IWI Discussion Paper Series
88 (March 5, 2019)[1]

ISSN 1612-3646

Analysis of Augmented Reality Applications within the German Automotive Industry

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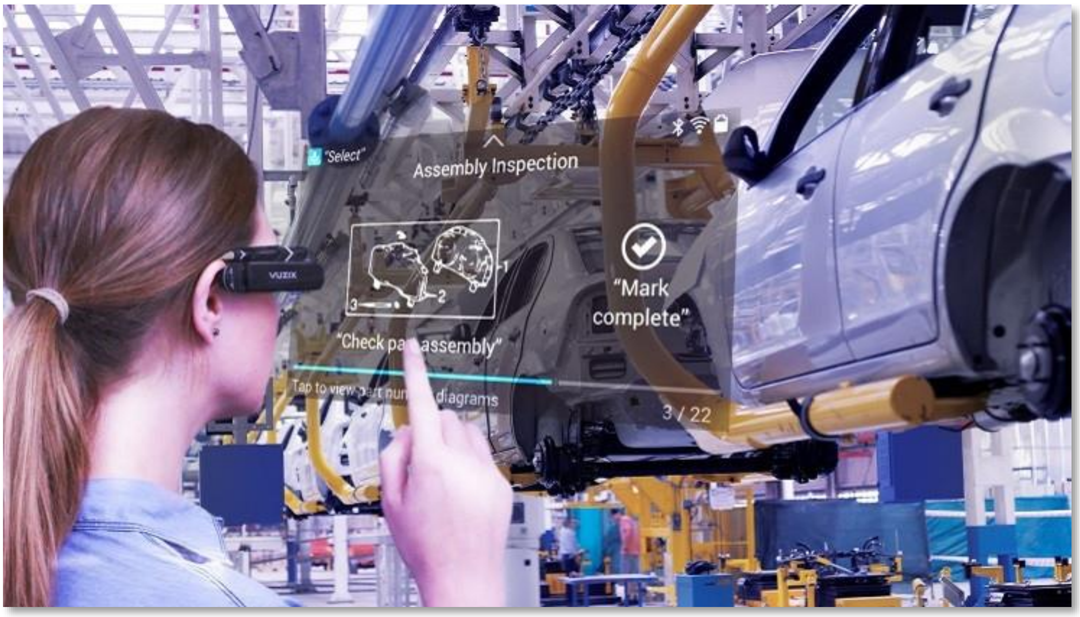

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Abstract

Augmented Reality (AR) is a modern technology that offers new opportunities along the entire value chain of the automotive industry. In this paper, the potential of AR in different use cases of the German automotive industry is presented. Furthermore, strengths and weaknesses of the technology are discussed and the influence of this technology on the strategic perspective of the German automotive industry is investigated. The results of the investigation reveal that AR can make a significant contribution to increased efficiency, cost savings and process optimization. The available hardware, however, still shows some weaknesses in its current state of development, which can be remedied by research. The mature technology holds great opportunities for the German automotive industry to exploit opportunities arising from the development of the corporate environment and to avert threats.

Keywords

Augmented Reality, German Automotive Industry, SWOT Analysis, PEST Analysis.

1. Augmented Reality

In a globalized and fast-moving world, the automotive industry is under constant pressure. The challenge is to constantly reduce costs, launch new and innovative products on the market while guaranteeing high quality (Anastassova and Burkhardt, 2009). At the same time, the amount of data and the complexity of the technologies are constantly growing due to new technological developments.

In order to meet the various challenges facing the industry, technological assistance measures were introduced to support employees in achieving more efficient work performance. Augmented Reality (AR) is a promising new form of human-computer interaction suitable for use in various divisions such as factory planning, design, training, manufacturing and service (Wang et al., 2016). In this divisions of a company, for individuals the flood of information presents the challenge of obtaining the right information at the right time quickly and efficiently. Time-to-content is becoming increasingly relevant (Ludwig and Reimann, 2005). AR offers an innovative alternative to the classic media of information transfer to present information to users in a particularly efficient way. In many areas of the economy, this technology can be identified as a potential for increasing efficiency by guiding users through unfamiliar or complex use cases (Ludwig and Reimann, 2005; Borsci et al., 2015).

In Germany, the automotive industry is the most advanced industry in the digitization of its processes and can deploy virtual and augmented realities at every step of the value chain. This is confirmed by a KPMG study which examined 260 relevant application areas of AR for their industry relevance and states that these can be classified as trendsetting technologies for the automotive industry in almost every field of business (von der Gracht et al., 2016).

While scientific literature largely focuses on the technological aspects of AR, a critical examination of the strengths and weaknesses of application of AR in the automotive industry has received little attention in the literature. This paper is dedicated to this research gap and discusses the importance of AR for the automotive industry on the basis of a SWOT analysis.

Therefore, our research questions are:

1. What are the relevant strengths and weaknesses of the use of AR applications in the German automotive industry?
2. How can the strategic use of AR in the German automotive industry support manufacturers in tackling future challenges?

1.1 Definition and Functionality

There is no common definition of AR in the existing scientific literature. Broad definitions of AR include any overlapping of human sensory perceptions with computer-generated information (Milgram and Colquhoum, 1999). These definitions include not only the extension of real visual information by computer-generated information, but also haptic, olfactory and acoustic information (Dörner et al., 2013). AR systems offer added value for individuals by enriching the real environment with information generated by computers and thus expanding perception to include information that is outside perception without AR (Friedrich, 2004).

Azuma (1997) has defined three characteristics of an AR system. The first attribute of AR is the combination of the virtual and the real-world. Users are provided with virtual information based on their current situation. Thus, their perception of the real environment is extended by digital information. The second characteristic is the feature of interactivity in real-time. The systems are faced with the challenge of interacting as naturally as possible with the user. Distinctive sensors integrated into the AR systems ensure that the information displayed is adapted to the user and can be influenced. Furthermore, the enrichment of the real-world with computer-generated information must take place in real-time in order to ensure functionality. As a third characteristic, Azuma (1997) names registration in three dimensions. To create the illusion of virtual objects being embedded in the user's real environment, the objects of the real and virtual world must be appropriately aligned in their representation. Virtual, three-dimensional objects must be displayed accurately and positioned correctly in perspective. This creates the impression of a mixed reality. Milgram et al. (1994) have classified AR technically according to their "reality-virtuality continuum". This continuum shown in Figure 1 represents a continuous transition from a real to a virtual world. AR represents a mixed reality in this space. This is defined as a mixture of real and virtual objects. In the continuum of Milgram et al. (1994), the number of real objects decreases moving right into the figure and the proportion of virtual objects increases. Thus, AR is located in the field between reality and a completely virtual environment. For AR, however, the share of real objects outweighs the share of digital objects (Dörner et al., 2013). In contrast to AR, VR creates a fully simulated world. In VR applications, the real environment of a user is replaced by a digital one (Furht, 2011).

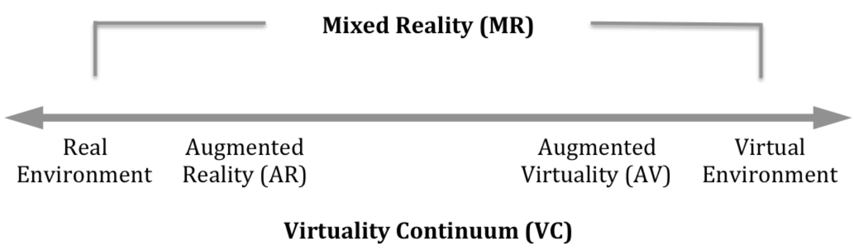

Figure 1. Reality-Virtuality Continuum according to Milgram et al. (1994)

The purpose of an AR system is to enrich a user's real environment with computer-generated information in order to generate added value. **Fehler! Verweisquelle konnte nicht gefunden werden.**2 illustrates the basic functionality of AR systems.

