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Analysis of Augmented Reality Applications within the German Automotive Industry

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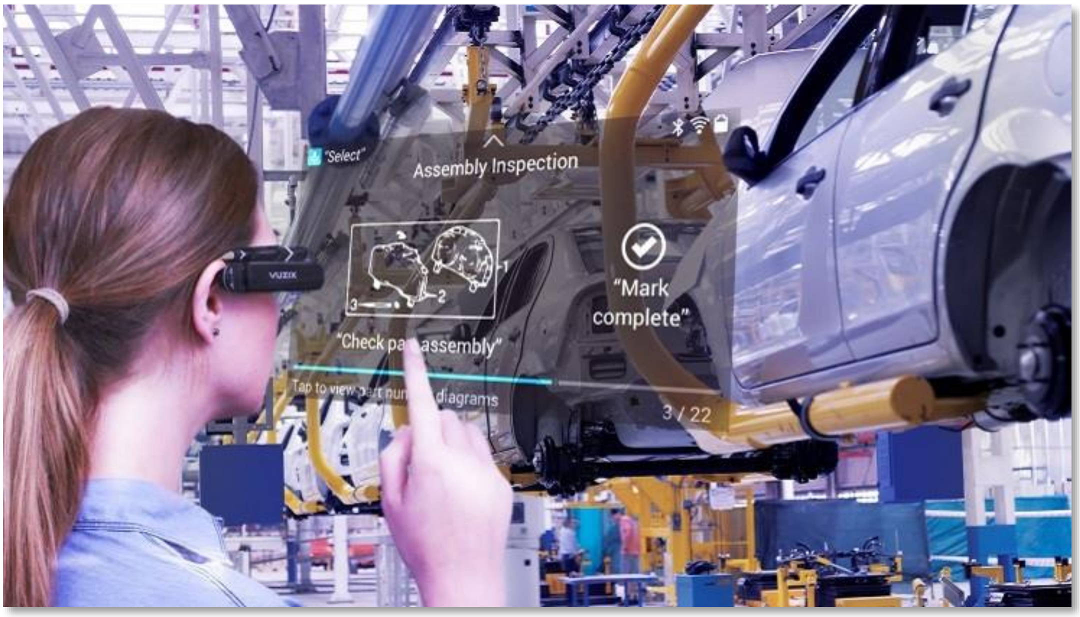

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1. Augmented Reality

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).

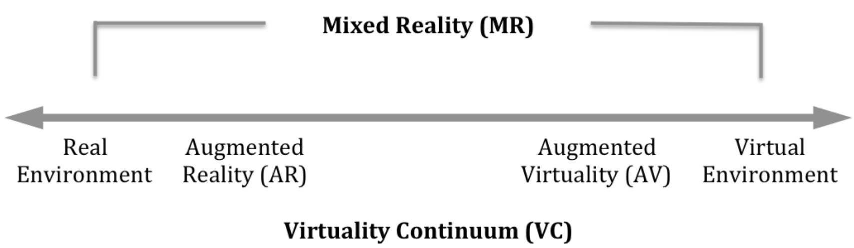

Figure 1. Reality-Virtuality Continuum according to Milgram et al. (1994)

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.

