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MECHANICAL ENGINEERING | RESEARCH ARTICLE

Critical success factors of total quality management in autonomous driving business models

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Abstract: Autonomous driving is undoubtedly one of the most strategically relevant and financially promising developing industries. The requirements for autonomous driving systems' reliability are dramatically higher than in the driver-based car industry. This study explores a model to identify the structure and evaluate the critical success factors (CSFs) of total quality management (TQM) in the autonomous driving industry. Fifteen CSFs are defined according to the expected ecosystem of autonomous driving. VDA and IATF 16,949 quality systems are used as starting points for deriving the CSFs for an autonomous driving TQM system (AD-TQM). The CSFs are integrated into a framework to reveal their effects and interdependencies. The framework is qualitatively empirically tested and designed to be employed as a model for future (quantitative empirical) research.

Subjects: Engineering & Technology; Economics, Finance, Business & Industry; Information Science

Keywords: total quality management; autonomous driving; automotive industry; IATF 16949; VDA

Subjects: quality technology; digital business model

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PUBLIC INTEREST STATEMENT

Autonomous Driving is a fundamental change in car industry. New players and complex technology will define the relations in the business ecosystems which need to be organized for implementing autonomous driving. A central pre-condition for reaching the required high level of reliability in these business ecosystems is a TQM-system which guarantees automated and cross-companies coordination with view to high levels of quality standards. Research on the topic of autonomous driving TQM-systems creates the conceptual basis of such new TQM-systems for enabling the participating companies to implement autonomous driving.

This paper provides a model that states the role of each member of an autonomous driving system and derives the new critical success factors of total quality management in this upcoming new industry. Proposals for implementing the success factors are also derived.

1. Introduction

"Total Quality Management" is a comprehensive process that coordinates customers, suppliers, and employees while integrating statistical monitoring for conducting a continuous improvement process (Rothlauf, 2014). Quality, productivity, and competitiveness can be improved while errors can be prevented in the international marketplace (Kumar et al., 2009; Rothlauf, 2014). Over the past few decades, the topic has been developed by many scholars, who have advocated certain prescriptions. According to the literature review by AQUILANI, Barbara, et al. (2017), by that year, there were already 103 academic papers covering the CSFs of TQM.

In the future, autonomous vehicles will actively participate in road traffic as part of the next mobile revolution. Therefore, the automotive industry, and public institutions, as well as economic and academic circles have made this topic a core focus of their activities (Matthaeia et al., 2015). Increasing the efficiency and safety of the transport system, preventing traffic accidents, covering the need for assistance (e.g., fatigue, lack of motivation to drive, under the influence of medication) by drivers, and optimisation of traffic flow can be defined as the main motivations for the study of this topic (Matthaeia et al., 2015, 4). To reach a high degree of acceptance, overcome insurance issues, and meet high ethical requirements, autonomous driving must have a very high tier of reliability.

Humans (in this case, the drivers) are delegating essential responsibility to a technical system (in this case, the ecosystem of autonomous driving), which is expected to exhibit a maximum level of reliability, i.e., when producing and supervising the system, a superior TQM-system must be in place.

Because of the essential importance of the automotive industry and the disruptive characters, there is ample need for research into autonomous driving, so TQM studies are fundamentally necessary. However, the academic and practical literature on "autonomous driving-TQM" (AD-TQM) is surprisingly quite rare. The method of summary literature review on TQM (KAruppusami & Gandhinathan, 2006) with the additional keyword, "autonomous driving", was used and the references of the above-mentioned 103 papers were checked (Aquilani, Silvestri, and Ruggieri 2017), but only three papers (Sinha et al., 2016; Arumugam, Mojtahedzadeh, and Malavizhi, 2011; Mojtahedzadeh & Arumugam, 2011) covered the CSFs of TQM in the current automotive industry, and no papers about TQM in the autonomous driving (AD) industry were found. This shortage of literature proves that academic research has paid little attention to the topic. Therefore, we aim to contribute to the identification of CSFs in AD-TQM and the establishment of highly reliable technical systems for autonomous driving.

The remainder of this paper is structured as follows. The second section provides a literature review of the current research on TQM in the automotive industry and identifies the present CSFs of TQM. The third section describes the ecosystem of autonomous driving. The fourth section discusses the potential challenges to autonomous driving in the ecosystem. The fifth section provides the CSFs of AD-TQM according to the challenges and ecosystem of autonomous driving. The sixth section describes the empirical method and procedure and implements a pretest for the further empirical study of the hypotheses of AD-TQM. The seventh section summarizes the CSFs of AD-TQM and recommends the further research direction.

2. CSFs of TQM

In some papers, the quality management principles of the important quality norms have been defined as the input of the CSFs of TQM (Sinha et al., 2016). We take the current TQM-system of the automotive industry as the basis for our newly designed AD-TQM with the intention of developing the current system to a new level of quality management. This means that in the present study, TQM is conceptualized based on the seven quality management principles from IATF 16,949, which is the most widespread standard quality norm in the automotive industry in the world. They are 1.

Table 1. Matrix between the quality principles of IATF 16,949 and the CSFs of TQM (own representation according to IATF 16,949. 2016, 12; Kumar & Sharma, 2014, Aquilani, Silvestri & Ruggieri, 2017)

Quality principles of IATF 16,949	CSFs of Kumar & Sharma, 2014	CSFs of Aquilani, Silvestri, and Ruggiere 2016
Customer focus	Customer Satisfaction/Customer interaction (SN 10)	Customer focus/satisfaction (2)
Leadership	Involvement of Top Management (SN 2)	Leadership/top management commitment/role of top management (1)
Engagement of People	Linking with HR practices (SN 3)	Training of education (3) Employee commitment and attitude/involvement (9)
Process approach	Quality Management—Process management (SN 4)	Process quality management (6)
Improvement	Continuous improvement (SN 5)	Continuous improvement (7)
Evidence-based decision-making	TQM tools and techniques (SN 7)	Measurement of metric systems/ data information and analysis/ quality data and reporting (4)
Relationship management	Quality Management (SN 4)—Supplier Quality Management	Supplier collaboration/ management/supplier quality (management) (5)

Customer focus; 2. Leadership; 3. Engagement of people; 4. Process approach; 5. Improvement; 6. Evidence-based decision-making; 7. Relationship management (IATF, 2016, 12).

Those seven principles are not only widely implemented in practical management but are also subjects of academic research. To analyse whether the seven quality principles of IATF 16949 are covered as the important CSFs by TQM, two core scientific papers have been rechecked. According to (Kumar & Sharma, 2014), 36 CSFs have been identified on TQM. An analysis of the above-mentioned 103 papers on TQM by (Aquilani, Silvestri, and Ruggieri 2017) has identified the most important 10 CSFs on TQM. The CSFs on both papers are independent of industry. By both papers, the seven principles of IATF have been integrated as the most core CSFs although dependent in automotive industry. Therefore, these seven quality principles will be the input for the hypotheses of AD-TQM in this paper. The resulting matrix is shown in Table 1:

In the following, the contents of the seven quality principles will be described using evidence from these scientific studies (Ahire et al., 1996; Anderson et al., 1994; Aquilani, Silvestri, and Ruggieri 2017; Arumugam and Mojtahedzadeh 2011; Das et al., 2008; Dean & Bowen, 1994; Deming, 1986; González-Benito et al., 2003; Hietschold et al., 2014; Hodgetts, 1998; Jayaram et al., 2010; Mehra et al., 2001; Mojtahedzadeh & Arumugam, 2011; Motwani, 2001; Mustafa & Bon, 2012; Sinha et al., 2016; Powell, 1995; Rao et al., 1999; Samson & Terziovski, 1999; Snell & Dean, 1992; Soltani et al., 2005; Talib & Rahman, 2010; Tsang & Antony, 2001; Yusof & Aspinwall, 2000; Zhang et al., 2000; Zineldin & Jonsson, 2000).