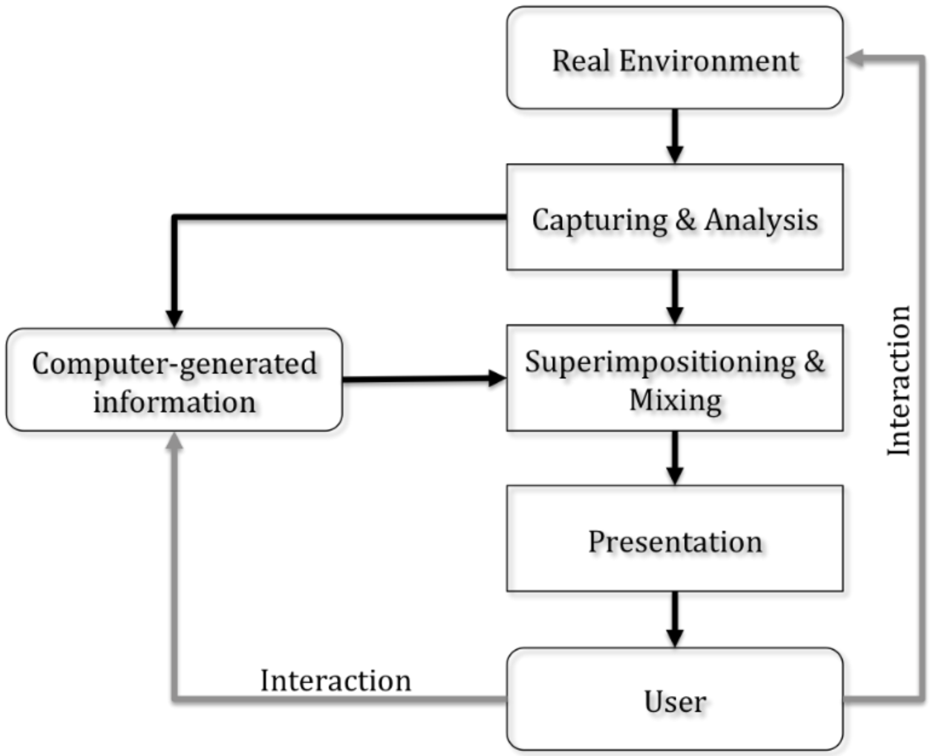

Figure 2. Functionality of an AR System according to Carmigniani and Furht (2011)

To add digital information to the real world, a first step is to capture the real world itself. Technical sensors, especially video cameras, are used for this purpose. In a next step, the data collected by the sensors, which provide information about the user's environment, is analyzed (Furht, 2011). On the basis of this analysis, for example, the positions of objects in the real world can be determined. This serves to connect the information of the virtual and real world with each other and creates the basis for a situational and positional augmentation of sensory perception. The data is used to adjust the alignment of the objects to be enriched so that they blend seamlessly into the real image. Once the data have been coordinated, real and computer-generated objects are mixed and then presented to the user. Through interaction, the user can influence his real environment as well as the enriched information (Ma et al., 2011).

1.2 Technical Realization

In the following, the technical background of AR technology will be explained in order to clarify basic technical terms, technical requirements and functionalities of different AR approaches to convey a basic understanding of AR. AR systems can be abstracted by three fundamental technologies (Schmalstieg and Höllerer, 2016). These components must roughly fulfill two basic tasks in each temporal sequence of the augmentation. First, the application must determine the current position within the real and virtual world. As a second step, the application must make the virtual world (taking into account the real world) sensorial perceptible to the user of the system, for example by means of a screen on which visual information is displayed. These actions can be subdivided into many smaller components (Craig, 2013).

1. *Tracking component* to detect and determine the position and orientation of the user, as well as of objects in the environment:

Tracking is generally understood as the calculation or more accurate the estimation of the position and/or location/orientation (Broll, 2013). Tracking computation is crucial in order to display the composed images properly and maintain correct registration of real and virtual worlds (Tsihrintzis and Jain, 2008). The software that performs this task is called the tracking software or tracker (Mehler-Bicher and Steiger, 2014). A tracker should capture the real environment and any objects in it at any time and recognize and track the viewer's point of view and/or the position of a so-called marker in space as accurately as possible and in real-time (Broll, 2013; Mehler-Bicher and Steiger, 2014). Müllner (2013) distinguishes between the two essential principles of inside-out tracking and outside-in tracking.

In inside-out tracking, the moving object determines the tracking information itself. Cameras are attached to the object to be monitored and record the surroundings (Grimm et al., 2013). The data is provided by the environment, e.g., by markers (Mehler-Bicher and Steiger, 2014). For this purpose, the cameras are attached to the objects whose movement is to be recorded (e.g., at the head of a user to implement head tracking). The position and orientation of the camera to one or more reference points in the environment can be determined from the video stream recorded. The disadvantage of inside-out procedures is that the user has to put up with movement restrictions caused by carrying around cameras. The advantage is that the user is not restricted to a specific interaction space and can therefore move more freely (Grimm et al., 2013). Furthermore, the trackers used for inside-out tracking are passive and therefore much more cost-effective and are increasingly favored (Mehler-Bicher and Steiger, 2014).

If the object to be tracked has no knowledge of its own position and orientation, this is called outside-in tracking (Mehler-Bicher and Steiger, 2014). Outside-in methods are characterized by the camera or cameras recording the scene from outside the interaction area, i.e. directed at the object to be monitored from the outside capturing the tracking data from the recorded video stream. In most cases, the methods combine several cameras with the objective of increasing the interaction area or being less susceptible to masking. The advantage of outside-in methods is that the user does not have to carry heavy cameras including their electronics. In combination with marker-based methods, however, the user may have to carry markers. The calibration of outside-in methods is usually carried out with the help of test objects of known shape and size that are moved inside the monitored space. The disadvantage of outside-in methods is that they may require many cameras to cover larger areas of interaction and that the total costs, especially when using special cameras, can quickly increase. Further problems may arise if the cameras used are facing each other and if flash lights are used for illumination, as this can lead to dazzling images resulting in malfunctions of the entire AR system (Grimm et al., 2013).

Basically, a distinction can also be made between visual and non-visual tracking (Mehler-Bicher and Steiger, 2014). Visual tracking, also called optical/vision-based tracking, is usually realized with a video camera. In recent years, optical tracking methods have become increasingly popular because they enable high accuracy and flexible use. Different methods are used in the field of optical tracking. In particular, feature-based systems exist, these are camera-based tracking techniques which recognize characteristics within the camera image and assign them to already known models from an existing database (Mehler-Bicher and Steiger, 2014). These may be 2D or 3D models. In this respect, it constitutes a generic version of the marker-based tracking approach. They are rooted in the idea of using objects recorded in the video stream to determine the relative positioning and orientation of objects relative to the camera (Hartley and Zisserman, 2003). Non-visual tracking methods or sensor-based tracking include compasses, GPS, ultrasonic sensors or inertial sensors (Yu et al., 2016; Mehler-Bicher and Steiger, 2014).

2. *Registration component* to link virtual objects with real counterparts:

Registration or recognition refers to embedding or correctly fitting artificial virtual content into reality. This means that on the basis of the position and position estimation of tracking, the coordinate system of the individual virtual contents and the observed reality are put into relation in such a way that virtual contents appear firmly located (registered) in reality. This leads to the fact that an artificial object that does not move in the virtual world also appears to have a fixed place in reality, regardless of the changing point of view of the user (or the camera) (Broll, 2013).

The correct integration of virtual content into the real environment is also called geometric registration. Meaning that a virtual object appears to be at the same place in reality when the camera perspective changes. The correct registration in relation to the lighting situation of the real environment is called photometric registration. In this respect, geometric registration is a basic requirement for the use of AR, whereas photometric registration is still only carried out in isolated cases (Broll, 2013; Mehler-Bicher and Steiger, 2014).

3. *Visual display and output component* to create augmentation by replacing or expanding real elements with virtual elements:

The representation of virtual content is based on the transformations of the respective camera perspective resulting from the (geometric) registration (in the case of camera-based tracking methods). This process is called rendering. The recorded video image is correctly superimposed by the virtual content and thus the actual augmentation is carried out. The resolution and sharpness of the virtual image often have to be adjusted for a seamless overlay (Broll, 2013).

For the effective use of AR, a variety of user interfaces equipped with different projection methods have been developed. When selecting the display and output components for AR applications, the method of augmentation (optical see-through, video see-through or projection-based) and the output devices as hardware components are important.

What all AR methods have in common is that they are based on a spatially correct projection of the virtual content into the user's environment or into the previously recorded video image. The point of view and the viewing direction between the real and virtual environment must coincide at all times. Furthermore, the virtual field of view must correspond to the actual field of view of the respective display. Ultimately, the scope of the virtual content needs to be adapted to the real environment. Ideally, the perspective of the captured image and that of the user should also match. This gives the user the impression that his environment has changed immediately. He looks through the display at the underlying reality, even if, depending on the degree of augmentation on the display, only a video image of reality can be seen. In this case, the so-called magic-lens metaphor is present (Brown and Hua, 2006).

In contrast to the AR technology described so far, a video image of the real environment is not absolutely necessary with optical see-through AR. In fact, the real environment is always directly perceived by the viewer. For this purpose, the virtual contents of reality are optically superimposed by the output device (Broll, 2013). This represents a display strategy in which the virtual superimposed content is projected onto beam splitters (e.g., half mirrors or combined prisms), so that the real world remains visible in the background (Billinghurst et al., 2015; Schmalstieg and Höllerer, 2016).

In video see-through systems, visual sensors (e.g., RGB camera, infrared camera or similar) are used to generate a video image of the real world, which is expanded in a further step by virtual content, i.e. correctly superimposed in detail and then displayed on an output device (Broll, 2013; Schmalstieg and Höllerer, 2016). In order to achieve the magic-lens effect described above, it is crucial that the focal point, the viewing direction and the viewing angle of the video camera and the output (i.e. the virtual camera) match. Otherwise, this leads to a separation between the viewer's real environment and the augmented environment being viewed (Broll, 2013).

Projection-based AR is characterized by the fact that the virtual content is projected onto objects of the real environment. It is a form of spatial AR (SAR), in which the augmentation is not performed by a single display or handheld device (Bimber and Raskar, 2005). In contrast to the two previous variants, spatial projection systems project the generated content directly onto real objects in space. Due to this form of projection, such AR systems are stationary according to the ubiquitous computing concept and cannot be used ubiquitously in contrast to the two previous AR system types (Van Krevelen and Poelman, 2010). Since no new spatial structures can be created by this, the AR technique is mostly concentrated on the manipulation of surface properties (such as color or structure) and the visualization of additional information on the surface (explanations, highlighting, symbols, etc.) (Broll, 2013).

