOR: Volkswagen. Retrieved February 3, 2017, from http://www.sfu.ca/~sheppard/478/syn/1151/Group_E.pdf

Oslo Manual The Measurement of Scientific and Technological Activities: Guidelines for Collecting and Interpreting Technological Innovation Data. *OECD*. Retrieved May 19, 2016, from https://www.oecd.org/sti/inno/2367580.pdf

Our History (2016). Retrieved August 20, 2016, from Kia, http://www.kmmgusa.com/about-kmmg/our-history/

Pander, J. (2012, August 22). VW golf VII: Es ist ein auto! Retrieved January 31, 2017, from SPIEGEL, http://www.spiegel.de/auto/aktuell/neuer-vw-golf-volkswagen-praesentiert-den-golf-vii-a-851264.html

Pare, M. (2010, February 26). Installation begins of VW body shop robots. Retrieved December 1, 2016, from Times Free Press, http://www.timesfreepress.com/news/volkswagen/story/2010/feb/26/installation-begins-of-vw-body-shop-robots/7393/

Park, Y., & Lee, H. (1997). Korea: Recent Development and Policy Options. In T. Kochan, R. Lansbury, & J. P. Macduffie (Eds.), *After Lean Production: Evolving Employment Practices in the World Auto Industry*. (pp. 273–303). New York: Cornell University Press.https://books.google.co.uk/books?id=D758A49TcWQC&printsec=frontcover#v=onepage&q&f=false

Parking Aids. (2016). Retrieved January 31, 2017, from Toyota, https://www.toyota.co.uk/world-of-toyota/stories-news-events/parking-aids.json

Parrot, V. (2013, August 29). 2014 Volkswagen Passat to set new safety standards. Retrieved January 26, 2017, from http://www.whatcar.com/news/2014-volkswagen-passat-set-new-safety-standards/

Partner Robot Family. (2016). Retrieved November 30, 2016, from Toyota, http://www.toyota-global.com/innovation/partner_robot/family_2.html

Partner Robot. History. Retrieved November 23, 2016, from http://www.toyota-global.com/innovation/partner_robot/history.html

Passenger Car Deliveries Worldwide. (2015). Retrieved December 15, 2016, from http://annualreport2015.volkswagenag.com/group-management-report/business-development/deliveries.html

Passenger Cars World. (2016, June 1). Retrieved December 4, 2016, from ACEA, http://www.acea.be/statistics/article/world-passenger-car-production

Patente der Automobilhersteller. (2015, July 31). Retrieved October 22, 2016, from Die Welt, https://www.welt.de/motor/news/article144664614/Patente-der-Automobilhersteller.html

Pathway to Driverless Cars: Proposals to support advanced driver assistance systems and automated vehicle technologies. (2016, July). *Centre for Connected and Autonomous Vehicles*. Retrieved January 22, 2017, from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/536365/driverless-cars-proposals-for-adas-and_avts.pdf

Paukert, C. (2015, September 21). 2017 Audi A4. Retrieved January 30, 2017, from https://www.cnet.com/roadshow/auto/2017-audi-a4/preview/

Perry, J. (2014, September 18). VW Anchieta: Production pioneer. Retrieved November 13, 2016, from Automotive Manufacturing Solutions, http://www.automotivemanufacturingsolutions.com/focus/vw-anchieta-production-pioneer

Perry, J. (2016, October 12). Kia's brave new world. Retrieved December 2, 2016, from Automotive Manufacturing Solutions, http://www.automotivemanufacturingsolutions.com/focus/brave-new-world

Personalising your Audi Q3. (2016). Retrieved January 28, 2017, from Audi, https://www.audi.co.uk/content/dam/audi/production/PDF/PriceAndSpecGuides/q3.pdf

Pfeil, C. (2015, November 2). Der neue Audi A4 – Ein fahrendes Hindernis? – FAHRERASSISTENZSYSTEME IM TEST. Retrieved January 25, 2017, from http://imaedia.de/2015-audi-a4-fahrerassistenzsysteme-im-test/

Philip, L. (2015, December 1). Robots at the wheel: Machines increasingly replacing manual workers in auto plants in India. Retrieved December 2, 2016, from The Economic Times, http://articles.economictimes.indiatimes.com/2015-12-01/news/68688197_1_body-shop-car-plants-auto-plants

Pioneers in the industrial robots sector. (2016). KUKA Robotics. Retrieved November 23, 2016, from KUKA, http://www.kuka-robotics.com/germany/en/company/group/milestones/1956.htm

Pocketbook 2015/16. (2016). EUROPEAN VEHICLE MARKET STATISTICS. Retrieved December 3, 2016, from http://www.theicct.org/sites/default/files/publications/ICCT_EU-pocketbook_2015.pdf

Polo Park Assist. (2014). Retrieved January 22, 2017, from https://vimeo.com/92272157

Ponticel. P. (2003, April). Automation: a tool, not an end. Retrieved November 29, 2016, from Toyodagosei, http://www.toyodagosei.com/company/media/media_coverage/articles/aei_april_2003.pdf

Pope, A. (1993). The Iliad. Book XVIII. The grief of Achilles, and new Armour made him by Vulcan, 440-445. Retrieved June 29, 2016, from http://www.bartleby.com/203/185.html

Popely, R. (2016, August 24). 2017 Lexus ES: What's changed. . Retrieved January 31, 2017, from https://www.cars.com/articles/2017-lexus-es-whats-changed-1420690155165/