2.1. CSF 1. Customer focus/satisfaction

Understanding the customer´s specific requirements and providing products and services that conform to these requirements can improve competitive advantage. The customer´s requirements must be identified to find the best possible means of meeting those requirements. The customer´s opinion should be respected at each stage of the product development process. Customer satisfaction, as well as any complaints and TABLEfeedback from the customer on the quality levels of currently available products and services, should be measured and taken into account so that the organisation can improve its performance.

2.2. CSF 2. Leadership (Involvement of leadership and top management)
The top management should plan the strategy and develop the politics of TQM for the organisation. Thus, top-management must have the ability to influence and help others in the organisation to understand and implement the strategy of TQM. For example, top management should train the employees the principles of TQM and inform them of their responsibilities.

2.3. CSF 3. Engagement of people
In TQM, every member of the organisation should be involved in continuous improvement process, such as decision-making and problem-solving processes. Members of different departments should work as a team to solve any problems. Efforts and contributions should be encouraged. The participation of all members in a quality program can lead to more efficient and transparent transfer of information, knowledge and experience to the board of directors and senior management for quick solutions to problems.

Maintaining high-quality levels requires capable employees. To better understand quality-related issues and their roles in TQM, the employees should be trained and given responsibility for generating products and services that conform to the customers´ requirements. Knowledge of innovation is very important for attaining full benefits and business excellence. Only employees with sufficient necessary knowledge and abilities are able to make constructive contributions to TQM.

2.4. CSF 4. Process approach
Organisations should be built as systems with interlinked processes, of which the key ones of TQM should be identified. Improvements in these key processes lead to the optimisation of quality performance. Thus, better quality of products and services will be achieved.

2.5. CSF 5. Improvement (Continuous improvement process as CIP)
CIP implies that the organisation learns from its current processes to optimise them in the future and continuously searches for better methods and procedures of the technical and administrative side to fulfil the customer´s requirements. All the processes in the company should be integrated and all the employees should participate.

2.6. CSF 6. Evidence-based decision-making
By measuring quality data information (supplier quality levels, process capability, cost of quality, etc.), the organisation can monitor its current quality status and identify success in its improvement activities. The feedback on quality information should be analysed as the base to make effective decisions.

2.7. CSF 7. Relationship management
Successes in TQM, such as reduction in quality costs, ensuring lasting provisions of components with the required quality, and finding the right reasons for complaints in time can be implemented through partnerships between the customers and their suppliers in the supply chain. All major suppliers must respect and conform to the quality specifications of their customers in order to improve the quality of their products and services.

3. Internet of Things (IoT) as the ecosystem for autonomous driving
In an ecosystem, self-organising and shared resources, protocols, processes, and infrastructures that enable collaboration should be implanted to allow the suppliers, distributors, outsourcing firms, and producers of related products and services, as well as technology providers (as the main actors of the ecosystem), to function as a loose network that combines their individual offerings into a customer-facing solution (Adner 2006; Fjeldstad et al., 2012; Iansiti & Levien, 2004).

According to Lima et al. (2016), an ecosystem for autonomous driving comprises five actors which face the end users directly (in this case, the drivers).

S-Car: A car with its own sensors and driving robots that can communicate with other sentient components by using the sensors in the communication networks of the ecosystem. The actuation can actively enable the overall operation´s activities according to the communication in the ecosystem (Lima et al., 2016; Datta et al., 2017; Matthaeia et al., 2015, 9–36).

Road-Side Unit (RSU): Communication between S-Cars and roads can be implemented with the RSU, which can acquire and control data to coordinate the necessary information of the S-Cars with traffic situations. Near-real-time images of the state of traffic in an area can be built (Lima et al., 2016; Datta et al., 2017; Matthaeia et al., 2015, 9–36).

S-Components: Other sentient components, such as motorcycles or the roads and traffic lights, in the ecosystem can also communicate and actively react according to the information received from their own sensors and actuators (Lima et al., 2016; Datta et al., 2017; Matthaeia et al., 2015, 9–36).

Trusted Authorities (TA): These are public and private organisations such as TÜV and NHTSA, which certify the RSUs, S-Cars, and S-components (Lima et al., 2016).

Environment: everything else, such as non-autonomous cars, bicycles, and the physical environment itself, i.e., roads, weather, obstacles, etc., that are not interconnected in the ecosystem (Lima et al., 2016; Datta et al., 2017; Matthaeia et al., 2015, 9–36).

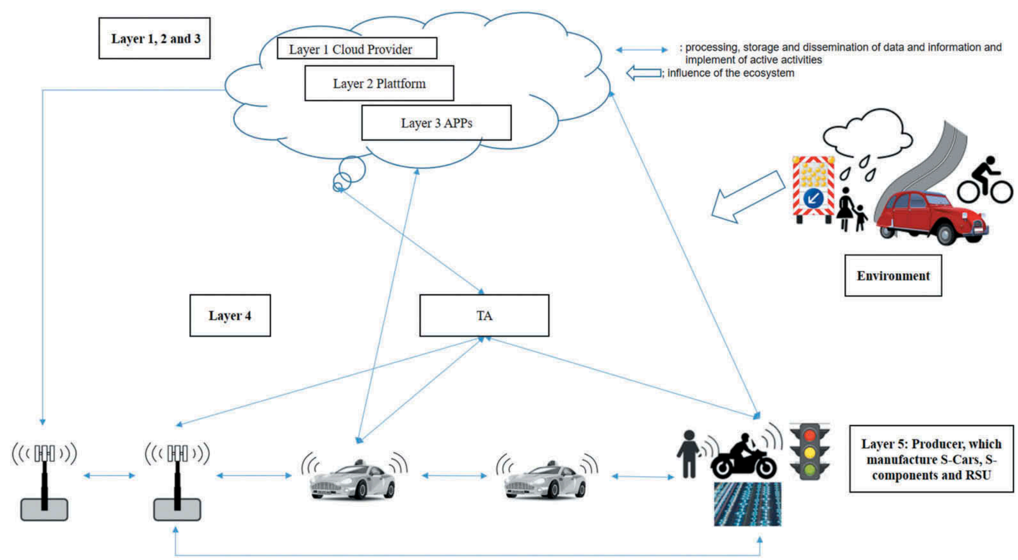
In autonomous driving, the necessary data are generated by cameras and sensors, then processed by computers within a fraction of a second. The participants in AD-ecosystem permanently exchange data with each other to form suitable reactions to end users according to real-time situations. In addition, the influence of the environment must be considered during the processing of the data. Information must be taken into account when activities in the ecosystem are executed. Humans (in this case, the drivers) are gradually being relieved of an ever-increasing number of tasks by driving robots (Datta et al., 2017; Matthaeia et al., 2015, 9–36). The final purpose of autonomous driving is at the highest level, 5: “Full Automation”, which means that the dynamic driving task is performed on any road surface and under any environmental conditions as if by a human driver (Smith, 2013).