1.3 Hardware

In the context of today's AR systems, three hardware types are used in different forms. Sensors and input devices are used for direct user interaction and tracking in order to determine the position and orientation of the user or device by providing information about the real world. Collected information is therefore transmitted to processors, where it is converted depending on the application and forwarded to the last hardware component, the output device (Craig, 2013). Depending on the requirements for AR systems, for the underlying hardware components and their interaction techniques, different graphical user interfaces (GUI) can be used, also depending on the method of augmentation. This is mainly achieved by visual AR displays. AR devices can be distinguished between wearables and non-wearables, as shown in Figure 3.

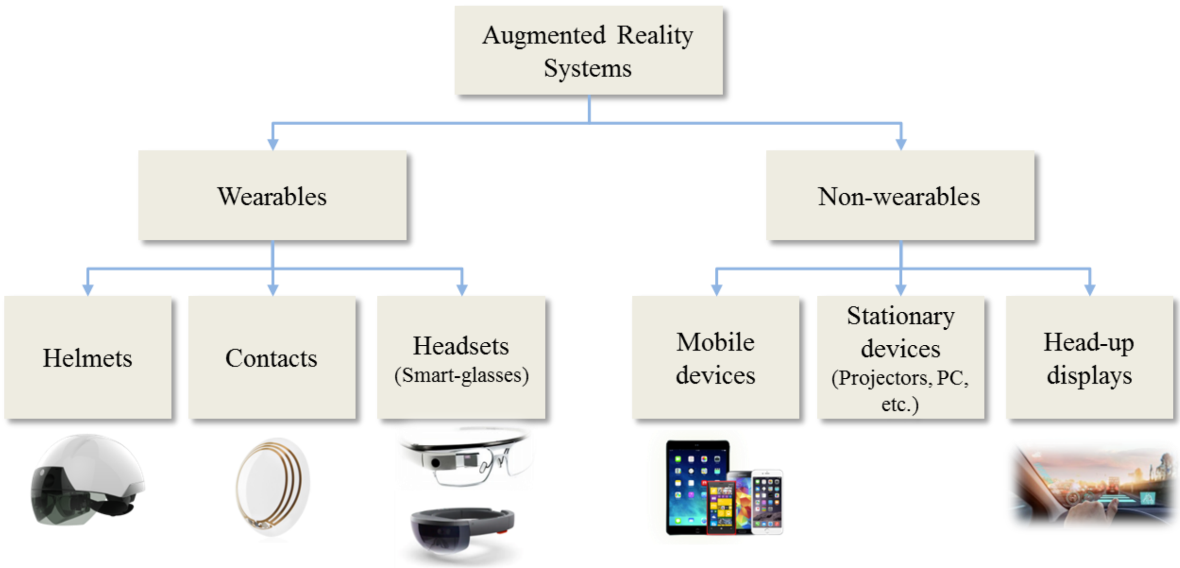

Figure 3. Overview of AR System Devices according to Peddie (2017)

Displays that are located close to the head are the most important representatives of output devices, the so-called head-mounted displays (HMD), like smart glasses and headsets (Broll, 2013; Peddie, 2017). With video see-through HMD, a video image of reality is captured by cameras attached to data glasses and then superimposed on a display directly in front of the eye, giving the user the impression of being able to view the surroundings through the glasses (Billinghurst et al., 2015; Mehler-Bicher and Steiger, 2014). The video image is correctly inserted as a background image during the rendering process. Data glasses can also be used as optical see-through displays. They allow the operator to see-through and, at the same time being able to reflect computer generated images into the user's eyes (Palmarini et al., 2018). In other words, the view of reality is always direct and immediate with such data glasses, whereby the virtual content is only superimposed optically. Basically there are different construction methods (e.g., closed or open) of data glasses with equally different effects on the perception of the environment. While the field of vision of the user is limited to the field of vision of the data glasses in closed designs, in contrast, the environment outside the display can be perceived without restrictions in open designs (Broll, 2013).

Body-attached devices are handheld displays like smartphones or tablets. As the computing power of smart mobile devices continues to evolve and increase, AR technologies are increasingly being integrated into smartphones and tablets as they combine processor, memory, display and interaction technology into a single device. They enable wireless handling as well as unlimited mobile handling, creating an all-in-one hardware system and rapidly increasing the number of computer vision based AR applications (Martínez et al., 2014). Due to the built-in cameras video see-through is the preferred concept here. Integrated video cameras capture live video streams of the environment that are overlaid by graphical augmentations before displaying them (Bimber and Raskar, 2005). Due to their widespread use, portability and often standard sensor technology (GPS, motion sensors and/or compass functions), AR systems are becoming increasingly important for handhelds in everyday life and a growing awareness as well as for AR technology acceptance (Mehler-Bicher and Steiger, 2014; Schmalstieg and Höllerer, 2016).

The last category for visual displays is spatial displays. SAR systems project the virtual content directly on the real-world objects in actual dimensions and proportions (Kiryakova et al., 2017). Spatial displays are usually installed at a fixed location in the surrounding environment and include screen-based video see-through displays (e.g., flat screens, notebooks, holograms), optical see-through and projection-based displays. This type of display is suitable for large presentations and exhibitions with limited interactions (Van Krevelen and Poelman, 2010).

2 Applications of AR in the Automotive Industry

2.1 Design & Prototyping

A high-quality product design is a crucial factor for the success of a new automobile (Fründ et al., 2005). Traditionally, the process of design and prototyping in the automotive industry is supported by computer-based software, namely computer-aided design (CAD) (Ong et al., 2011). With an increasing number of equipment and model variants, the design and development process is becoming more cost and time intensive. In order to counter this development, virtual technologies were introduced in the design and development process to enhance the CAD process (Dörner et al., 2013; Ong et al., 2011). Nonetheless, the purely virtual development of vehicles also has some disadvantages. On desktops, it is difficult to evaluate the shapes, curves and geometry of models because the representation is not realistic. On conventional displays, virtual data is displayed in scaled proportions and the user has no reference to reality. The perception of these completely virtual models therefore usually does not correspond to reality (Dörner et al., 2013). Due to these weaknesses, AR is gaining in importance in the design and development process of the automotive industry. The advantages over purely virtual methods are where interaction with tangible objects is of importance (Ong et al., 2011).

One application is the use of SAR to project different designs onto hardware models using projections. Different designs and arrangements of the individual elements are simulated on a real scaled model (Menk et al., 2011). This allows numerous equipment variants to be designed with little effort. Studies have shown that the acceptance of SAR among employees is significantly higher than with conventional visualization applications, since the models can be assessed particularly realistically (Menk et al., 2011). Another application is design and prototyping via HMD using Microsoft HoloLens at Volkswagen (VW). AR is used during the early design phases to virtually assemble the new vehicle models on a platform. While the platform basis sets the real component in the AR application, various components like the exterior are augmented on the basic platform model. Virtual components are generated by 3D-CAD-data (Fründ et al., 2005). The computer integrated in the glasses is controlled by voice and gesture control. At the same time, the HMD also serve the purpose of collaborative design. Different project teams can work together at the same time, regardless of location (Dörner et al., 2013). Engineers, planners and designers can thus already be involved in early design phases for discussions and brainstorming. Participants can visualize the model, track changes in real-time, compare and make decisions (Dörner et al., 2013). As engineers have profound knowledge of the following production steps, the design teams benefit from their experience downsizing the design process (Ong et al., 2011).

2.2 Manufacturing

Manufacturing is one of the application fields of AR, in which its use offers large potential for the improvement of existing techniques and promises solutions for problems of the future (Ong and Nee, 2004). Increasing digitalization is making information flows more dynamic and changes in production are taking place. In addition, the number of product variants is increasing and production tasks are changing more and more frequently. This particularly affects assembly line operators within industry (Danielsson et al., 2018). The complexity of product structures and assembling sequences in combination with time pressure and the need for high quality are challenging for optimal performances of operators (Syberfeldt et al., 2015). AR as an information system in manufacturing is one way to cope with the increasing complexity (Danielsson et al., 2018). AR aided manufacturing stands for the support of all activities in the manufacturing process by AR (Novak-Marcincin et al., 2013). It qualifies for a wide range of problems across the whole assembly process (Wang et al., 2016).

In order to increase the quality of the manufactured products, General Motors (GM) relies on SAR for industrial quality assurance of welding spots (Doshi et al., 2016). A typical vehicle body has thousands of welding spots, which frequently have to be examined for their quality (Zhou et al., 2011). By using SAR as a method, GM provides visual aids to the welder to increase the precision of manual welding. Computer generated virtual imagery is superimposed on the physical surface of automotive parts using SAR. Virtual cues show the operator both the exact position and the tolerance range on the vehicle part (Doshi et al., 2016). This procedure has several advantages in the manufacturing process. The system is unobtrusive for the user as he does not have to carry or operate any additional equipment. Moreover, workers can perform their work much faster because the weld spots on the body are easy to find and they don't have to use another medium to find the spots that need to be spotted. In addition, the quality of the work has improved significantly. The precision of the welding spots of trained operators has improved by 52%. Thus, the SAR system not only contributes to the user having an optimized workflow, but also improves the process as a whole without burdening the operator (Doshi et al., 2016).