Portrait & Production Plants. (2016). Retrieved November 1, 2016, from Volkswagen, http://www.volkswagenag.com/content/vwcorp/content/en/the_group/production_plants.html

Poucke, J. & James, A. (2006). Long Glass Fiber Polypropylene Technology for Automotive Applications. *Society of Plastics Engineers Automotive Division*. Retrieved December 10, 2016 from http://speautomotive.com/SPEA_CD/SPEA2006/PDF/b/b1.pdf

Powell, H. & Wiemer, K. (1996). Joining technology for high volume manufacturing of lightweight vehicle structures. Retrieved January 25, 2017, from TWI, http://www.twi-global.com/technical-knowledge/published-papers/joining-technology-for-high-volume-manufacturing-of-lightweight-vehicle-structures-1996/

Pratt, G. (2016, April 7). On the Road to Autonomous Driving, Toyota Establishes Ever Deeper Roots in Ann Arbor Tech Community with Third US Research Facility. Retrieved October 22, 2016, from Toyota, http://pressroom.toyota.com/releases/toyota-research-institute-ann-arbor-facility.htm

Pratte, D. (2009, May 20). A look at twin scroll turbo system design - divide and conquer? Retrieved January 22, 2017, from Engine, http://www.superstreetonline.com/how-to/engine/modp-0906-twin-scroll-turbo-system-design/

Pries, L. (2016). Accelerating from a multinational to a transnational carmaker: The Volkswagen consortium in the 1990s. In M. Freyssenet, K. Shimizu, & G. Volpato (Eds.), *Globalization or Regionalization of the European Car Industry?* (pp. 51–72). Palgrave Macmillan. Retrieved November 11, 2016, from Research Gate, https://www.researchgate.net/publication/305755446_Volkswagen_in_the_1990s_Accelerating_from_a_Multinational_to_a_Transnational_Automobile_Company

Prius v How-To: Brake Assist. (2012). Retrieved February 1, 2017, from Toyota, https://www.youtube.com/watch?v=B287IOxrdxg

Prius How-To: Lane Keep Assist (LKA) Lane Departure Control/ 2010 Prius. (2009). Retrieved February 1, 2017, from Toyota, https://www.youtube.com/watch?v=bB5nuy-1Eiw

Product Creation Part 2. (2016). Retrieved December 6, 2016, from Volkswagen, http://en.volkswagen.com/en/company/responsibility/recycling/product_creation/product_creation_part_2.html#none

Production fit for the future - the Audi smart factory - Audi MediaTV. (2017). Retrieved January 10, 2017, from Audi, https://www.audi-mediacenter.com/en/audimediatv/video/production-fit-for-the-future-the-audi-smart-factory-2115

Project IONIQ lab to drive future mobility innovation. (2016, July 22). Retrieved October 10, 2016, from Hyundai, https://www.hyundai.news/eu/brand/project-ioniq-lab-to-drive-future-mobility-innovation/

Produktion. (2015, July 22). Retrieved December 9, 2016, from Audi, https://www.audi-mediacenter.com/de/fotos/album/produktion-227

Q5 Assistenzpaket Parken. (2016). Retrieved January 25, 2017, from Audi, https://www.audi.de/de/brand/de/neuwagen/q5/q5.mediathek_infolayer.GPCFPCF.html

quattro®. (2016). Retrieved December 11, 2016, from Audi, http://www.audi.com/en/innovation/quattro/quattro_ultra.html

quattro® Crown Gear. (2016). Retrieved December 5, 2016, from Audi, http://www.audi.ie/ie/web/en/models/layer/technology/quattro/quattro-with-crown-gear-differential.html

Ramesh, M. (2008, May 3). Brand perception – Hyundai's main worry. Retrieved December 2, 2016, from The Hindu Business Line, http://www.thehindubusinessline.com/todays-paper/tp-marketing/brand-perception-hyundais-main-worry/article1623239.ece

Ramsey, J. (2015, March 30). Toyota, Lexus will offer low-cost automated braking system. Retrieved February 2, 2017, from http://www.autoblog.com/2015/03/30/toyota-lexus-offer-low-cost-

Ranking list of the ten most innovative automobile brands. (2015). Retrieved January 30, 2017, from CAM, http://www.auto-institute.com/index_htm_files/AI15_Brands.png

Ravenhill, J. (2001, June 4). From National Champions to Global Partnerships: The Korean Auto Industry, Financial Crisis and Globalization. *MIT Japan Program*. Retrieved June 29, 2016, from https://dspace.mit.edu/bitstream/handle/1721.1/16569/JP-WP-01-04-52137339.pdf?sequence=1

Read, R. (2015, November 10). 2013-2015 Toyota Avalon, Avalon hybrid, Lexus ES300h, ES350 recalled to fix auto-braking problem. Retrieved February 1, 2017, from http://www.thecarconnection.com/news/1100862_2013-2015-toyota-avalon-avalon-hybrid-lexus-es300h-es350-recalled-to-fix-auto-braking-problem

Record Sales For Lexus Europe In The First Quarter Of 2016. (2016, April 11). Retrieved December 5, 2016, from Japan Bullet, http://www.japanbullet.com/auto-moto/record-sales-for-lexus-europe-in-the-first-quarter-of-2016

Redden, E. (2016, July 26). Why are some countries better at science and technology? Retrieved August 20, 2016, from https://www.insidehighered.com/news/2016/07/26/why-are-some-countries-better-science-and-technology

Regan, J. (2012, April). Volkswagen unveil the next MQB vehicle – golf VII. Part 1. Retrieved December 8, 2016, from Auto Industry Insider, http://www.autoindustryinsider.com/?p=5289