The ecosystem can be represented by the five definable layers in the Internet of Things (IoT) (Table 2). These layers are also adaptable to the ecosystem of autonomous driving.

Table 2. The five layers of an autonomous driving ecosystem (own representation according to Berger, 2016a; 2016b, 2018; Datta et al., 2017; Lima et al., 2016; Matthaeia et al., 2015, 9–36)

Layers	Components of layers	Descriptions of actors
Layer 1	IoT infrastructure providers	Providers of data centres, cloud services, and telecommunications
Layer 2	IoT platform providers	Providers of platform solutions that deliver apps and software
Layer 3	App and software developers	Developers and providers of software solutions
Layer 4	Trusted Authorities	Public or private organisation that certify the RSUs, S-Cars, and S-Components
Layer 5	Producers, who manufacture S-Cars, S-Components, and RSUs	Produce the sentient components with active sensors and actuators in the ecosystem

Figure 1. The ecosystem of autonomous driving.



The Cloud Infrastructure represents layer 1, where computing ability and storage capacity are provided. Using the Cloud Infrastructure, "big data" in the ecosystem must be processed, stored, and disseminated in near-real-time (Berger, 2016a; 2016b, 2018; Datta et al., 2017; Lima et al., 2016).

Layer 2 comprises the IoT´s platform providers, who enable the digital connections of physical objects, as well as the transactions over the IoT via a coordinating platform (Berger, 2016a; 2016b, 2018).

Layer 3 comprises the applications and software developers who provide services and solutions on the platform (Berger, 2016a; 2016b, 2018).

The TA can be defined as layer 4. They provide the institutional platform for autonomous driving (Berger, 2016a; 2016b, 2018; Datta et al., 2017; Lima et al., 2016).

Layer 5 comprises the producers, which manufacture the S-Cars, S-Components and RSUs with active sensors and actuators (Berger, 2016a; 2016b, 2018; Lima et al., 2016).

Figure 1 shows an ecosystem of autonomous driving, as well as the definitions of the five layers (own representation according to Berger, 2016a; 2016b, 2018; Datta et al., 2017; Lima et al., 2016; Matthaeia et al., 2015, 9–36), in a graphical description.

4. Challenges in the ecosystem of autonomous driving

Regarding the ecosystem in Figure 1, the technical perspective (TP) is one of the main challenges in autonomous driving. Discussions with experts of TQM in the automotive industry revealed the following questions for AD-TQM (Lima et al., 2016; Datta et al., 2017; Matthaeia et al., 2015; Aquilani, Silvestri, and Ruggieri 2017; Sinha et al., 2016; Arumugam et al., 2011; Mojtahedzadeh & Arumugam, 2011):

(1) How can failures and complaints from different layers be managed? (TP 1)

(2) How should the CIP be performed? (TP 2)

(3) How should the data and information on quality be measured and analysed to make an effective decision? (TP 3)

(4) How should the influence of the environment on the processing of data and information, as well as the implementation of active measures, be considered in the ecosystem? (TP 4)
(5) How can safety and security be implemented in the ecosystem also with regard to the economic aspect? (TP 5)
(6) How should the AD-ecosystem be standardised? (TP 6)

The technological perspective of autonomous driving is not the only main challenge. AD-TQM will indirectly affect the cultures of the organisations. For example, in communication with customers in the automotive industry, many critical questions of AD-TQM from the non-technical (NT) side may be asked (Aquilani et al., 2017; Arumugam et al., 2011; Datta et al., 2017; Lima et al., 2016; Matthaeia et al., 2015; Mojtahedzadeh & Arumugam, 2011; Sinha et al., 2016), such as

(1) How should top management be involved in the AD-TQM? (NT 1)
(2) How should the employees be trained and involved? (NT 2)
(3) How should the process approach be implemented (NT 3)
(4) Which partnerships should be established in the supply chain of autonomous driving in the ecosystem? (NT 4)

5. CSFs of AD-TQM based on VDA and IATF 16,949 quality standards

The Verband der Automobilindustrie (VDA) and International Automotive Task Force (IATF) 16,949 can be defined as two of the most relevant and integrated quality management systems in the automotive industry (Franceschini et al., 2011; IATF, 2016; VDA2., 2012). Therefore, OEMs and their suppliers in non-autonomous driving often refer to TQM as per these quality requirements (IATF, 2016; VDA2., 2012). Hence, employing these detailed and proven requirements of TQM based on these two quality standards as a basis and starting point for developing an AD-TQM for the ecosystem of autonomous driving makes sense. In this paper, 15 CSFs of TQM have been identified from VDA and IATF 16,949 standards, as well as form theoretical papers in journals, to represent suitable CSFs of AD-TQM.

5.1. Customer focus of AD-TQM

Because of deviations (defined as complaints) from the expectations of customers during the application phase, potentially defective parts are replaced and requested by the car manufacturer (OEMs) or their suppliers via the OEMs in the supply chain for analysis (VDAS, 2009). The planning, execution, and monitoring of all actions regarding complaints are documented by a complaints report (for example, an 8D report), which is sent to concerned members and defined as the answer to the complaint (VDAJ, 2009). Currently, in the automotive industry, the process is defined in Layer 5 (OEMs and suppliers, who manufacture the end products for the end customers). For autonomous driving, the processing of driving is implemented in the ecosystem throughout all five layers. The complaints cannot concern only the components of the vehicles themselves but must also concern the connections and all other components, such as the cloud infrastructure, in the ecosystem. Therefore, defining the process for the whole ecosystem is also necessary. The hypothesis for CSF 1 of TP 1 of AD-TQM can be stated as:

6. Handling of complaints must be harmonised in the whole ecosystem, i.e., for all five layers

Both the VDA and IATF 16,949 standards have defined emergency planning as a CSF for a quality management system (IATF, 2016; VDA2., 2012; VDA6.3., 2016; VDA6.7., 2012). According to these standards, emergency planning can be defined as a plan to ensure that the project, product, process, and service can still meet the customer´s specifications after an emergency (production stoppages, exchange of jobs of team members, suppliers are unable to deliver products on time, etc.) that prevents the necessary resources from being properly offered and delivered. Emergency planning by VDA and IATF 16,949 is defined for project management, product and process planning, operations, supplier selection, and parts delivery. The current CSFs concern parts of Layers 5 (OEMs and suppliers, who manufacture the cars for the end users) in the ecosystem (IATF, 2016; VDA2., 2012; VDA6.3., 2016; VDA6.7., 2012). Since autonomous driving causes the end-users (in this case, the drivers) to pay much less attention during driving, the main liability for any accident is transferred from the drivers to the manufacturers (Matthaeia et al., 2015, 69–85; Lima et al., 2016), so to integrate an emergency plan for all the layers of an autonomous driving ecosystem is necessary in order to increase customer satisfaction and trust. Double guarantees should be made to avoid accidents during autonomous driving if the necessary parts or systems cannot work correctly (for example; the RSU cannot work correctly because of a virus attack). Therefore, the hypothesis for CSF2 of TP 1 of AD-TQM can be stated as:

7. An emergency plan for products, processes, services, and systems that incorporates all five layers must be integrated into the ecosystem