In logistics in particular, digitization can offer great advantages for companies in terms of employee efficiency. So far, workers in more or less well-assorted warehouses have had to search laboriously for every item that is needed, for example, for the production line in automobile production. By using AR in the form of smart glasses, employees can be given specific information about the exact location of the product they are looking for. The data goggles can also detect when the worker is reaching for the wrong product and warns him visually by a signal in the display of the goggles as well as acoustically. Thus errors can be minimized. In addition, production comes to a standstill much less frequently because workers are less prone to errors and urgently needed products are available on time in production. This approach can result in massive cost savings, as less time is required for companies to find a part. VW uses these spectacles for the aforementioned purpose in logistics at the German plant of Wolfsburg. Here, the data goggles automatically scan the codes of the respective crate and thus recognize whether it is the correct crate. At VW, considerable time savings could be observed, so that by use of the glasses a more efficient work was enabled. Based on these positive experiences, VW plans to use this system in the next few years (Huber, 2016).

AR technology can also be used in completely different locations than the warehouses in the company. For example, Audi is researching a system in which the AR glasses support the employee in the functional test department. In this way, the worker can be shown instructions on his current work in real-time and the results of the functional test can be documented. However, Audi did not introduce this system because the great advantages of greater efficiency due to the fact that the manual documentation of the results is no longer required and that there are still too many problems at present. On the one hand, the battery life of the glasses was still too short for smooth use in production, on the other hand, the cameras needed to detect the respective step had problems with poor lighting conditions. Nevertheless, research on this promising technology continues (Huber, 2016).

2.3 Maintenance & Repair

AR is another enabling technology that can be used for dealing with the increasingly complex maintenance procedures (Mourtzis et al., 2017). Maintenance and repair service activities are mostly done manually by skilled technicians following rigorous procedures in documenting and carrying out maintenance operations in a relatively static and predictable environment (Alostad and Aziz, 2018). Manual process means that operators need to physically navigate tasks in maintenance and this can be extremely time consuming (Mourtzis et al., 2017). Even the most trained maintenance personnel still need to follow manuals in restricted space. Although the instructions are often shown schematically or illustrated by pictures, they are not necessarily intuitive in today's vehicles (Gay-Bellile et al., 2015).

State-of-the-art vehicles are characterized by a constantly increasing complexity. In the last 15 years most OEMs have more than doubled the number of vehicle models and derivatives while reducing the average product cycle from eight to six years (Deloitte, 2016). The reasons for the increasing product complexity are above all the ever increasing demands of customers (e.g., infotainment systems and customizability) and the permanent competition as well as innovation pressure, whereby the manufacturers are forced to always offer the latest digital and connected car services (Deloitte, 2016). Regulatory requirements, such as safety relevant features or vehicle modifications to emission limits, increase the complexity of vehicles, user manuals and maintenance operations resulting in higher time consumption and higher human error probability (Martinetti et al., 2017). As a result, technicians need to be increasingly qualified to maintain not only the electrical and mechanical parts of vehicles, but also their digital components (Porcelli et al., 2013). For OEMs it is therefore becoming more relevant to avoid preventable complexity in this business fields and expect in AR application in workshops and service stations to achieve process optimization and added customer value at the same time (Deloitte, 2016; Lucas and Wagner, 2017). Therefore, more and more efforts are currently being made by OEMs and suppliers to make car maintenance and repair services a potential area for the application of AR technology to significantly assist service employees with digital information in their day-to-day activities (Martinetti et al., 2017).

The requirement of effectively supporting service technicians led to advanced developments of AR application scenarios in workshops. These include, e.g., displaying step-by-step repair instructions and maintenance related information to perform tasks (e.g., live equipment visualization, assembly configurations and test specifications), x-ray functionalities to display hidden areas within the car or digital user manuals that can be augmented into the real image on AR devices by only capturing the vehicle with a built-in camera (Gay-Bellile et al., 2015). A number of solutions have emerged, either by using HMD or smart devices, testing various ways of AR system user interaction (e.g., voice commands, gesture control, device-hosted menus). The potential of AR in supporting maintenance tasks is renowned especially by large automotive businesses and suppliers (Mourtzis et al., 2017). Mobile markerless augmented reality solutions such as the Mobile Augmented Reality Technical Assistance system (MARTA) from the Volkswagen Group or the Common Augmented Reality Platform (CAP) from Bosch are just two examples that may address the issues mentioned. Both visual display systems do not require special tracking methods with markers.

MARTA provides employees with real-time information about step-by-step instructions and additional information (e.g., relevant repair tools) in real-time by capturing the world video and adding virtual information and showing them on handheld displays (Volkswagen AG, 2018).

Bosch is pursuing a similar approach with the development of the AR platform CAP. Through the integration of a comprehensive data base, from which relevant data on the object under consideration is extracted and matched with the real world for the relevant AR application, hidden areas or components as well as cable routing behind the dashboard of vehicles can be visualized as 3D animation on a tablet screen. By means of the touch screen, the displayed objects can be con-trolled and additional information can be accessed. It is possible to display step-by-step instructions and required tools at the live image, but also video clips, pictures, safety cues, audio clips, technical drawings and 3D data can be accessed. Besides the use of handheld displays, Bosch promotes the use of the CAP with HMD technologies, which allows service technicians to carry out direct error diagnoses and virtually displayed repair tasks on the vehicle with both hands free. Bosch (2018) claims that by using their platform it would be possible to reduce complex repair time by 10-15% (Bosch, 2018).

In the assembly environment on the production floor of large automotive companies, quality assurance maintenance and repair activities are becoming increasingly complex (Lamberti et al., 2014). The use of AR technology for vehicle quality assurance and maintenance of machinery or robots on the production floor works in the same way as augmented maintenance and repair activities in service stations and workshops.

Since February 2018, Porsche has been testing the use of AR in quality assurance (Porsche AG, 2018). The basic idea is that quality professionals can take photos of parts or assemblies on vehicles under inspection, and then compare those images to ones provided by the company's suppliers via an augmented reality overlay. By using augmented reality technology, a technician can therefore analyze a part that failed tolerances and determine if it is salvageable or needs to be fully replaced. For this purpose, vehicle-individual CAD data is imported into a tablet app. By simply holding the tablet over a vehicle component to be controlled, the respective CAD image is superimposed into the live image, making flaws or derivations immediately visible. Detected flaws and errors can then be stored in the plant's central data base and made available word wide. Additionally, the test process can be streamed in real-time to any site or partner (Porsche AG, 2018). More recently, the concept of enabling communication between an expert and the on-spot technician has arisen. In AR literature this feature is often called tele-maintenance or remote assistance (Lamberti et al., 2014; Mourtzis et al., 2017; Porcelli et al., 2013). One corresponding approach was made by Mourtzis et al. (2017). They developed a system that implements AR technology for remote maintenance support, to enable cloud-based communication between, e.g., technicians with limited skillset to deal with malfunction of certain machinery on the production floor and a supervising expert from elsewhere. In case of a malfunction or concerning scheduled maintenance, the technician can create a malfunction report, using an AR application on an AR device. Text descriptions, photographs or sound recordings can be used to create a detailed description of the situation. The maintenance support operator can access this report stored in the cloud and edit it from any location (remote maintenance) (Masoni et al., 2017). Exact instructions or additional information can then be provided in an AR instruction scene sequence, adjusted to the problem, by the supervising expert. In order to do so, access to cloud data bases and consults are possible. In doing so, the reuse of pre-created part movement scenes, scripts, etc. allows the expert to quickly respond and create AR step-by-step instructions to perform the maintenance or repair task. The combination of features like malfunction report composition, remote diagnosis, AR instruction generation and maintenance and evaluation, targets at improving maintenance support efficiency and making already applied expertise reusable, which also reduces machine downtime (Mourtzis et al., 2017). Figure 4 illustrates the basic idea of a tele-maintenance framework.