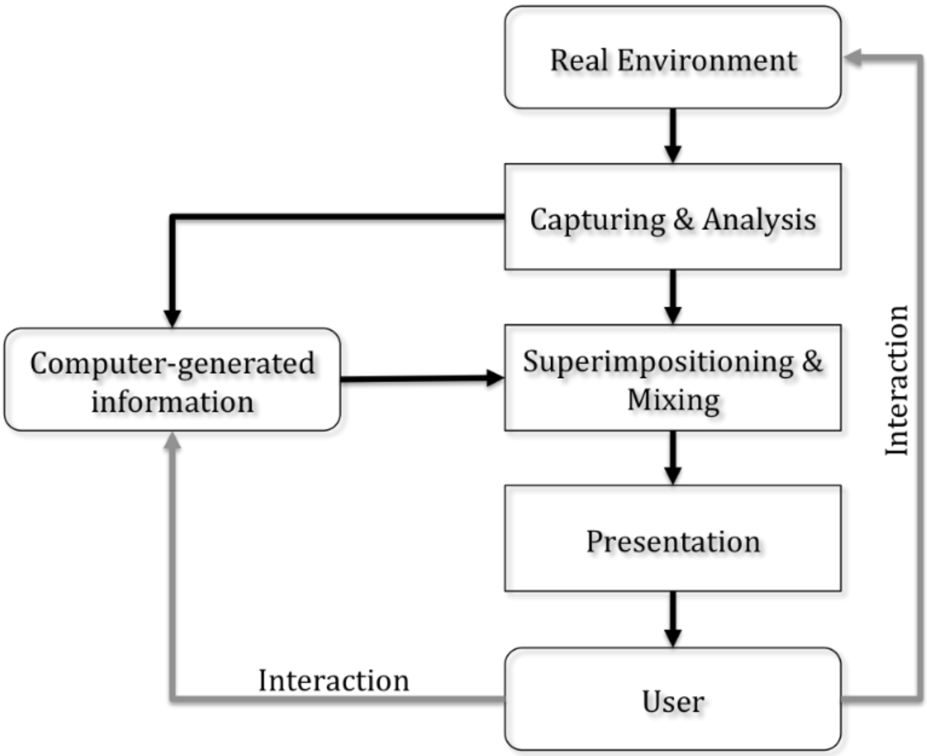

Figure 2. Functionality of an AR System according to Carmigniani and Furht (2011)

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.

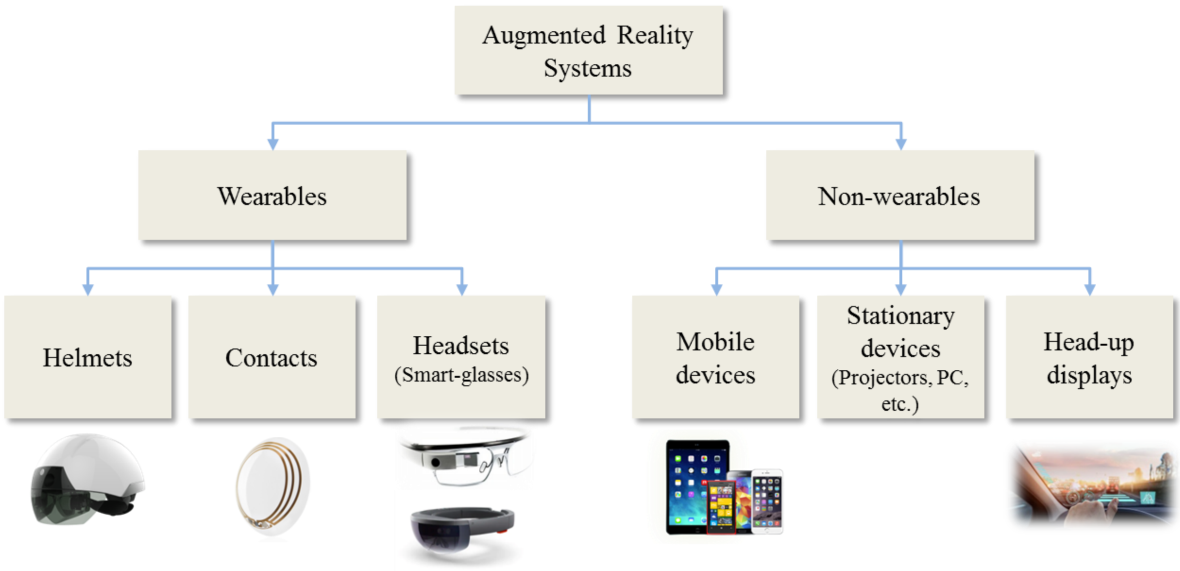

Figure 3. Overview of AR System Devices according to Peddie (2017)

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).

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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