7.1. Leadership of AD-TQM

Top management shall ensure that the responsibility and authority for the relevant roles of TQM are assigned, communicated, and understood throughout the organisations (IATF, 2016). Since management and sub-management have a decisive influence on the definition, implementation, and monitoring of quality assurance, their involvement is an essential requirement of the TQM system (VDA6.1., 2016). Currently, the involvement of the leadership in TQM concerns a part of Layer 5 (OEMs and their suppliers) in the automotive industry (IATF 16,949). The CSFs of AD-TQM, in this respect, are much more complex. In AD-TQM, top management should consider and understand the whole ecosystem of autonomous driving (Figure 1) in terms of all five layers, instead of only a part of one layer. Hence, the hypothesis for CSF 3 of NT 1 of AD-TQM can be stated as:

8. Top management´s involvement with all actors for all five layers in the ecosystem of autonomous driving is a necessary precondition for a high- level AD-TQM system

8.1. Engagement of people of AD-TQM

The organisation should establish and maintain a documented process to identify training needs so that employees can obtain these competencies and perform those activities that affect product and process success. Employees, who perform tasks relevant to customer-specific requirements (CSRs) should be appropriately qualified (IATF, 2016). The organisation should prioritise talents that can meet the new requirements in the ecosystem of the IoT (Berger, 2016b). For the AD-TQM, neither researchers in the academic field nor quality standards in the practical field have emphasised that employees should be specifically trained and involved to understand and work in the ecosystem of autonomous driving.

The organisation should define and document the processes for motivating the employees to improve the TQM system continuously (IATF, 2016). All employees in the organisation should be integrated into TQM so that they can understand and fulfil their responsibilities (VDA6.1., 2016). Employee satisfaction in the organisation should be defined and maintained continuously as a management principle (VDA6.1., 2016). The same as the training process, the employees should be also specifically involved in the whole AD-ecosystem instead of only regarding the separate TQM-system of their companies. Since there are many more interfaces between the actions of the five layers in the ecosystem of autonomous driving, special attention should be given to the performance and motivation of the employees working at those interfaces.

The hypothesis for CSF 4 for NT 2 of AD-TQM can be stated as:

9. Employees should be trained and involved in the processes of the ecosystem of autonomous driving

9.1. Process approach of AD-TQM

The respective organisation must determine the processes required for the quality management system and their applications in the organisation by (1) defining the required input and success of the processes, (2) determining the sequence and interactions of these processes, (3) determining the criteria and procedures (including monitoring, measurements, and performance) to ensure the effective implementation of these processes; (4) identifying the required resources for those processes and ensure their availability, (5) assigning responsibilities of these processes, (6) handling the risks and opportunities according to CSR, (7) evaluating the processes and implementing the necessary changes, and (8) improving the quality management system (IATF, 2016).

10. *This CSF remains the same in autonomous driving, because generally, this process is also fit and useful for processing in the ecosystem of autonomous driving.* (NT 3)

10.1. Improvement (Continuous improvement process as CIP) of AD-TQM

The organisation must identify and select opportunities for improvement and take any necessary actions to meet the customer´s requirements and increase customer satisfaction. These actions include improving products and services, correcting, preventing, or reducing unwanted impacts, and improving the governance and effectiveness of TQM (IATF, 2016; VDA6.3., 2016; VDA6.7., 2012). According to IATF 16,949 (IATF, 2016), innovation is one of the most important methods of supporting the CIP. Much of the current research deals with the concept, “quality of connectivity in the cloud”, in digital factories (Berger, 2016a; 2016b; Thorsten, 2016; Rexroth, 2016) to describe the concept of data that can be automatically exchanged, analysed, and processed between different interfaces. All the relevant information of the machines in the digital factories can be documented for the continuous tracking of operational procedures and kept available as “digital curriculum vitae” for analysis at any time (Rexroth, 2016; Thorsten, 2016). The condition of monitoring every component of the machines could also be performed so that predictive maintenance based on predicted component conditions is realised to increase the lifetime of machines and avoid failures (Berger, 2016a; 2016b, 2018; Thorsten, 2016). These two processes can also have a positive influence on all the components in the ecosystem of autonomous driving. Therefore, the hypotheses of CSFs 6 and 7 for TP 2 of AD-TQM can be stated as:

11. Digital curriculum vitae processing should be realised and implemented for all components in the ecosystem

11.1. Predictive maintenance processing should be realised and implemented for all components in the ecosystem

11.1.1. Evidence-based decision-making of AD-TQM

The organisation should analyse and evaluate the relevant data and information through monitoring and measurement to make an effective decision. The results of the analysis should be used to assess (1) the conformity of products and services, (2) the level of customer satisfaction, (3) the performance and effectiveness of the quality management system, (4) whether or not the plan has been successfully implemented, (5) the effectiveness of measures, (6) the performance of external services, and (7) the need for the improvement of the quality management system (IATF, 2016; VDA2., 2012; VDA6.3., 2016; VDA6.7., 2012). Regarding the increasing importance and necessity of processing the data and information in the ecosystem (Datta et al., 2017; Lima et al., 2016; Matthaeia et al., 2015), the hypothesis for CSF 8 of TP 3 can be stated as:

12. Data and information exchange for all five layers in the ecosystem should be coordinated and monitored

12.1. Relationship management of AD-TQM

To ensure the success of TQM under increasing cost pressures, ever shorter development times, internationalisation, etc., a release-process of concerned products and processes in the supply chain in the automotive industry between customers (OEMs) and suppliers are defined (VDA2., 2012). When and to which degree the release process should be finished is also described (VDA2., 2012). In addition, a standard audit process handles how the customers make potential analyses and releases of suppliers in the supply chain (VDA6.3., 2016; VDA6.7., 2012). The supply chain management is currently implemented in Layer 5 of the ecosystem, partnerships between OEMs and their suppliers. In autonomous driving, the partnerships should be enlarged to all five layers in the ecosystem so that all concerned components and processes can be released and controlled. In addition, which organisations should release which components in the ecosystem should be specified. Therefore, the hypotheses of CSFs 9, 10, and 11 for NT 4 of autonomous driving can be stated as:

13. A production process and product release procedure should be defined for all five layers in the ecosystem

13.1. The audit process should be performed for all five layers in the ecosystem

13.1.1. The responsibilities of the public and private organisations for the processing of the components in the ecosystem must be defined and a legal framework must be established

Besides the above-mentioned factors, for AD-TQM there are additional influencing variables in comparison to traditional TQM which must be taken into account. The environmental range of the applications of the components in the vehicles must be identified and determined (VDAB, 2011; VDAR, 2009; VDAZ, 2016). In autonomous driving, the end-users (in this case, the drivers) are not experts and would not pay any attention to the loads and environments of the applications for their S-Cars. They trust that accidents would be avoided automatically, since they are sitting in the cars, which drive themselves, because the ecosystem has already accomplished all the necessary risk management. To avoid responsibility for potential accidents, as well as increase the trust and purchasing motivations of the end-users, a suitable application environment of autonomous driving with automated measurements should be defined and a stop (no drive) function, which operates when environmental factors are out of application range, should be integrated into the S-Cars. Therefore, the hypothesis for CSF 12 for TP 4 of AD-TQM can be stated as:

14. A suitable application environment (temperature range, dampness range, visual clarity, road conditions, etc.) with integrated automated measurements and a stop (no drive) function, which operates when environmental factors are out of application range, should be implemented for the S-Cars