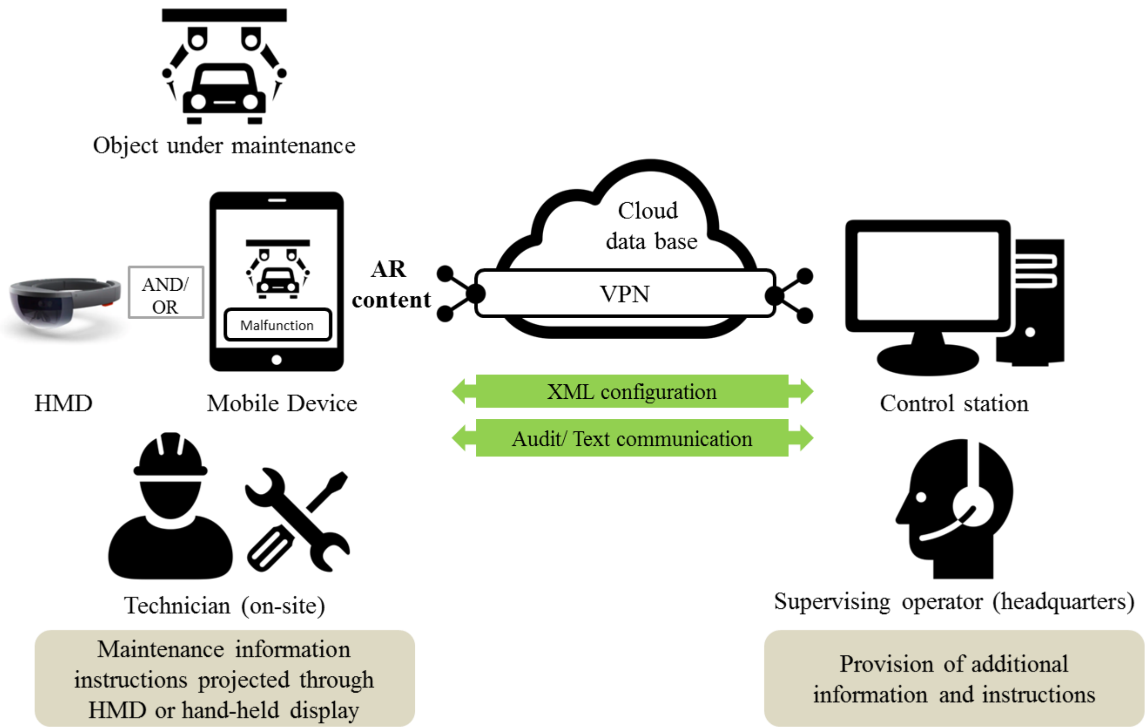

Figure 4. Exemplary Illustration of an AR-based Tele-Maintenance Framework according to Lamberti et al. (2014) and Mourtzis et al. (2017)

2.4 Training

Another important application of AR in manufacturing is assembly training. With changing production conditions by changing equipment variants or models, the required skills of the workers also vary. Efficient training methods therefore play an important role in the automotive industry. AR has proven effective in supporting assembly training in specific industrial contexts by providing time efficiency, high effectiveness and the assurance that technicians will achieve immediate capacity to perform the task (Wang et al., 2016). HMD in particular are used to provide operator guidance on assembly processes. Context sensitive applications are also widely used that superimpose reality with information on individual components and processes.

Compared to other industries (e.g., military, healthcare, aeronautics, etc.), AR applications as a system for improving the training of maintenance operators has only recently been introduced. This is shown by various international projects for the development of AR and MR systems assisting car service operators (e.g. the European project SKILLS and VISTRA), as well as already mentioned tools like MARTA or CAP (Borsci et al., 2015). Given the economic relevance of service and maintenance in the automotive business in terms of customer loyalty and overall brand experience, the quality and efficiency of car maintenance services is of crucial importance for OEMs (Gaiardelli et al., 2014). Since the automotive industry has emerged as one of the most competitive markets (Godlevskaja et al., 2011), the increasing product complexity, the growing number of vehicle models and configurations for reasons already mentioned, the complexity of maintenance tasks in the assembly and car maintenance service environment is all the more increasing. This requires efficient training and assembly skills that accelerate technicians' acquisition of new maintenance procedures (Webel et al., 2013). Therefore, AR technology is increasingly under investigation by OEMs and suppliers on how AR (or MR) systems are able to effectively assist maintenance technicians in daily operations and specifically participate in future operators' training. Since the application of AR systems as a use case in car maintenance has already been presented in the previous section, this subsection concentrates specifically on AR usage in training scenarios.

Findings from the several experiments revealed that an animated AR system yielded shorter task completion times, less assembly errors, and lower total task load (Gaiardelli et al., 2014; Gavish et al., 2011; Hou et al., 2013). The results also revealed that the learning curve of novice technicians was reduced and task performance relevant to working memory was increased when using AR training (Hou et al., 2013). Based on such research results, OEMs and suppliers are implementing more and more AR training applications.

Since autumn 2018, the automotive supplier Bosch has started to offer AR-based training and education in Germany and Denmark. The AR platform CAP makes it possible to publish new content and applications, especially for the training sector. The platform accesses existing locally or centrally stored content and compiles the data required for the desired AR application. This also allows different training scenarios to be implemented, which can be expanded as desired and transferred to any hardware platform. In the so-called "trainer mode", the trainer controls the participants' end devices and decides which application scenario they see on their devices. The individual point of view of each individual, such as the engine compartment, is retained.

In the so-called "trainee mode", the trainer switches to a participant's device and can thus give him direct advice and tips on how to proceed. By using HMD, trainees can project the training content selected by the trainer directly into the real image. Using UMTS and VPN transmission, remote multi-user trainings are also possible in a connected workshop. If, for example, an engine block is to be disassembled into its individual parts, the trainer may transfer this in a 3D animation to the end devices of each participant, even if he or she is not physically present. For trainees who are equipped with a HMD, a realistic virtual image of the engine in the real world is then displayed. The assembly/disassembly steps of certain vehicle components can also be projected into the real-world image at the correct position. This allows trainees the visual and tactile understanding on how complex vehicle components, electronics or driver assistance systems work and how they are constructed, making learning more interesting and easier. Since the trainee can interact with the real-world objects and simultaneously access the additional virtual information for guidance, there would be no need to use "external" separate training material (e.g. analogue user manual or text books). Additionally, remote training enables trainers, especially in large corporations, to hold training sessions from a random location and enables trainees to participate from a random location (Bosch, 2018).

3 SWOT-Analysis

A SWOT analysis is a strategic planning tool to systematically assess and evaluate strengths, weaknesses, opportunities, and threats of an organization. While strengths and weaknesses are typically internal to an organization, opportunities and threats usually refer to external or environmental factors. Developed by the Harvard Business School in the 1960’s, the objective of the SWOT is to investigate interdependencies between the organization and its environment and to derive recommendations for the organization (Müller-Stewens and Lechner, 2011). The internal analysis assesses strengths and weaknesses of the observation object itself, including core capabilities, skills, routines, and resources. It also involves a comparison with competitors to clearly identify where the organization is considerably better or weaker (Matzler et al., 2013). The external analysis reviews opportunities and threats, and, as suggested by Matzler et al. (2013), can be supported by means of a PEST analysis to strategically assess political, economic, social and technological factors. Outcomes of the sub-analyses of the SWOT are then integrated into a 2x2-matrix, allowing to correlate all aspects with each other and to draw recommendations for strategic planning, with the ambition to maximize strengths and opportunities and minimize weaknesses and threats (Pearce and Robinson, 2011).

3.1 External Analysis

Political Environment

Politically initiated measures and restrictions (e.g., on safety standards or CO_2 emission reduction) illustrate the influence of the political environment on the strongly export-oriented automotive industry (Proff and Proff, 2012; Wyman, 2012). Achieving environmental goals appears on the immediate agenda of the triad market governments and many growth markets (Jaroschinsky, 2018). In order to meet the targets agreed by politicians and to avoid the threat of additional costs and penalties in the event of non-compliance with politically prescribed standards in the respective sales markets, the automotive industry is increasingly reacting with R&D activities (Thierhoff and Müller, 2016). Due to the implementation of numerous safety and assistance systems, alternative drive technologies (e.g., e-mobility) and the constant need for new vehicle modifications, the number of product innovations, product and component complexity and demands on vehicle development are increasing (Martinetti et al., 2017). Furthermore, rigid local-content requirements in the countries (i.e. the maximization of local production) force OEMs to shift their production to the respective countries in order to reduce transport risks and logistics complexity. This presents suppliers in particular with major investment and management challenges, as they also adapt their production and logistics processes (Steinberger, 2010). Given the activities of manufacturers and suppliers in various sales markets, political and economic stability in the respective countries plays an important role in maintaining competitive advantages in terms of location. In addition, political conflicts can have an impact on the banking sector in the market and endanger the financial stability of companies (Jaroschinsky, 2018).

Economic Environment

The importance of the automotive industry in Germany is particularly high. In 2017, total industrial sales amounted to €426 billion, representing growth of 5.6% compared with the previous year. This makes the automotive industry the sector with the highest turnover in German industry and accounts for around 20% of total industrial turnover (VDA, 2019). However, most of this revenue was generated outside the domestic market (Bormann et al., 2018). The worldwide demand for automobiles is increasing and more and more vehicles are being produced. This is mainly due to the development of growth markets. Emerging markets are becoming increasingly important for manufacturers and suppliers in the automotive industry due to increased sales potential (Wyman, 2012). Because of the capacities of these markets, production abroad will continue to grow faster in the future than at domestic level. China and Brazil in particular offer great opportunities for future growth in sales markets with large market volumes. The Chinese market offers the potential to triple by 2030 (Schade et al., 2012).

Vehicle production is thus proof of the structural change in the global economy (Thierhoff and Müller, 2016). In addition to the shift in sales markets, markets outside the major industrial nations also play a role due to lower production costs (Sopha, 2012). In order to ensure international competitiveness, it is essential to reduce production costs. Since automobile manufacturers are in global competition, development and production are carried out across national borders in order to exploit cost advantages (Sopha, 2012). Due to globalization, automobile manufacturers are confronted with international competition. Innovative strength can be regarded as a decisive success factor that determines the competitiveness of automobile manufacturers (Gottschalk, 2006). The global competitive pressure and the associated innovation performance and cost efficiency of the players on the market will ultimately lead to a concentration within the industry (Gottschalk, 2006).