Rendell, J. (2014, May 22). First details and sketches of new Volkswagen Passat revealed. Retrieved December 6, 2016, from Autocar, http://www.autocar.co.uk/car-news/paris-motor-show/first-details-and-sketches-new-volkswagen-passat-revealed

Research and Development Bases. (2016). Retrieved October 26, 2016, from Toyota, http://www.toyota-global.com/company/history_of_toyota/75years/data/automotive_business/products_technology/research/bases/index.html

R&D is an investment, not an expense – how capitalizing R&D impacts understanding corporate profitability - Valens research. (2016, September 20). Retrieved November 29, 2016, from Valens Research, http://www.valens-research.com/rd-investment-not-expense-capitalizing-rd-impacts-understanding-corporate-profitability/

R&D spending by Hyundai, Kia gains 10 pct in 2014. (2015, April 4). Retrieved August 29, 2016, from http://english.yonhapnews.co.kr/news/2015/04/01/0200000000AEN20150401008700320.html

Research Fundamental Technologies (2016). Retrieved October 26, 2016, from Toyota Central R&D Labs., Inc., http://www.tytlabs.com/tech/tec4.html

Research Partnerships. (2016). Retrieved August 28, 2016, from Volkswagen Group of America, http://update.vw.com/innovation/research_partnerships.htm

Robarts, S. (2015, November 26). Volkswagen rolls out 3D smartglasses to factory workers. Retrieved December 10, 2016, from New Atlas, http://newatlas.com/volkswagen-wolfsburg-3d-smartglasses/40547/

Robots Rising in India Factories. (2015, June 5). Retrieved December 2, 2016, from Financial Tribune, https://financialtribune.com/articles/world-economy/18360/robots-rising-in-india-factories

Rohatgi, P. K., Gupta, N., & Daoud, A. (2008). Synthesis and Processing of Cast Metal-Matrix Composites and Their Applications. *ASM Handbook, 15*, 1149–1164. doi:10.1361/asmhba0005339

Rose, M. B. (1991/2006). *International Competition and Strategic Response in the Textile Industries Since 1870*. Oxon: Routledge. Retrieved June 15, 2016, from https://books.google.co.uk/books?id=fVb-AQAAQBAJ&printsec=frontcover#v=onepage&q&f=false

SABIC innovative Plastics SABIC® STAMAX® Long Glass fiber PP helps Hyundai Sonatas plastic door module win 2010 SPE innovation award. Retrieved December 11, 2016, from http://www.pr.com/press-release/280688

Safely Drive and Play in the Snow with All Wheel Drive and HTrac from Hyundai. (2016, January 12). Retrieved December 5, 2016, from Planet Hyundai, http://www.planethyundai.com/blog/2016-all-wheel-drive-and-htrac-from-hyundai/

Safety Based on Radar Technology – Audi Braking Guard. (2008, May 18). Retrieved January 19, 2017, from http://www.fourtitude.com/news/publish/Audi_News/article_4002.shtml

Safety Technology History. (2016). Retrieved January 31, 2017, from Toyota, http://www.toyota-global.com/innovation/safety_technology/history/

Sales by Model. (2016). Retrieved August 20, 2016, from Hyundai, http://worldwide.hyundai.com/WW/Corporate/InvestorRelations/IRActivities/SalesPerformance/SalesbyModel/index.html?NextRow=1&selx2=

Sandbrook, D. (2013, August 2). How German cars beat British motors - and kept going. *BBC Magazine*. Retrieved from http://www.bbc.com/news/magazine-23406467

Seat Ibiza on Sale in China. (2013, April 20). Retrieved January 25, 2017, from SEAT, http://www.seat-mediacenter.com/en-content/2013-2/04/20/seat-ibiza-on-sale-in-china/

SEAT Ibiza review. (2016, July 28). Retrieved January 15, 2017, from Auto Express, http://www.autoexpress.co.uk/seat/ibiza

SEAT Leon ST Technology - Front Assist. (2013, December 5). Retrieved January 20, 2017, from https://www.youtube.com/watch?v=3qBp78nDKls

SEAT Leon ST Technology - Lane Assist. (2013, December 5). Retrieved January 15, 2017, from SEAT, https://www.youtube.com/watch?v=JKhD6hlQD0w

SEAT Leon X-Perience. (2016). Retrieved December 5, 2016, from SEAT, http://www.seat.co.uk/new-cars/leon-x-perience/overview.html

Sedgwick, D. (2016, February 21). VW led auto r&d spending in '15. Retrieved January 25, 2017, from Automotive News, http://www.autonews.com/article/20160221/OEM06/302229977/vw-led-auto-r&d-spending-in-15

Segarra-Oña, M., Peiró-Signes, A. & Payá-Martínez, A. (2014, March). Factors Influencing Automobile Firms' Eco-Innovation Orientation. *Engineering Management Journal, 26*(1), 31-38.

Self-parking – Volkswagen. (2009). Retrieved January 29, 2017, from Auto Express, http://www.autoexpress.co.uk/car-reviews/39301/self-parking-volkswagen

Self Study Program 861803: Tiguan Haldex All-Wheel Drive (2008, March). Retrieved December 5, 2016, from Team BHP.