According to (VDAB, 2011) and (VDAR, 2009), the special characteristics of the vehicles are defined at three levels: (1) special characteristics related to safety (high level), (2) special characteristics related to legal and regulatory requirements (medium level), and (3) special characteristics related to functional requirements (low level). The quality requirements, as well as the range of all the actions to meet the requirements for these characteristics, are defined in different quality standards (IATF, 2016; VDA2., 2012; VDA6.3., 2016; VDAB, 2011; VDAR, 2009; VDASi, 2010). Currently, Layer 5 takes the main responsibility for defining and controlling the characteristics (IATF, 2016; VDA2., 2012; VDA6.3., 2016; VDAB, 2011; VDAR, 2009; VDASi, 2010). AD-TQM requires a classification of the different quality requirements for the characteristics of all five layers in the ecosystem as CSF 13 for TP 5:

15. Different quality requirements for special important characteristics of all five layers in the ecosystem should be classified, realised, and controlled

There must be a clear justification when personal data are collected and transmitted. In Norm ISO 29,100 "Privacy Framework", eleven data protection principles that must be implemented in the information and communication technology system are defined. Because of the large amounts of data and information in the ecosystem, data protection can be defined as CSF 14 for TP 5 of AD-TQM:

16. The data protection principles should be defined and implemented in the ecosystem

Heterogeneity in the ecosystem of autonomous driving is also one of the big challenges of AD-TQM (Lima et al., 2016; Datta et al., 2017; Berger, 2016a; 2016b, 2018). Multimodal data and different encodings of software, as well as different radios and communication protocols, in the ecosystem make the processing of autonomous driving very difficult (Datta et al., 2017; Lima et al., 2016). Therefore, the hypothesis of CSF 17 for TP 6 can be stated as:

17. The platform, frameworks, and interlinks in the ecosystem must be standardised

The overview of the 15 corresponding hypotheses is shown in Table 3.

Table 3. Hypotheses of the CSFs of AD-TQM

Current CSFs of TQM in automotive industry	CSFs as hypotheses of AD-TQM in this study
1. Customer focus/ satisfaction	1. Handling of complaints must be harmonised in the whole ecosystem, i.e., for all five layers.
	2. An emergency plan for products, processes, services and systems that incorporates all five layers must be integrated into the ecosystem.
2. Leadership	3. Top management´s involvement with all actors for all five layers in the ecosystem of autonomous driving is a necessary precondition for a high- level AD-TQM system.
3. Engagement of people	4. Employees should be trained and involved in the processes of the ecosystem of autonomous driving.
4. Process approach	5. Process approach remains the same: Organisations should be built as systems with interlinked processes, of which the key ones of TQM should be identified.
5. Improvement	6. Digital curriculum vitae processing should be realised and implemented for all components in the ecosystem.
	7. Predictive maintenance processing should be realised and implemented for all components in the ecosystem.
6. Evidence-based decision-making	8. Data and information exchange for all five layers in the ecosystem should be coordinated and monitored.
7. Relationship management	9. A production process and product release procedure should be defined for all five layers in the ecosystem.
	10. The audit process should be performed for all five layers in the ecosystem.
	11. The responsibilities of the public and private organisations for the processing of the components in the ecosystem must be defined and a legal framework must be established.
No description	12. A suitable application environment (temperature range, dampness range, visual clarity, road condition, etc.) with integrated automated measurements and a stop (no drive) function, which operates when environmental factors are out of application range, should be implemented for the S-Cars.
No description	13. Different quality requirements for special important characteristics of all five layers in the ecosystem should be classified, realised, and controlled.
No description	14. The data protection principles should be defined and implemented in the ecosystem.
No description	15. The platform, frameworks and interlinks in the ecosystem must be standardised.

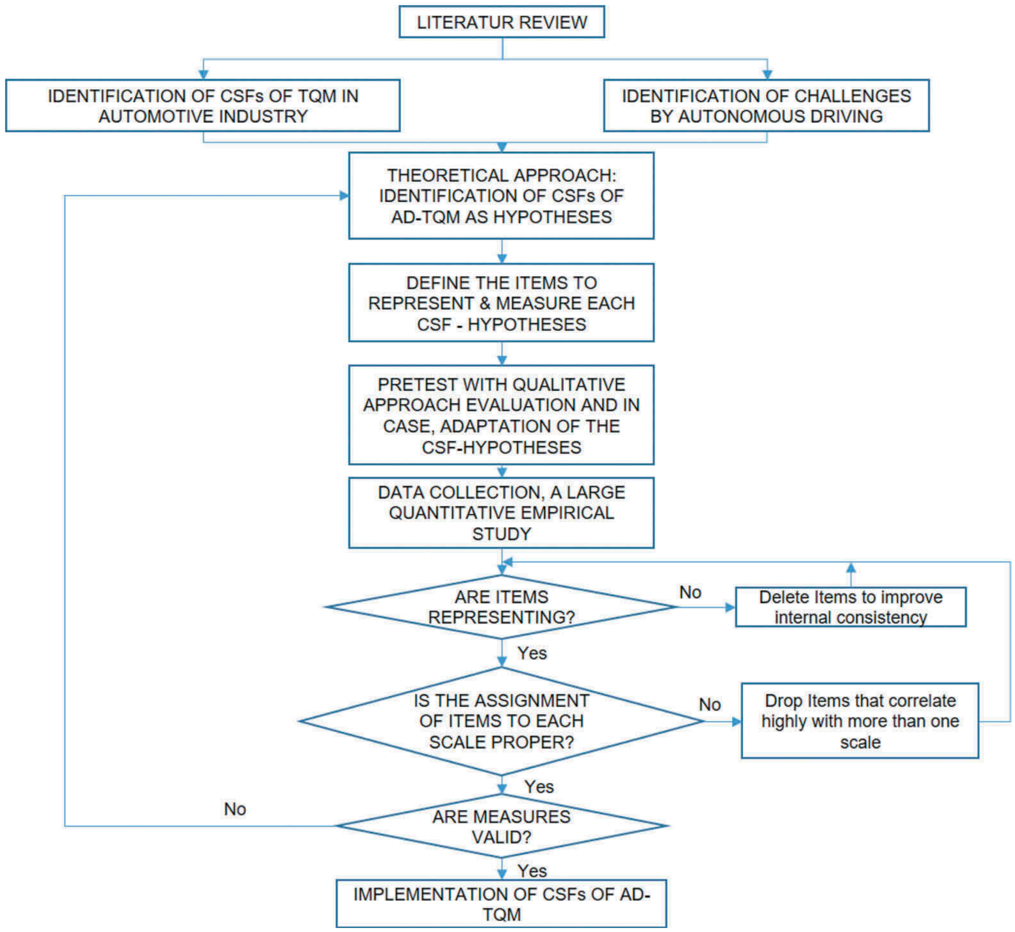


Figure 2. A proposed research path for AD-TQM.

18. Empirical testing of the CSF-hypotheses—a first approach

18.1. The empirical research design

As mentioned above, research on TQM in AD is a relatively new field of research. Figure 2 presents a typical process of logical steps of how the new CSFs of AD-TQM can be implemented in science. (own representation according to Black & Porter, 1996; Hietschold et al., 2014; Saraph et al., 1989; Sen & Taylor, 2007).