Social Environment

The social analysis of the automotive industry's environment shows that supply and complexity of the market are increasing. As a result of global competition, manufacturers have to satisfy needs, which competitors outside of the domestic market are able to satisfy (Proff and Proff, 2012; Wyman, 2012). This makes supply much more fragmented and individualized. After all, the individualization of society in consumer markets results in an increase in the variety of products on offer (Schindler, 2006). In the automotive industry this trend affects the variety of models, drive technologies, and equipment variants. By using module and platform strategies, an attempt is made to minimize the costs associated with this trend (Proff and Proff, 2012).

As a result of digitalization, market transparency is increasing and the bargaining power of end-users rises (Crone and Werner, 2014). For this reason, the rising costs for increased need for innovation and complexity due to the development of individualization can only be passed on to consumers to a limited extent (Wyman, 2012). Automobile manufacturers must therefore try to save these costs in other ways. Another social development of industrial markets is the much more demanding and less easily persuaded customer. As a consequence of this change, brand loyalty is progressively decreasing. If the performance of a product does not meet the requirements of the customer, they tend to change the supplier of the product if there are products of equivalent quality. Brand loyalty has consequently been replaced by brand preference (Jahanshahi et al., 2011). Furthermore, the society in Germany and Europe is undergoing a structural change. On average, society is getting increasingly older. It is estimated that Germany's population will fall to 65 million by 2050 (Obermeier, 2014). As a result, the total number of available workers will also decrease. Scientists agree that there is no general shortage of labor. However, there are shortages of skilled workers in certain sectors. There is already a severe bottleneck in the machinery and vehicle technology sector. This can be put at 4.4 vacancies per unemployed person. In addition, the increasing technologicalization of the world of work is accelerating exclusion and selection processes on the labor market. To put it simply, on the one hand, technology-related redundancies will be made at the expense of the low-skilled, and technology-related attitudes will be made at the expense of the more highly-skilled.

Technological Environment

The disruptive technological change and the increased technological complexity of today's vehicles is the consequence of the political, economic and socio-cultural influences. Therefore, a continuous adaptation of technical innovations in the automotive sector is inevitable (Wyman, 2012). In the political context, both ecological and technical regulations (e.g., safety equipment, weight and emission reduction) create difficulties for OEMs and suppliers in the shape of additional costs for technological solutions (Wyman, 2012). Since sustainability, resource conservation and climate protection are not only part of the political agenda but also a global trend, car manufacturers and suppliers cannot avoid implementing ecological guidelines (Diez et al., 2012). Economic competitive advantages in the automotive industry are primarily achieved through the development of innovative technologies, which is why manufacturers and suppliers make the highest R&D investments compared to other industries (Kleinhans et al., 2015). Trends like power train electrification and autonomous driving are additionally causing a major structural change in vehicle manufacturing, while fast technology developments have already led to higher component variety and increased complexity costs (Diez et al., 2012; Martinetti et al., 2017; Wyman, 2012). Platform module and modular strategies significantly contributed to increasing the efficiency of OEMs. This approach makes it possible to produce high quality lot sizes in large quantities, despite the high variance of vehicle types, while simultaneously reducing development times (Kleinhans et al., 2015; Schade et al., 2012). Moreover, increasing customer requirements with regard to individualization options are a reason for growing variant and technology diversity and thus also a driver contributing to complexity (Diez et al., 2016). At the same time, product life cycles have shortened to less than four years (Deloitte, 2016). In order to continue to be able to cover the product variety and to produce efficiently, (innovations in processes are required (Kleinhans et al., 2015). Platform module and modular strategies can also be applied in this scenario. The structural change, through the expansion of the OEMs' vehicle furniture range to include electric vehicles and later autonomous driving, can lead to considerable power shifts in the entire automotive industry between all involved stakeholders. From a technological view, the entire automotive industry is under constant pressure to innovate as it is becoming steadily more difficult to achieve competitive advantages through technological advances based on rapid technological developments (Jaroschinsky, 2018).

Based on these before mentioned analyses, the resulting opportunities and threats are presented:

Opportunities

Due to the socio-cultural development of individualization, car buyers are becoming more and more demanding. Even with a product for the mass market such as a car, they are looking for performance and design elements that make vehicles unique (Mohr et al., 2013). In this way, uniqueness and individual taste are demonstrated through the status symbol car. Car manufacturers are responding to this development with an increasing variety of variants in order to serve niches (Mohr et al., 2013). This diversity relates both to vehicle models and their equipment. In order to make this diversification profitable, the models make use of common product elements (Schade et al., 2012). In the high-price premium segment, opportunities for OEMs lie in identifying further niches. In segments with lower price levels, the opportunity lies in producing as many vehicles as possible on as few platforms as possible in order to save costs (Proff and Proff, 2012). As a result, it is therefore possible to optimize the platform strategy across vehicle segments, different markets and price levels (Mohr et al., 2013).

Another opportunity arises from the ongoing growth of the global automotive industry. This growth is not only taking place in the industrial nations, but the center of growth is increasingly shifting to emerging markets (Schade et al., 2012). The share of established markets in global vehicle sales will be only 40% by 2020. The greater part of demand, 60%, will come from the new markets (Mohr et al., 2013). More than half of future profit growth will be in the premium segment. Since the German OEMs in this vehicle segment have the best basis with a large variety of products, this development is an opportunity to strengthen the competitive position of German manufacturers (Bormann et al., 2018).

Threats

Numerous developments in the environment of automotive manufacturers lead to threats to their position in the business environment. Some particularly severe developments result from changes in customer behavior. Since society is becoming increasingly individualized, there are no longer any individual solutions that cover a large part of the demand on the market (Schade et al., 2012). Customers are increasingly demanding and want to customize their vehicles according to their individual preferences (Mohr et al., 2013). Manufacturers are forced to meet this customer demand because brand loyalty has given way to brand preference. If a manufacturer does not fulfill the customer's expectations, consumers will not be deterred by a sense of loyalty from buying another product from a competing company. This development has the consequence that automobile manufacturers have to develop and offer an increasing number of models and equipment variants (Schade et al., 2012). Additionally, these developments pose a threat of cost pressure by satisfying increasingly individualized customer wishes. Increased costs result from additional expenditure in all areas of the company, while at the same time the number of individual models decreases. As a result, the economies of scale of lean production could be lost. Increasing complexity and cost pressure are also being exacerbated by the political environment of the German economy. The government is forcing the rapid development of alternative drive technologies for vehicles with lower emission values through legal regulations. In order to meet these legal requirements, OEMs must make substantial investments. This budget is therefore not available for the development of new features that can differentiate companies from their competitors. In summary, numerous developments of a political and socio-cultural nature pose a threat to increasing complexity and cost pressure.

An economic development that is of great importance for automobile manufacturers and their strategic positioning is globalization and its consequences. Competition takes place on a global level and, for this reason, automobile manufacturers face new challenges. On the internal market, there is a risk of a competitive disadvantage compared to overseas companies, as production costs in Germany and Europe are comparatively high. By the year 2020, the share of the worldwide turnover of the emerging markets will increase to 60% of the total turnover of the automotive industry (Mohr et al., 2013). However, the production facilities of the German automotive industry are not sufficiently geared to potential capacities. Moreover, demand in these markets is primarily for smaller vehicle classes. The OEM locations' portfolios are not yet sufficiently geared to this demand. As a result, there is a risk of a "portfolio mismatch" (Mohr et al., 2013). Another danger poses social change for the automotive industry in Germany and Europe. The population in the industrial nations is declining while the average age is rising at the same time. This development strengthens the development of a shortage of skilled workers, which is currently already present in the areas of mechanical engineering and vehicle technology (Obermeier, 2014). In the long term, this development could lead to manufacturers being unable to meet market demand due to a lack of production capacity (Mohr et al., 2013).

3.2 Internal Analysis

Strengths

In the production process, the use of AR systems in manufacturing and assembly offers decisive advantages for the executing technicians and mechanics. When executing complex assembly tasks, the executing assembly worker receives significant assistance through AR solutions. By using camera-based smart AR devices in the form of handheld displays, the executing operator can retrieve critical information (e.g., on required tools or how to perform a specific task) in complex situations on-demand and in real-time (Gay-Bellile et al., 2015). If an additional HMD is used to display this virtual content in the direct field of view, this offers the possibility to simultaneously carry out the work and document the process in real-time (Martinetti et al., 2017; Turić et al., 2015). Leaving the workstation for time-consuming task or component research is therefore not necessary and the assembly tasks appear less complex, which accelerates the assembly process (Turić et al., 2015). Through remote assistance systems, maintenance operators are able to consult technical experts in real-time for complex assembly task or machinery repair operations. The expert can then guide the executing maintenance operator at the production floor from any location via textual instructions or the provision of animated operation sequences (Porcelli et al., 2013). Here AR opens up an additional interface for a worldwide, seamless flow of information. This reduces costs and accelerates maintenance and repair work. In addition, AR can be used in production and analytics to improve manufacturing processes and ensure the quality of supply through regular virtual checks (Lamberti et al., 2014; von Lewinski, 2017).