Siler, S., (2016). Toyota Corolla. Retrieved January 25, 2017, from http://www.caranddriver.com/toyota/corolla

Simister, J. (2015, July 29). First drive review: Hyundai Tucson (2015). Retrieved December 10, 2016, from First Drives, http://www.driving.co.uk/car-reviews/first-drive-review-hyundai-tucson-2015/

SINEK, J. (2016, May 10). Base model Toyotas to come standard with full suite of safety features by 2017. Retrieved January 30, 2017, from http://www.theglobeandmail.com/globe-drive/culture/technology/base-model-toyotas-to-come-standard-with-full-suite-of-safety-features-by-2017/article29864419/

Škoda Adaptive Cruise Control. (2014, February 13). Retrieved January 18, 2017, from Skoda Australia, https://www.youtube.com/watch?v=iKiqMO6XMKc

Skoda Adaptive Cruise Control. (2016). Retrieved January 29, 2017, from Škoda, http://www.skoda.com.au/models/hotspotdetail?HotspotName=AU-OCT-AdaptiveCruiseControl&Page=technology&WebID=309a52a8-ed96-46dd-a5e4-280553817507

Škoda Annual Report 2015. (2016). Retrieved August 25, 2016, from Škoda Auto a.s.

Škoda Annual Report 2014. (2015). Retrieved August 25, 2016, from Škoda Auto a.s.

ŠKODA 4x4 models. (2016). Retrieved December 5, 2016, from ŠKODA, http://www.skoda.co.uk/why-skoda/4x4

SKODA Octavia 2013 launch review. (2013, November 27). Retrieved January 28, 2017, from Škoda, http://www.skoda.com.au/news/skoda-octavia-2013-launch-review

Škoda Octavia Brochure. (2016, November). Retrieved January 25, 2017, from Škoda, https://tools.skoda.co.uk/content/brochure/brochure_octavia.pdf

Skoda premieres Front Assistant in new Fabia. (2014, December 3). Retrieved January 18, 2017, from Safe Car News, http://safecarnews.com/skoda-premieres-front-assistant-in-new-fabia_d533/

Skoda previews potent new Octavia RS 230 ahead of Geneva debut. (2015, February 24). Retrieved January 20, 2017, from http://www.autoblog.com/2015/02/24/skoda-octavia-rs-230-geneva-official/

The Sleek and Sporty hatchback that's packed with power. (2016). Retrieved January 18, 2017, from Kia, http://www.kia.com/uk/new-cars/ceed/

Smart Parking Assist System (SPAS) with Sorento. (2014, March 17). Retrieved January 18, 2017, from Kia Singapore, https://www.youtube.com/watch?v=qJNKtMj4OwM

Sonata Safety. (2016). Retrieved January 16, 2017, from Hyundai, https://www.hyundaiusa.com/vehicles/2016/sonata/safety.aspx

Sorento 2016. (2016). Retrieved January 16, 2017, from Kia, http://www.kia.com/us/en/vehicle/sorento/2016/innovation

Sportage 2017. (2016). Retrieved January 16, 2017, from Kia, http://www.kia.com/us/en/vehicle/sportage/2017/technology

Srinivasan, S. (2012, February 6). Article: Toyota's latest processes have less automation and more people: Jeffrey K Liker. Retrieved November 28, 2016, from The Economic Times, http://economictimes.indiatimes.com/opinion/et-commentary/toyotas-latest-processes-have-less-automation-and-more-people-jeffrey-k-liker/articleshow/11773410.cms

Stanford Artificial Intelligence Laboratory. (2016). Retrieved October 22, 2016, from Stanford, http://ai.stanford.edu/ http://www.autoalliance.org/index.cfm?objectid=B44C9610-B4D4-11E1-827E000C296BA163

Staszewski, R., & Estl, H. (2013). Making cars safer through technology innovation. Retrieved 20 July 2016, from http://www.ti.com/lit/wp/sszy009/sszy009.pdf

Steady Demand from Developing Markets to Drive Growth in the Passenger Cars Market. (2015, April 30). Retrieved August 20, 2016, from Global Industry Analysts, Inc., http://www.strategyr.com/MarketResearch/Passenger_Cars_Market_Trends.asp

Steady Demand from Developing Markets to Drive Growth in Passenger Cars Market. (2016). Retrieved August 20, 2016, from Ceramic Industry Magazine, http://www.ceramicindustry.com/articles/94768-steady-demand-from-developing-markets-to-drive-growth-in-passenger-cars-market

Step by Step: Offboard Diagnostic Information System software (2016). Retrieved November 13, 2016, from erWin Volkswagen, https://erwin.volkswagen.de/erwin/showVasStepByStep01.do

Stress-Free Safety. (2016). Retrieved January 18, 2017, from SEAT, http://www.seat.co.uk/new-cars/ibiza-5dr/safety.html

Strumberger, N., Gospocic, A., & Bartulic, C. (2005). Polymeric Materials in Automobiles. Traffic Engineering, 17(3), 149–160. Retrieved from http://www.fpz.unizg.hr/traffic/index.php/PROMTT/article/viewFile/630/484

Stubbs, V. (2010, July 21). Dealer view: Volkswagen's TSI engines explained. Retrieved January 15, 2017, from http://www.polodriver.com/technology/dealer-view-volkswagens-tsi-engines-explained/

Subbaraman, N. (2015, November 24). This car will park itself: Somerville, Audi prepare to test self-driving tech. Retrieved January 26, 2017, from http://www.betaboston.com/news/2015/11/24/this-car-will-park-itself-somerville-audi-prepare-to-test-self-driving-tech/

A successful car is now even better – the new Audi Q3. (2014, November 6). Retrieved January 20, 2017, from Audi, https://www.audiusa.com/newsroom/news/press-releases/2014/11/a-successful-car-is-now-even-better-the-new-audi-q3

Sundbo, J. (1998). *The Theory of Innovation: Enterpreneurs, Technology and Strategy*. Cheltenham: Edward Elgar Publishing Limited. Retrieved October 29, 2016, from https://books.google.co.uk/books?id=VurHZn3_8IcC&printsec=frontcover#v=onepage&q&f=false

Supplemental Material for Financial Results for FY2015 (Consolidated). Retrieved December 3, 2016, from Toyota, http://www.toyota-global.com/pages/contents/investors/financial_result/2015/pdf/q4/consolidated.pdf

Sustainability 2014 at a Glance. (2015). . Retrieved October 20, 2016, from Volkswagen.