Some papers about CSFs of TQM were conceptually implemented by using the secondary data without an empirical study, especially with the main purpose to define a new proposed research direction for the present research object using the synthesis of literature review (Arumugam et al., 2011; Idris & Zairi, 2006; Mandava & Bach, 2015; Mustafa & Bon, 2012; Seetharaman et al., 2006; Soltani et al., 2005; Talib & Rahman, 2010). The procedure was as follows. First, identification of the current CSFs of TQM by extensive literature review. Second, explanation of the identified CSFs in detail. Third, identification of the framework conditions as well as the challenge and change by the present research object. Finally, taking into account the framework conditions as well as the challenge and change, the summary and conclusions implement the suitable CSFs of TQM for further research. In the present paper, this process for the present research object, the AD-ecosystem, was successfully performed. The CSFs of AD-TQM for further research are presented in Table 3.

Table 4. Three categories and the associated CSFs		
Category	**CSFs**	**Main Interviewees**
Organizational	1, 5, 9, 10, 11, 13	Senior quality experts of automotive industry
Technological	2, 6, 7, 8, 12, 14, 15	Senior technical experts, whose research main focus is autonomous driving
Human resources and management	3, 4	Senior manager and senior technical experts of autonomous driving

In a very innovative, i.e. unstructured field of research it makes sense to start the empirical part with a pretest for gaining first knowledge of a maybe necessary adaptation of the hypotheses before entering into a large-scale analysis (see Figure 2). With the identification of the CSFs and the formulation of associated hypotheses, this paper lays ground for the steps to implement an empirical study as the pretest.

The cognitive expert interview is a core method for pretesting (Presser & Blair, 1994). The same method was also conducted by some papers about CSFs of TQM (Mellahi & Eyuboglu, 2001; Mensah et al., 2012; Niu & Fan, 2015). The qualitative cognitive expert interview approach was used for three reasons. First, there is not much literature or practical experience yet for the AD-TQM. A survey-based quantitative method can lead to the difficulty that the response rate is very low because the respondents have neither much experience nor readiness to implement such a sensitive theme without a good networking with the investigator or a previous face-to-face introduction of the topic. Second, the expert interview can help the researcher to begin research in the early development efficiently and successfully (Mellahi & Eyuboglu, 2001), such as the implementation of CSFs of AD-TQM. In addition, it can lead to possible solutions of the identified problem (CSFs of AD-TQM) efficiently (Tomczak, 1992). It cannot be implemented as a real multiple-case study because third, right now this theme is so new that all the processes in the practical business are still only in the hypotheses and development phase. There is no real case for the AD-TQM. The experts can only be questioned which are their forecasts for the further AD-TQM instead of what´s the current case of the AD-TQM. Due to these reasons, the cognitive expert interviews (see for details of this empirical method, e.g. Kaiser, 2014) proves to be an adequate research design for the pretest as the basis for the future large quantitative research.

As preparation for such a qualitative study, it is necessary to purposefully order the CSF-hypotheses for being able to present the questions to the adequate interviewee and to exactly formulate them. Therefore, in this paper, the 15 CSFs are categorized into three groups so that in empirical research the interviewees can be specifically selected (see Table 4).

The first category is the organizational CSFs. To test these CSFs, it is necessary to make a comparison between the current quality norms and standards (VDA, IATF, PPAP, APQP, etc.) and the new quality requirements of the AD-system. The main interviewees should be senior quality experts who know the current quality norms and standards well and have direct experience for the projects of the autonomous vehicles so that they are able to judge their suitability for an AD-system.

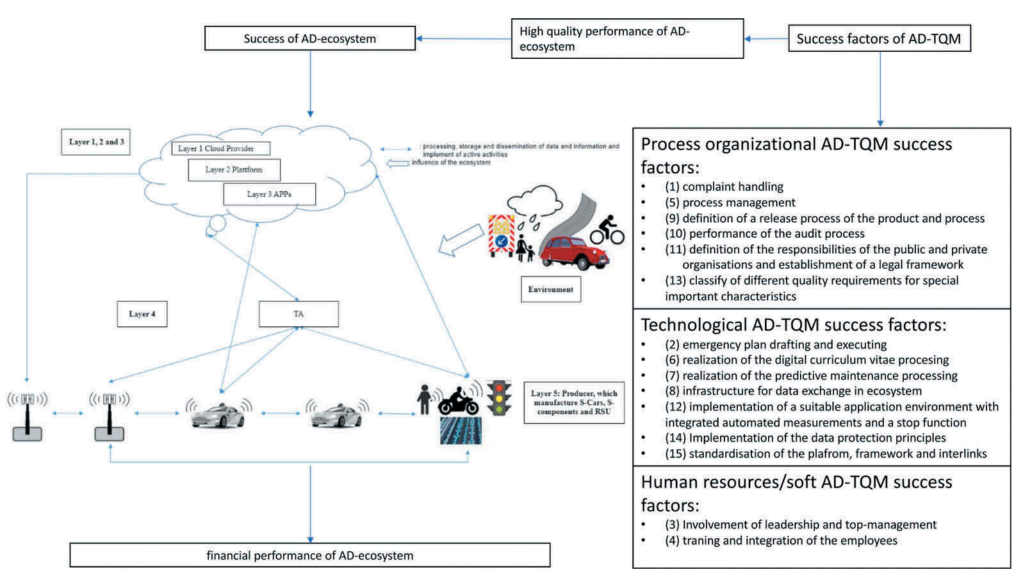
The second category is technological CSFs. To analyse and confirm these CSFs, it is necessary to understand the challenge as well as the change of the technical requirements from the current automotive industry to an AD-system. The main interviewees should be senior technical experts, whose research main focus is autonomous driving.

The third category is the CSFs of human resources and management. To analyse and confirm these CSFs, it is necessary to understand the challenge as well as the change of the new management requirements from the current automotive industry to an AD-system. The main interviewees should be the senior managers as well as the senior engineers (who have direct contact with the senior managers), who have direct project experience for the autonomous vehicle in the AD-ecosystem.

The execution of the 15 CSFs of AD-TQM is supposed to support an excellent quality performance of an AD-system which is one of the most important pre-conditions for an implemented AD-system. In the end, with other important success factors, the AD-ecosystem will successfully achieve technical and, equally important, financial performance. The basic system is shown in Figure 3.

Ordered according to each of the three categories (see Table 4), at least one question has been asked for every CSF. Basic relevance of the CSF and preconditions for its implementation have been discussed with the experts. The experts must have in-depth knowledge for the comprehensive interviews (Niu & Fan, 2015). In the present research, it means as the preconditions that the experts must have **direct** project experience for the AD-ecosystem, either for the autonomous vehicles or for the IoT ecosystem. In addition, the experience should not only be implemented with the traditional OEMs in the automotive industry but also with the IoT provider as well as public research institutes. It leads to that the expertise of the experts was exactly attributed to different layers of the AD-ecosystem, which makes it possible to cover different views. What is more, all the interviewees should be reached from personal contacts of the author so that the experts can have the trust and readiness to express their real opinions for that new, unfamiliar and sensitive theme instead of statements with mere political correctness. Therefore, two TQM-experts by an innovative medium automotive supplier, whose employer has **direct** development cooperation for the autonomous vehicles with **both traditional OEMs and IoT providers**, were interviewed. One TQM expert is the deputy vice president of quality management and the other TQM expert is the director of the advance quality planning department. Both TQM experts have more than 3 years of experience as a senior manager of quality management. Two senior technical experts by autonomous driving were interviewed. One senior technical expert works by the development department of autonomous driving by a concern automotive supplier, whose employer has also **direct** development cooperation for the autonomous driving vehicles with both **traditional OEMs and IoT providers**. The other interviewed senior technical expert is a professor by an elite university, whose main research is the IoT for the AD-ecosystem, which is encouraged by a famous public research

Figure 3. Integration of the 15 CSFs of AD-TQM in the AD-ecosystem (own representation).



institute. Both technical experts have more than 3 years of experience as senior engineers in the AD/IoT ecosystem research field. The profile of the interviewees and the working organizations are reported in Table 5.