As an additional strength for OEMs are a higher level of employee performance accuracy and lower human error probabilities, faster task completion and therefore higher productivity (Alostad and Aziz, 2018; Borsci et al., 2015). The support of HMD and tablets reduces the complexity of tasks and thus reduces task completion time and effort. Live remote assistance by technical experts from any location, at any time, during the work process reduces the technical competence requirements on the assembly personnel on-site of a production plant. Especially Tier-1 and Tier-2 suppliers, who provide assembly machinery, vehicle components, electronics and/or software solutions for automobiles, telemaintenance is a strength or an advantage, because in case of a problem at production site or at workshops, it is not necessary to have highly-skilled engineers on site .

This also applies to maintenance and repair operations both at manufacturing site and in workshops. Car workshops and OEM service shops benefit from the AR technology to the extent that maintenance workers can be virtually guided by receiving necessary digital maintenance or repair instructions either with the help of HMD or handheld devices (Bosch, 2018; Halim, 2018). Error detection and rectification is facilitated as even hidden vehicle parts, cables or electronics behind the dashboard can be identified, virtually displayed, analyzed and quickly rectified at the intended location in the vehicle (Bosch, 2018). Repair and maintenance work are simplified in such a way that even the end customer can carry out minor maintenance tasks on the vehicle using instructions via AR apps (e.g., oil change) (Halim, 2018; von Lewinski, 2017).

This prevents time-consuming searches in increasingly comprehensive user manuals or technical documentation, as task-related information on components can always be displayed in the field of view of an HMD carrier or on the tablet display (Alostad and Aziz, 2018; Turić et al., 2015). Frequently occurring errors, 3D animations to correct errors, as well as remotely supported task completions can be recorded, documented, stored and permanently accessed by connecting AR applications to central enterprise databases, making the re-usability of already applied knowledge another strength of AR systems in the automotive industry (Mourtzis et al., 2017; Turić et al., 2015). In addition, the acceleration of maintenance and repair services and quality improvement, reduced customer waiting times, fewer errors when performing maintenance, and the possibility of virtual leadership (e.g., step-by-step repair instructions) via AR applications in workshops leads to improved customer loyalty and greater trust in the long term, as well as increased customer satisfaction (von Lewinski, 2017).

In automotive production, this strength is reflected in reduced machine downtime costs. The use of AR-based HMDs for repair work on production facilities continues to enable hands-free working, which makes improvement of employee safety a further strength (Gay-Bellile et al., 2015).

Furthermore, AR has proven effective in supporting assembly training in specific industrial contexts by providing time efficiency, high effectiveness and the assurance that technicians will achieve immediate capacity to perform the task (Wang et al., 2016). AR offers advantages especially for the education and training of personnel. Through collaborative training using AR platforms, visual and manipulable 3D animations of real-scaled vehicle components and parts can be presented to multiple trainees simultaneously in real-time (Barfield, 2016). AR training applications allow trainers to control training content, e.g., assembly/disassembly of an engine, via tablet and transfer it to HMD in the participant's field of vision (Bosch, 2018). Compositions and functionalities of vehicle components, electronics or assistance systems can thus be visualized and internalized more quickly by AR usage, which is why complexity reduction is also a major strength of AR systems here. Training efficiency is increased by virtual guidance and live remote assistance, as well. Through the use of AR technologies, training can be designed more flexibly and adapted as required. Due to the expandability of AR applications, it is also possible to react quickly to new vehicle variants or models during training. Faster learning of complex assembly and maintenance tasks can also be seen as a strength for manufacturers and suppliers alike (Borsci et al., 2015; Mourtzis et al., 2017; Mourtzis and Vlachou, 2016).

AR applications offer OEMs various advantages during the design process and prototyping. The use of SAR platforms enables to overlay the real-world image with virtual real-scaled 3D models, based on existing 3D map-based CAD data in geometrically correct form and size. Digitally designed vehicle parts can be made realistically visible and tactile through the application of HMD (Gay-Bellile et al., 2015; von Lewinski, 2017). Visualization and manipulation of real-scaled prototypes can therefore be seen as a strength coming from AR technology capabilities. One of the strengths of AR in design and prototyping lies in collaborative design. Different project teams can work together at the same time, regardless of location, with the help of HMDs, which facilitates decision-making process (Barfield, 2016; Dörner et al., 2013). Engineers, planners and designers can thus already be involved in early design phases for discussions and brainstorming, which improves knowledge exchange and communication between divisions across company sites, and therefore streamlines development processes (von Lewinski, 2017). Components can be virtually designed and their installation in a specific vehicle can be simulated with an AR application, design concepts can be experimentalized and processes can be iterated at will. This avoids the need for designers to actually produce designed vehicle components, reduces research and development costs and shortens the development process (von der Gracht, 2016).

Weaknesses

Despite a multitude of supposed strengths and potentials, which AR technologies and the use of AR systems imply for the automotive industry, it is above all the weaknesses of the technology that have recently led to a decline of hype around AR.

These primarily include fundamental weaknesses in AR technology. Since AR is an internet-based technology that can only be used in a production hall, for example, if stable and smooth WIFI and/or VPN connections are guaranteed, the overall connectivity requirements represent a disadvantage (Lamberti et al., 2014). Furthermore, ubiquitous network access to centralized databases must always be guaranteed and secured for use in the assembly process or in quality assurance (Lu et al., 2014; Mourtzis and Vlachou, 2016). Especially R&D data for design and prototype development are sensitive and AR systems are anyway more susceptible to security breaches and hackers due to the use of mobile devices and data glasses, which is why ubiquitous availability and data/device security can be understood as a prerequisite for AR use and at the same time as a weakness of the technology (Lu et al., 2014; Mourtzis et al., 2017). Since the benefits of AR systems are mostly derived from the use of cameras, this aspect represents a weakness in terms of privacy concerns of employees who consequently may be less willing to accept technology (Borsci et al., 2015). The lack of experience with AR in business processes and privacy concerns of users could be formulated as a lack of user acceptance. As maintenance tasks are considerably simplified by AR and thereby operators may rely on technology, there is at the same time a risk that the willingness to acquire new technical expertise decreases if AR is used excessively (Borsci et al., 2015). One weakness accordingly is the loss of knowhow, which becomes a critical aspect if AR technology is not available at one point.

Due to the current uncertainty about expected benefits (for process optimization, cost reduction or customer added value) of the technology, and uncertainty as to whether AR hardware can meet the high system requirements (e.g., tracking accuracy, processor performance, battery life of devices, gesture and noise recognition or had-to-eye tracking), current hardware maturity can still be regarded as a weakness (Gay-Bellile et al., 2015; Lucas and Wagner, 2017; Martinetti et al., 2017; Porcelli et al., 2013). This also refers to errors in the overlay technique or augmentation and localization errors of mobile AR devices, which is why experts believe the UI experience is not yet optimized (Lucas and Wagner, 2017). Furthermore, important AR functionalities, such as interaction possibilities and visualization of CAD data, require the complex integration of IoT data, which is why data management is another technology-related weakness (Porcelli et al., 2013).

3.3 Recommendations

After having conducted the internal and external analyses for AR applications in the German automotive industry, Figure 5 depicts the results of the SWOT Analysis.