Sutton, M. (2016, August). Hyundai sonata. Retrieved December 9, 2016, from http://www.caranddriver.com/hyundai/sonata

The SUV/4x4 KIA. (2016). Retrieved December 5, 2016, from Kia, http://www.kia.co.uk/new-cars/range/suvs-4x4-cars

Synergies and Alliances. (2015). Retrieved October 20, 2016, from Volkswagen, http://annualreport2014.volkswagenag.com/group-management-report/sustainable-value-enhancement/research-and-development/synergies-and-alliances.html

Szinkota, M., & Ronkainen, I. (n.d.). Case 3 Toyota Incident. In *International Marketing* (10th ed., pp. 535-540). South-Western, Cengage Learning. Retrieved January 30, 2017, from https://books.google.co.uk/books?id=kSYXAAAAQBAJ&printsec=frontcover#v=onepage&q&f=false

Tan, P. (2014, January 28). 2014 Volkswagen Polo facelift gets new technology. Retrieved January 15, 2017, from http://paultan.org/2014/01/28/volkswagen-polo-facelift-unveiled/

Tay, K. H. (2003). Achieving competitive differentiation: the challenge for automakers. In *Strategy & Leadership*, *31*(4), 23 -30. Retrieved January 30, 2017, from http://www.emeraldinsight.com/doi/abs/10.1108/10878570310483951

Taylor, J. (2016, February 22). Review: Audi's new-for-2016 "Quattro with ultra" all-wheel-drive system. Retrieved December 5, 2016, from Car Magazine, http://www.carmagazine.co.uk/car-news/tech/review-audis-new-for-2016-quattro-with-ultra-all-wheel-drive-system/

Taylor, M. (Mark) (2016). *The Politics of Innovation: Why Some Countries Are Better Than Others at Science and Technology*. New York: Oxford University Press. Retrieved June 20, 2016, from https://books.google.at/books?id=cUcnDAAAQBAJ&printsec=frontcover&hl=de#v=onepage&q&f=false

Taylor, M. (Michael) (2015, January 29). The Grim Future of the Naturally Aspirated Engine, Or: The Turbos Are Winning. Retrieved January 29, 2017, from http://blog.caranddriver.com/the-grim-future-of-the-naturally-aspirated-engine-or-the-turbos-are-winning/

Tech: Driver Assist. (2016). Retrieved January 16, 2017, from Kia, http://www.kia.com/us/en/vehicle/forte/2017/tech

Technical Development, Materials. (2016). Retrieved December 6, 2016, from Toyota http://www.toyota-global.com/company/history_of_toyota/75years/data/automotive_business/products_technology/technology_development/materials/organic/index.html

Technology switched on. (2016). Retrieved January 29, 2017, from SEAT, http://www.seat.co.uk/new-cars/leon-st/technology.html

10 Most Cars: Here Are the Bestselling Cars in America for 2015 (2016). Retrieved December 5, 2016, from http://www.caranddriver.com/flipbook/10-most-cars-here-are-the-bestselling-cars-in-america-for-2015#10

Tew, B. (1950). Review: Invention And Innovation In The Radio Industry. By W. Rupert Maclaurin. *The Economic History Review, 3*(2), 255-256. doi: 10.2307/2590782. Retrieved July 30, 2016, from http://www.jstor.org.uaccess.univie.ac.at/stable/2590782?sid=primo&origin=crossref&seq=1#page_scan_tab_contents

Theta TGDI. (2010, September 20). Retrieved January 22, 2017, from Hyundai Global, https://www.youtube.com/watch?v=PTG8bANl3vs

This is beauty and brawn. (2016). Retrieved January 25, 2017, from Audi, https://www.audiusa.com/technology/efficiency/ultra

Thomas, F. (2016, July 13). Assistenzsysteme: Opel Corsa, Ford Fiesta, Skoda Fabia, Seat Ibiza und VW Polo im Vergleich. Retrieved January 20, 2017, from MeinAuto, http://www.meinauto.de/ratgeber/assistenzsysteme-opel-corsa-ford-fiesta-skoda-fabia-seat-ibiza-und-vw-polo-im-vergleich

Thomson, A. (2016). Toyota's Generic Strategy & Intensive Growth Strategies. Retrieved January 31, 2017, from Panmore Institute, http://panmore.com/toyota-generic-strategy-intensive-growth-strategies

Tiguan Technical Specifications. (2016). Retrieved December 5, 2016, from Volkswagen, http://media.vw.com/doc/1540/166120949755c8c73d718cb.pdf

Together we can help make the road safe. (2016). Retrieved January 30, 2017, from Toyota, http://www.toyota.com/safety-sense/

Toomgum, S. (2015). Toyota predicts Thai car sales to be low. Retrieved October 29, 2016, from the Nation, http://www.nationmultimedia.com/news/business/automobiles/30270261