With all the four interviewees one respective interview was conducted. The interviews lasted from one to two hours and were tape-recorded. During the interviews, the inaccuracies in the questions were immediately discussed and optimized for several times until the experts can understand and answer them in the right direction. It was also arranged with the experts that they are always available for further asking. In the next chapter, the results of the interviews are presented.

18.2. Empirical results and further research

The answers of the experts have led to an evaluation of the hypotheses according to three levels: "confirmed" (all interviewed experts have confirmed); "in doubt" (one expert has not confirmed and the other has confirmed) or "not confirmed" (no interviewed experts have confirmed). The results of the interviews are presented as follows:

19. Handling of complaints must be harmonised in the whole ecosystem, i.e., for all five layers

19.1. Hypotheses are confirmed

Both of the senior quality managers have confirmed the hypotheses. They both have emphasized the importance of understanding and analysis of the interactions and interfaces between the different five layers. In their opinion, the software and programming process should be in particular integrated and considered in the handling process. According to their opinions, further research should be focused on how to handle complaints for all five layers.

20. An emergency plan for products, processes, services and systems that incorporates all five layers must be integrated into the ecosystem

20.1. Hypotheses are not confirmed

Both of the senior technical experts have the argument that such an emergency plan should not be necessary for the AD-ecosystem. Because the AD-ecosystem failure can lead to life danger. When the system is on the move, the system must be 100% guaranteed. In the test phase of the AD-ecosystem before it is introduced to the market, all the possibilities, which can influence the system, must be considered, defined and implemented for the test process of the AD-ecosystem. A similar case can be presented to the software development for aircraft that a test process must be set up and passed to ensure that the system can and will function 100%. The focus for this CSF should be how could the AD-ecosystem be 100% guaranteed and tested under the environment with all the possibilities before it really goes to the market.

21. Top management´s involvement with all actors for all five layers in the ecosystem of autonomous driving is a necessary precondition for a high- level AD-TQM system

21.1. Hypotheses are confirmed

All the four managers and senior engineers believe that the top management in the AD-ecosystem must be involved with all actors for all five layers. Because the TQM plays a core role in AD-ecosystem, the highest manager, for example, the CEO must be integrated. The clear definition for the general specifications, quality management and security for the products in the AD-ecosystem from top management is very important. Therefore, the correct integration of the top management for all the five layers must be implemented. The top management must be able to integrate all the partners including the employees, external cooperation partners as well as the competitors

Table 5. Profile of the experts as well as the working organisations

Partners reference of OEMs, IoT provider or public institutes	Revenue (2019)	Number of employees	Job title	Interview Nr.	Industry	Direct project for autonomous driving vehicle
Daimler; Apple	190 Mio US Dollar	950	Deputy vice president of quality management	1	Automotive industry	Active suspension system
Daimler; Apple	190 Mio US Dollar	950	Director of the advance quality planning department	2	Automotive industry	Active suspension system
BMW; Google	36.9 Billion US Dollar	150 K	Advanced engineering of autonomous driving	3	Automotive industry	Autonomous driving algorithm
German Federal Ministry of Transport and Digital Infrastructure	not applicable	850 (242 professors)	Professor of IoT ecosystem	4	University	AD-ecosystem

in different areas and different layers so that they can communicate and cooperate with each other. Then, the company can ensure its own innovations and competitiveness in the AD-ecosystem.

22. Employees should be trained and involved in the processes of the ecosystem of autonomous driving

22.1. Hypotheses are confirmed

The same as the top management, according to the opinions of the four managers and senior engineers, the employees should also be trained and involved to understand the interaction and interface of all the five Layers by AD-ecosystem. It is also recommended, that in the study programs of, e.g.,, universities, a major with the subject of integrating different technical and business aspects such as mechanical engineering, information technology, electronic engineering and business development instead of only one aspect for the students to understand the logic of the AD-ecosystem from theory should be developed. Thereby the participants (companies) of the AD-ecosystem can receive enough employees who have the suitable education background for further training to deepen the practical knowledge during the work. In addition, the creativity and motivation of the employees can be encouraged to build up an ecosystem that is able to optimize by itself. They should have the ability to decide which data should be considered and analysed in depth for the five Layers of AD-ecosystem. That needs also the understanding of different technical and business aspects.

23. Process approach: organisations should be built as systems with interlinked processes, of which the key ones of TQM should be identified (remains the same)

23.1. Hypotheses are in doubt

One senior quality manager has not confirmed the hypotheses. The risk management and software aspect is in his opinion too thin by the current process management according to the current system quality norms in the automotive industry (IATF and APQP). In this case, the interaction between the software and hardware manufactures should be in particular considered in AD-ecosystems so that the ethic of function safety can be strongly deepened. Right now the IATF is near this direction but still needs further work.

On the other hand, another senior quality manager has confirmed the hypotheses because the logic of the process approach is very suitable also for the AD-ecosystem. Of course, the software plays a core role in AD so that it should be integrated into the process approach. But the basic logic is actually similar.

24. Digital curriculum vitae processing should be realised and implemented for all components in the ecosystem

24.1. Hypotheses are in doubt

One senior technical expert has not confirmed the hypotheses because he is not sure, whether the digital curriculum can bring a big enough advantage, especially under the consideration that the process is very hard to be realized.

On the other hand, another senior technical expert has confirmed the hypotheses because the digital curriculum is very helpful to monitor the status of the products. It helps to increase the trust and acceptance of the AD-ecosystem in the market. Of course, he has also emphasized, it is very important to identify, how the digital curriculum can be implemented taking into account the technology and economy at the same time.

25. Predictive maintenance processing should be realised and implemented for all components in the ecosystem

25.1. Hypotheses are confirmed

Both of the senior technical experts gave the statement that the predictive maintenance is of course one core CSF for AD-TQM. It descripts what should be done in the next step to ensure the quality of an ecosystem. The reception and analysis of enormous amounts of data and information through the predictive maintenance are capable to improve the acceptance and trust of the AD-ecosystem in the market. But different from the production machines, the AD-ecosystem has many participants and many interfaces as well as the influence factors. Therefore, the difficulty is how to realize the process.

26. Data and information exchange for all five layers in the ecosystem should be coordinated and monitored

26.1. Hypotheses are confirmed

Both of the senior technical experts presented the statement that the data and information must be coordinated and monitored for all five layers in the AD-ecosystem. The AD-ecosystem is so much integrated that all the participants of the five layers must communicate and arrange with each other to identify the interface in the ecosystem. It is recommended that a file folder system can be built up so that the five layers can attach, exchange, communicate and analyse the data together to implement the CSF.