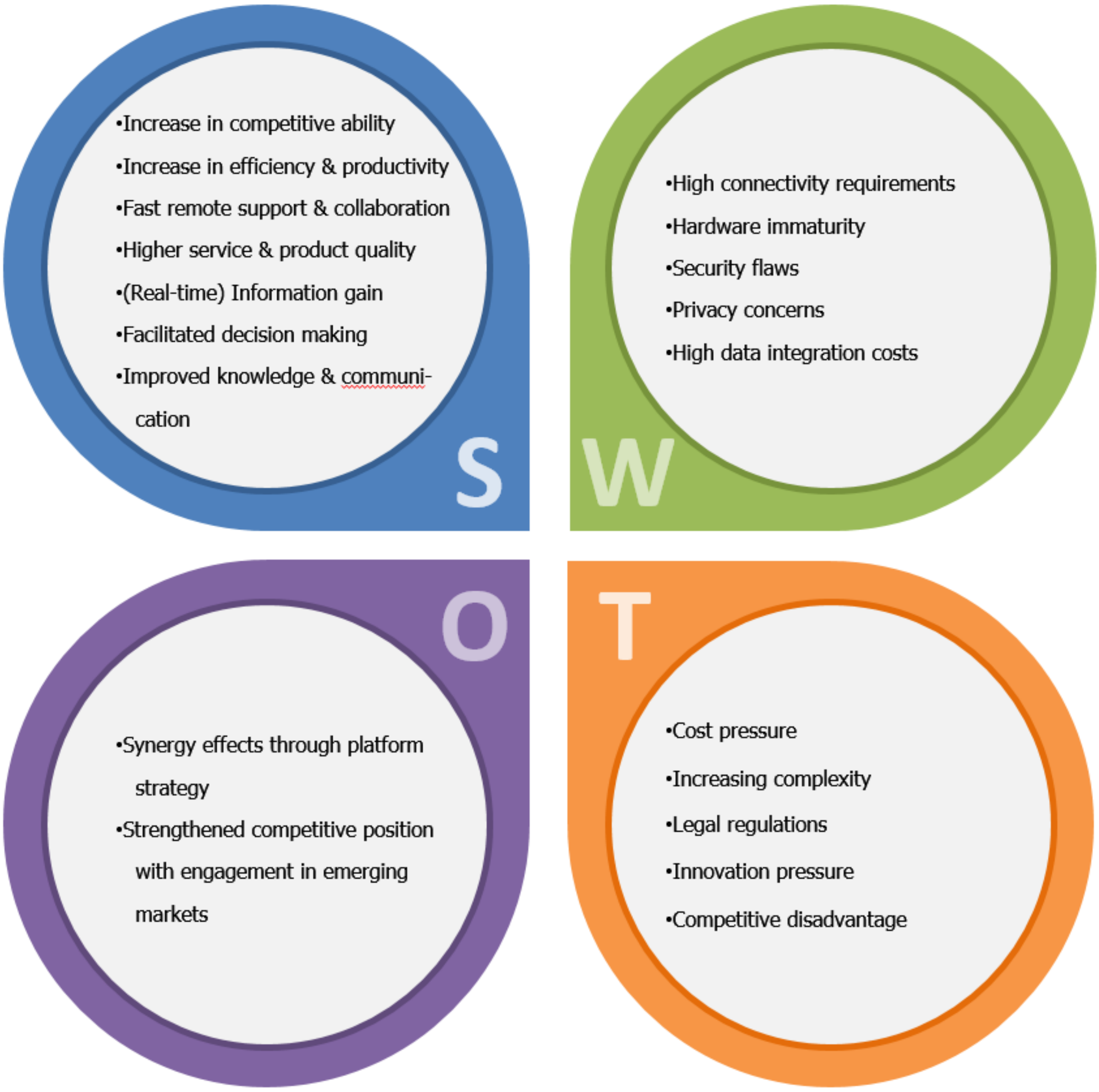

Figure 5. SWOT Analysis

As a result, the strategies for the German Automotive Industry are presented in Figure 6. Several recommendations are formulated for the German automotive industry as guidance on how these properties can be used to react to external developments in the industry's environment.

To realize these strategies, OEMs should implement a dedicated overall AR strategy. In this way, AR should be made an integral part of the organization. In order to accelerate progress in the company, the creation of a dedicated unit for the establishment of the infrastructure is recommended. The dedicated unit defines the overall AR strategy and sets priorities. Furthermore, technological standards and processes are defined by this unit. Thus the enablement of the business units is carried out by this department. The individual business units share the common AR strategy and should comply with the technological standards and processes. However, they should carry out their own projects in order to optimally adapt the potentials of AR to the conditions of their unit.

	Strengths	Weaknesses
Opportunities	An identified strength of the use of AR in the automotive industry is the increase in efficiency and productivity. The technology offers this strength in all areas of the value chain. Significant advantages are shorter development and production times, lower error rates and simplified processes. German automotive manufacturers should use this strength to intensify their involvement in emerging markets, which are increasingly becoming the largest sales markets. Establishment in these markets will sustainably strengthen the leading position of the German automotive industry.	One of the identified weaknesses is the high cost of data integration in AR applications. This weakness should be compensated by automotive manufacturers through targeted measures to make the large amount of data usable. High economies of scale can be achieved by integrating CAD data into AR applications for automobile development and prototyping. Manufacturers should implement diversified platform strategies through cost-effective and faster development processes.
Threats	A major threat to the automotive industry results from the high innovation pressure it is subject to from society and politics. Companies should use AR applications in the development process to enable decision-making facilitated by rapid visualization of data and a streamlined development process through real-time collaboration of designers, managers and engineers. In this way, novel innovations can be made marketable more quickly.	A threat to the automotive industry arises from the increasing complexity of its product portfolio and the associated drawbacks for manufacturing and service. As a countermeasure, the weakness of the hardware immaturity of AR applications should be eliminated. With usable technology, the context-sensitive and guiding functions of AR could be actively used to reduce complexity.

Figure 6. Strategies and Recommendations for the German Automotive Industry

4 Limitations and Further Research

Since scientific research generally does not aspire to be free of certain boundaries or limitations, the present investigation needs to be considered against this background.

Within the framework of this paper, four use cases in the automotive industry were considered. These could largely only be described on the basis of non-quantifiable information (blog posts, website articles, etc.), which is why only a low level of detail could be achieved. The reason for this in this case is that no AR applications have yet been concretely implemented by OEMs and the technology is still in a phase within the innovation process of the automobile manufacturers in which the disclosure of company-specific information and plans would lead to a competitive disadvantage.

Although the development and application of AR is globally on the agenda of R&D departments of OEMs, which also means that the availability of detailed information about current AR research and development projects and use cases in companies is very limited or information is not made available to the public for reasons of confidentiality and competitive pressure. The limited availability of information and the lack of empirical evidence in current literature, due to the novelty character of the AR technology, can thus be regarded as a significant limitation for the present work.

For this reason, this paper presents a critical analysis of potential AR applications in the entire German automotive industry and not from the perspective of a particular OEM. In this context, the SWOT analysis as a methodological basis reveals limitations, since e.g., the internal analysis in the actual sense aims at strengths and weaknesses of a company, and not at (dis-)advantages of a technology for a company.

In the course of this paper, it became apparent, due to the expected structural change in the automotive industry, automotive suppliers in particular could take on a pioneering role with regard to the future potential of AR technology in the nearer sector environment. In order to generate a holistic understanding of potentials, risks and possible strategies for the entire automotive industry through the use of AR, it is recommended that the role of suppliers and software suppliers in future research should be included. Qualitative research methods in the form of expert interviews could be particularly useful here in order to clarify important questions about industry-specific potentials and risks.

Since the novelty aspects of AR, especially in view of the AR potentials in production and assembly processes, it would be necessary to make the end users aware of the new technology. Therefore, it would be desirable for future research to investigate which factors drive assembly and maintenance employees' acceptance on AR usage. To this end, quantitative research approaches, e.g., empirical surveys of industrial workers, could reveal which factors influence the use of AR or the intention to use the technology in the industrial environment. The literature offers a variety of possible technology acceptance theories. For example, to predict the acceptance of AR technology in (OEM) business environments, the technology acceptance model by Davis (1989) or one of the several extensions could be applied in future research.

5 Conclusions and Outlook

The aim of this paper was to identify the strengths and weaknesses of AR applications in the German automotive industry and further to assess their potential for the strategic perspective of the industry. To achieve this goal, the methodology of a SWOT analysis was applied. After an analysis of some applications of the technology along the value chain, the external environment of the German automotive industry was analyzed.

The development of the external environment poses a number of major threats to the business of the German automotive industry. Essentially, these challenges can be summarized as growing complexity, increased cost pressure and a shift in markets. On the one hand, strong political regulations expose car manufacturers to a high and cost-intensive pressure to innovate. The rapid pace of technological development, especially outside the domestic market, increases the threat of being uncompetitive in the development of innovative vehicles and features. On the other hand, society's tendencies towards individualization are leading to a demand for a broader range of vehicles, leading to increasing complexity and costs. Furthermore, the center of demand for vehicles is moving from the market of industrialized countries to the very populous markets of Asia and South America.

At the same time, however, the environment also creates opportunities for the German automotive industry to expand its strong competitive position. Opening up new markets with a corresponding vehicle portfolio offers the opportunity to maintain its position as a pioneer in the global automotive industry and to continue to generate growth. In addition, the implementation of broadly diversified platform strategies can be seen as a great opportunity. On the one hand, individualized customer wishes can be satisfied and on the other hand, exploiting economies of scale can significantly reduce the costs for the development and production of vehicles. This strategy can significantly increase the profit margin.

An in-depth analysis of the application areas of AR and their strengths and weaknesses revealed that AR can provide significant added value across the entire value chain. The enrichment of the real world with computer-generated content contributes to a reduction of complexity in many different ways. Especially in training and manufacturing, AR generates considerable added value by guiding operators. Further positive effects are improved quality and lower costs. But also in the area of development, where processes can be streamlined and collaboration made location-independent. In addition to the advantageous properties of the technology, some weaknesses could also be identified. The most significant weaknesses of AR lie in three areas. On the one hand, the property of most variants of technology to provide ubiquitous information via mobile devices bears the danger of security breaches. These can have fatal consequences for companies, especially in connection with sensitive data, such as in the area of development. The second weakness is to be found in the lack of hardware maturity. There is indeed complex software for a large number of applications. However, the hardware can only withstand the requirements of the industry to a limited extent. Deficiencies in reliability are unacceptable in production, where even low downtimes already lead to high financial losses. Furthermore, there is a weakness in the nature of technology. In order to offer added value, it is dependent on sensors such as video cameras. This characteristic could cause privacy concerns among employees and ultimately result in employees not accepting the applications.

In order to make the application of AR usable for the automotive industry, strategic recommendations for dealing with the strengths and weaknesses of the technology were given. These strategies aim for the use of AR to achieve opportunities and reduce threats to the business of automobile manufacturers. In conclusion, it can be stated that the integration of AR systems offers OEMs a good opportunity to meet future challenges. By eliminating existing weaknesses of the technology, large potentials can be realized with AR.

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