Toyota achieves strong first-half sales growth in the West on the back of rapid hybrid growth and Lexus, and increased share in the East. (2016, July 16). Retrieved December 3, 2016, from Toyota, http://newsroom.toyota.eu/pressrelease/5160/1162/record-sales-lexus-europe-first-half-2016

Toyota Bird's Eye View Camera. (2016, November 28). Retrieved January 16, 2017, from Toyota, http://www.toyotaarlington.com/blog/2016/11/28/what-is-toyotas-birds-eye-view-monitor-system/

Toyota car safety: monitoring systems. (2014, June 4). Retrieved January 31, 2017, from Toyota, http://blog.toyota.co.uk/toyota-car-safety-monitoring-systems

Toyota completes new facilities in china, reaffirms commitment to localized R&D and production. (2013, November 14). Retrieved October 20, 2016, from TOYOTA MOTOR CORPORATION, http://newsroom.toyota.co.jp/en/detail/37321

Toyota Corolla generations – 2000-2006. (2015, April 21). Retrieved January 31, 2017, from Toyota, http://blog.toyota.co.uk/toyota-corolla-generations-2000-2006

Toyota Corolla Story. (2016). Retrieved 15 June 2016, from https://mjs.home.xs4all.nl/corollastory.html

Toyota Global Performance 2010-2022. (2016, December 6)http://focus2move.com/toyota-global-performance/

Toyota How-To: Bird's Eye View Camera with Perimeter Scan. (2016, May 13). Retrieved January 30, 2017, from Toyota, https://www.youtube.com/watch?v=K2PTeVgdYB0

Toyota in Europe. (2016). Retrieved October 29, 2016, from Toyota, https://www.toyota-europe.com/jobs/

Toyota Integrates Asia R&D Base with Production Support Company. (2007, April 2). Retrieved October 20, 2016, from TOYOTA, http://www.toyota.co.jp/en/news/07/0402.html

TMC and Tsinghua University to Continue Joint Research (2011, March 30). Retrieved October 25, 2016, from Toyota, http://www2.toyota.co.jp/en/news/11/03/0330_1.html

Toyota Partner Robots. (2016). Retrieved November 28, 2016, from Toyota, http://www.toyota-global.com/company/history_of_toyota/75years/data/automotive_business/production/production_engineering/partner_robots/index.html

Toyota Production System (2016). Retrieved November 30, 2016, from Toyota, http://www.toyota-global.com/company/vision_philosophy/toyota_production_system/

Toyota RAV4 Engine Layout. (2016). Retrieved January 3, 2017, from https://www.carleasingmadesimple.com/data/toyota/rav4/engine-layout/

Toyota RAV4 Owners Manual: Intuitive parking assist. (2016). Retrieved February 1, 2017, from Toyota RAV4, http://www.trav4.net/intuitive_parking_assist-112.html

Toyota Safety Sense. (2016). Retrieved January 31, 2017, from Toyota, https://www.toyota.co.uk/world-of-toyota/safety/toyota-safety-sense.json

Toyota Safety Sense: a new level of active safety for the Toyota range. (2015, March 2). Retrieved January 30, 2017, from Toyota, http://blog.toyota.co.uk/toyota-safety-sense-a-new-level-of-active-safety-for-the-toyota-range

Toyota To Assume TTDC's Vehicle-Development Business - Quick Facts. (2014). Retrieved October 29, 2016, from RTT News, http://www.rttnews.com/2422347/toyota-to-assume-ttdc-s-vehicle-development-business-quick-facts.aspx

Toyota to restructure R&D organisation, plans to introduce new safety and lighting technologies in 2015. (2014, November 26). Retrieved October 20, 2016, from IHS Markit https://www.ihs.com/country-industry-forecasting.html?ID=1065997284

TOYOTA UNVEILS NEW AURIS, AVENSIS AND 1.2T TURBO PETROL ENGINE AT THE GENEVA MOTOR SHOW. (2015, March 2). Retrieved January 22, 2017, from Toyota Europe, http://media.toyota.co.uk/2015/03/toyota-unveils-new-auris-avensis-1-2t-turbo-petrol-engine-geneva-motor-show/

Toyota Yaris – Parking Assist. (2015, October 26). Retrieved February 1, 2017, from Toyota, http://blog.toyota.co.uk/toyota-yaris-parking-assist

Toyota ZZ series engines. No room for error. (2003, December). Retrieved December 9, 2016, from Toyota-Club, http://toyota-club.net/files/faq/04-01-10_rem_1zzfe_eng.htm

Toyota's new R&D company hires technical team. (2016, January 5). Retrieved October 29, 2016, from Reuters, http://uk.reuters.com/article/tech-ces-toyota-idUKL3N14P4AV20160105

Tracy, D. (2013, June 11). How electronic fuel injection works. Retrieved May 30, 2016, from http://jalopnik.com/how-electronic-fuel-injection-works-499902815

Trends and outlook of the auto electronics industry. (2013, October). Retrieved January 10, 2017, from Deloitte China Automotive Practice, https://www.roboticsbusinessreview.com/wp-content/uploads/2016/05/deloitte-cn-mfg-auto-electronic-industry-en-210314.pdf

Trendsetting design.Trailblazing technology. (2016). Retrieved January 30, 2017, from Kia, http://www.kia.com/us/en/vehicle/optima/2017/technology

Trop, J. (2014, September 22). Toyota's big leap to aluminum. Retrieved December 9, 2016, from Autonews, http://www.autonews.com/article/20140922/OEM01/309229953/toyotas-big-leap-to-aluminum

Trudell, C., Hagiwara, Y., & Jie, M. (2014, April 7). Humans replacing robots Herald Toyota's Vision of Future. Retrieved November 30, 2016, from Bloomberg, https://www.bloomberg.com/news/articles/2014-04-06/humans-replacing-robots-herald-toyota-s-vision-of-future

TSI Maximum power with minimum consumption. (2016). Retrieved January 11, 2017, from Volkswagen Technology, http://www.volkswagen.co.uk/technology/petrol/tsi

Tutu, A. (2013, October 3). 2014 TOYOTA Corolla Review. Retrieved February 1, 2017, from Autoevolution, http://www.autoevolution.com/reviews/2014-toyota-corolla-review-2013.html

The 2015 EU Industrial R&D Investment Scoreboard. (2016, November 14). Retrieved August 29, 2016, from European Commission, http://iri.jrc.ec.europa.eu/scoreboard15.html

2015 Volkswagen Jetta — Forward Collision Warning (Front Assist). (2016). Retrieved January 19, 2017, from Owner's Manuals, https://ownersmanuals2.com/volkswagen/jetta-2015-forward-collision-warning-front-assist-31262

2005 Annual Report (2005). Retrieved September 15, 2016, from Kia, http://www.kiapressoffice.com/Company/Media/Kia/uploads/annual-reports/Kia%20Annual%20Report%202005.pdf

The 2014 EU Industrial R&D Investment Scoreboard. (2015, January 16). Retrieved August 29, 2016, from European Commission, http://iri.jrc.ec.europa.eu/scoreboard14.html

2017 Yaris. (2016). Retrieved January 30, 2017, from Toyota, http://www.toyota.com/content/ebrochure/2017/yaris_ebrochure.pdf

2016 Prius – the next generation of Toyota's technology ambassador. (2016, February 15). Retrieved February 1, 2017, from Toyota, http://blog.toyota.co.uk/2016-prius-the-next-generation-of-toyotas-technology-ambassador

2016 Toyota Corolla: New Car Review. (2015, August). Retrieved February 1, 2017, from Autotrader, http://www.autotrader.com/car-info/2016-toyota-corolla-new-car-review-242976

2016 Toyota RAV4 Hybrid Offers Bird's Eye View Camera. (2015, April 2). Retrieved January 30, 2017, from Toyota, https://www.youtube.com/watch?v=gFIaEpcsI3E

The 2013 EU Industrial R&D Investment Scoreboard. (n.d.). Retrieved August 29, 2016, from European Commission, http://iri.jrc.ec.europa.eu/scoreboard13.html

The 2012 EU Industrial R&D Investment Scoreboard. (n.d.). Retrieved August 29, 2016, from European Commission, http://iri.jrc.ec.europa.eu/scoreboard12.html

US Retail Sales. (2016). Retrieved December 6, 2016, from Hyundai, http://worldwide.hyundai.com/WW/Corporate/InvestorRelations/IRActivities/SalesPerformance/USRetailSales/index.html?NextRow=16&selx2=

Unterwegs im Toyota Prius IV. (2016, May 6). Retrieved January 20, 2017, from https://www.heise.de/autos/artikel/Unterwegs-im-Toyota-Prius-IV-3196841.html

Vasilash, G. S. (2007, January 8). VW Research: Vehicle Technology for Today and Tomorrow. Retrieved August 30, 2016, from http://www.adandp.media/articles/vw-research-vehicle-technology-for-today-tomorrow

Vincent, D. (1999). Changing Our World. In S. Nof (Ed.), Handbook of Industrial Robotics (Second ed.). Canada: John Wiley & Sons, Inc. Retrieved November 30, 2016, from https://books.google.co.uk/books?id=7od4alFKfNMC&pg=PR14&lpg=PR14&dq=toyota+industrial+robots&source=bl&ots=TtHrCfoiLJ&sig=-CAi56Rir3H4awoyxYxmnFoYY8w&hl=en&sa=X&ved=0ahUKEwjbhdaNtJHQAhWDzRQKHevwC8EQ6AEIUjAL#v=onepage&q=toyota%20industrial%20robots&f=false

Volkswagen Golf VII: Design story. (2012, September 8). Retrieved December 7, 2016, from http://www.carbodydesign.com/2012/09/volkswagen-golf-vii-design-story/

VOLKSWAGEN DEMOCRATIZES HIGH-END DRIVER ASSISTANCE FEATURES FOR THE 2016 MODEL YEAR. (2015, July 29). Retrieved January 29, 2017, from Volkswagen, http://media.vw.com/release/1031/

Volkswagen Passat – Area View. (2014, Novemver 14). Retrieved January 25, 2017, from Volkswagen, https://www.youtube.com/watch?v=bsWeh-nkS7c

VW Passat Spurhalteassistent. (2008, April 18). Retrieved January 20, 2017, from http://www.auto.de/magazin/video-vw-passat-cc-spurhalteassistent/

VW Passat: Take a break. (2011, December 8). Retrieved January 28, 2017, from Parkers, http://www.parkers.co.uk/cars/reviews/living-with-it/volkswagen-passat-estate/nov---take-a-break/

Volkswagen Passenger Cars. (2015). Retrieved August 20, 2016, from Volkswagen, http://annualreport2014.volkswagenag.com/divisions/volkswagen-passenger-cars.html

Volkswagen Passenger Cars 2015 (2016). Retrieved December 3, 2016, from Volkswagen http://annualreport2015.volkswagenag.com/divisions/volkswagen-passenger-cars.html

VW-Pläne bescheren Kuka-Aktie Rekordhoch. (2015, February 2). Retrieved November 23, 2016, from N-TV, http://www.n-tv.de/wirtschaft/VW-Plaene-bescheren-Kuka-Aktie-Rekordhoch-article14438036.html

Volkswagen Presents Worldwide Research Alliance on Electric Mobility. (2010, July 19). Retrieved August 28, 2016, from Volkswagen of America, http://www.volkswagenag.com/content/vwcorp/info_center/en/themes/2010/07/Volkswagen_presents_worldwide_research_alliance_on_electric_mobility.html

Volkswagen Tiguan Driver assistance systems. (2001, June 1). Retrieved January 15, 2017, from https://www.youtube.com/watch?v=RMmrxsSCKCA

VW Tiguan II: Palette wird ausgeweitet. (2015, April 22). Retrieved January 20, 2017, from http://www.meinauto.de/news/vw-tiguan-2-palette-wird-ausgeweitet

Volkswagen TSI engine animation. (2014, November 15). Retrieved December 10, 2016, from https://www.youtube.com/watch?v=zY_FgdgYxYI

Volkswagen Up! City Emergency Brake test. (2012, February 21). Retrieved January 20, 2017, from Volkswagen, https://www.youtube.com/watch?v=nZeoaFFWrP8

Volkswagen's safe distance technology. (2016). Retrieved January 29, 2017, from Volkswagen, http://www.volkswagen.co.uk/technology/adaptive-cruise-control-acc

Vondruska, J. (2001, November 5). Volkswagen factory tour. Retrieved November 29, 2016, from VWVortex, http://www.vwvortex.com/artman/publish/vortex_news/printer_329.shtml

Vorverkaufsstart für den neuen Jetta. (2014, September 5) . Retrieved January 20, 2017, from Volkswagen, https://www.volkswagen-media-services.com/detailpage/-/detail/Vorverkaufsstart-fr-den-neuen-Jetta/view/1641579/3ff26109c38d68649647ba2caa9da464?p_p_auth=mTqAob2I

Waldeck, W. & Watts, J. (2015, September 14). Wars on wheels – are patents the new revenue stream for car-makers? Retrieved January 27, 2017, from Freshfields Bruckhaus Deringer LLP, http://www.lexology.com/library/detail.aspx?g=0b5594c8-860a-45bf-be31-24c7810fe6e1

Wayland, M. (2015, May 12). It's 'the golden age' for turbochargers in cars. Retrieved January 15, 2017, from The Detroit News, http://www.detroitnews.com/story/business/autos/chrysler/2015/05/12/golden-age-turbochargers-cars/27216241/

Webzell, S. (2009, May 1). Robots extend their reach. Retrieved November 14, 2016, from Automotive Manufacturing Solutions, http://www.automotivemanufacturingsolutions.com/technology/robots-extend-their-reach

Weissler, P. (2010, August 31). Inside Hyundai's world-class R&D complex. Retrieved October 11, 2016, from SAE International, http://articles.sae.org/8735/

Wer macht das Rennen? (2010, April 18). Retrieved December 3, 2016, from Focus Online, http://www.focus.de/auto/news/das-meistverkaufte-auto-europas-wer-macht-das-rennen_aid_499693.html

What is Benchmarking? - Definition, Types, Process & Examples. (2016). Retrieved May 29, 2017, from http://study.com/academy/lesson/what-is-benchmarking-definition-types-process-examples.html

What is quattro? (2016). Retrieved December 5, 2016, from Audi, https://www.audi.co.uk/audi-innovation/quattro-all-wheel-drive.html

What is the Hyundai – Kia Partnership at University of California Irvine? (2016, June 2). Retrieved October 11, 2016, from Boucher Kia, http://www.boucherkia.com/blog/hyundai-kia-partnership-university-california-irvine/

Wilhelm, M. (1993, November) Materials used in automobile manufacture - current state and perspectives. *Journal de Physique IV*, 03 (C7), 30-40.

Wimmelbücker, S. (2016, February 2). Europas meistverkaufte Automodelle 2015: Kleinwagen bleiben gefragt. . Retrieved from http://www.automobilwoche.de/article/20160202/nachrichten/160209989/europas-meistverkaufte-automodelle--kleinwagen-bleiben-gefragt

Wimmer, E. (2012). *Motoring the Future: VW and Toyota Vying for Pole Position*. New York: Palgrave Macmillan. Retrieved January 25, 2017, from https://books.google.co.uk/books?id=7KP6NMfBcSwC&printsec=frontcover

Winter, D. (2012, February 6). Hyundai's small engine big Overachiever. Retrieved January 22, 2017, from http://wardsauto.com/technology/hyundai-s-small-engine-big-overachiever

Woodford, C. (2009). History of cars. Retrieved January 11, 2017, from http://www.explainthatstuff.com/historyofcars.html

World Investment Report. (2005). Transnational Corporations and the Internationalization of R&D. *United Nations*. Retrieved October 26, 2016, from http://unctad.org/en/Docs/wir2005_en.pdf

World War II Vehicles. (n.d.). Retrieved September 20, 2016, from http://ww2db.com/vehicle.php

The world's biggest and best working environments, right here in Korea. (2016). Retrieved December 3, 2016, from Hyundai, http://worldwide.hyundai.com/WW/Corporate/Network/Manufacturing/index.html

Worldwide Operations (2016, March 2). Retrieved November 1, 2016, from Toyota, http://newsroom.toyota.co.jp/en/corporate/companyinformation/worldwide