27. A production process and product release procedure should be defined for all five layers in the ecosystem

27.1. Hypotheses are confirmed

Both of the senior quality managers have confirmed the hypotheses. The release procedure must be defined and implemented for the whole AD-ecosystem. The risk management of the whole AD-ecosystem should be implemented. For example, to understand and analyse the interaction of the 5 Layers between the software and mechanical parts. One expert has a recommendation that the simulation process under the environment with all the possibilities should be realized as a release process for the end AD-ecosystem so that the system can be simulated to preview the status in the real use. The system is allowed to the market only after passing the release process.

28. The audit process should be performed for all five layers in the ecosystem

28.1. Hypotheses are confirmed

Both of the senior quality managers have confirmed the hypotheses that the audit process should be implemented for all five layers in the ecosystem. The IATF 16,949 is in this case a very helpful tool but the software and programming process must be extended. The product audit as an example VDA 6,7 and process audit as an example VDA 6,3 are also helpful but rather in support aspects.

29. The responsibilities of the public and private organisations for the processing of the components in the ecosystem must be defined and a legal framework must be established

29.1. Hypotheses are confirmed

Both of the senior quality managers have confirmed that a legal framework must be established for the release process of AD-ecosystem. They both have stated that the best solution is to establish a central certification/coordination organisation to coordinate the release process which doesn´t belong to any layers in the AD-ecosystem. The reason is that every layer in the ecosystem would have their own interests and that there is also a conflict of interest with each other. A central certification/coordination organisation can stay neutral in this case and coordinate the system fairly. For further research, it is necessary to identify what should the central organisation look like.

30. A suitable application environment (temperature range, dampness range, visual clarity, road condition, etc.) with integrated automated measurements and a stop (no drive) function, which operates when environmental factors are out of application range, should be implemented for the S-Cars

30.1. Hypotheses are confirmed

Both of the senior technical experts have the opinion that the S-cars in the AD-ecosystem should be able to tell the end users whether AD-ecosystem can run or not. If the environment is not guaranteed for the use of AD-ecosystem, the end users should be warned or better the system should be stopped automatically. It means that there is no more service in the area in which the environment is not fit for the use of AD. Of course, the big further research need is how to implement the processing.

31. Different quality requirements for special important characteristics of all five layers in the ecosystem should be classified, realised, and controlled

31.1. Hypotheses are confirmed

Both of the senior quality managers have found such a classification of the characteristics in the AD-ecosystem as very helpful and useful for the economic aspect so that the AD can entrance the market simply. In this case, risk management is very important to understand, identify and control the core risk potential in the whole AD-ecosystem. The question from both experts is how the special characteristics could be identified and defined. To implement the definition of the special characteristics, the FMEA (Failure Mode and Effects Analysis) may play a more important role in the AD-ecosystem. Of course, the balance should be different from the current situation. Because the quality safety of the AD-ecosystem plays a core role in the lives of people. The special characteristics, which are important for the lives of people, must be exactly identified and 100% controlled. If it is not sure, whether the characteristics are important or not, it must be defined and controlled as the special characteristics to ensure the ecosystem 100%. The economic aspect can´t be considered in this case no matter how low is the possibility of the danger in the AD-ecosystem.

32. The data protection principles should be defined and implemented in the ecosystem

32.1. Hypotheses are confirmed

The protection of data is a very important CSF for the AD-ecosystem according to the statements of the two senior technical experts. It protects the core know-how of the participants (companies) in the ecosystem so that the competitiveness of the innovative participants can be ensured. Therefore, the motivation of the development of their own know-how would be encouraged.

33. The platform, frameworks and interlinks in the ecosystem must be standardised

33.1. Hypotheses are in doubt

One senior technical expert has not confirmed the hypotheses because in his opinion there should be no pre-defined of a standard or non-standard platform and framework. Actually, the decision should be made by the market and the end customers, who pay for the ecosystem.

On the other hand, another senior technical expert has confirmed the hypotheses because the standardization is the precondition that the participants in the AD-ecosystem can exchange data and information with protection through the standard interface. It also helps the participants (companies) in the AD-ecosystem to evaluate themselves according to the standard platform and framework, whether they or their products/services can fulfil the quality requirement of the AD-ecosystem and entrance into the market.

During the interviews, the questionnaire (see the appendix questionnaire) was optimized, adapted and finally defined with the four experts. This questionnaire is the basis for further research by conducting a large quantitative empirical study.

Eleven CSFs (5 CSFs by organisational issues; 4 CSFs by technological issues and 2 CSFs by Human-resource and management issues) were confirmed. By one confirmed CSF of organisational issues (CSF 1) and two confirmed CSFs of technological issues (CSF 7, 12), the further research proposal from the experts can be summarized as: these CSFs are of course very important for AD-ecosystem, but in general, how should the CSFs be implemented, must be further researched.

With one confirmed CSF of Human-resource and management issues (CSF 4), one confirmed CSF of technological issues (CSF 8) as well as four confirmed CSFs of organisational issues (CSF 9, 10, 11, 13), the general questions are also how to implement the CSFs. But the experts have the statements of a further process for the implantations. The main focus was not only on how to implement the CSFs but rather how can the suggested implementation-process be realized.

The experts have not stated the exactly further process for one confirmed CSF of Human-resource and management issues (CSF 3) and one confirmed CSF of technological issues (CSF 14). Because right now they have the opinion that these two CSFs are sensitive and need more discussion in a large circle with other experts to define the development direction correctly.

Three CSFs (1 CSF by organisational issues and 2 CSFs by technological issues) are in doubt. By CSF 5 (organisational issues), the main doubt is that the current process approach should integrate the software aspect more specifically for further implementation. By CSF 6 (technological issues), the main doubt is the dilemma between the technical solution of digital curriculum vitae processing and high-cost pressure for further implementation. By CSF 15 (technological issues), the experts have not stated the exact proposal for further process because they have the opinion that this CSF, the same as the CSFs 3 and 14, is sensitive and needs more arrangement and discussion in a large circle with other experts.

The CSF 2 by technological issues is not confirmed. The main statement from the experts was, every failure by such a sensitive ecosystem will damage the trust of the customers. An emergency plan increases the cost pressure of the AD-ecosystem but still can´t convince the marketing to improve the acceptance of the failures. Further research is to define a simulation process to ensure the system will function 100% before it goes to the market.

In general, all the experts have the statement, that the current IATF and VDA quality norms as well as the current quality tools can be the significant basis to be extended and arranged with all the layers in AD-ecosystem in the further so that suitable quality norms and tools can be defined for AD-TQM. The summary of the results of the interviews whether the CSFs are confirmed or not as well as the further research need for implementing the CSFs according to the statement of the four interviewees is presented in Table 6.

34. Conclusion and outlook

The purpose of this study was to define and implement the CSFs of AD-TQM. Two of the three methodologies in the current papers about CSFs of TQM (conceptual and qualitative empirical study) were implemented. The other methodology (quantitative empirical study) is planned for the next further research.

Fifteen CSFs using the conceptual methodology without an empirical study (Arumugam et al., 2011; Idris & Zairi, 2006; Mandava & Bach, 2015; Mustafa & Bon, 2012; Seetharaman et al., 2006; Soltani et al., 2005; Talib & Rahman, 2010) based on the current CSFs of TQM in the automotive

Table 6. Summary of the results of the interviews

CSFs as hypotheses of AD-TQM in this study	Result	Further research to implement the CSFs
1. Handling of complaints must be harmonised in the whole ecosystem, i.e., for all five layers.	Confirmed	How should the handling of complaints for all five layers be exactly defined and implemented in the AD-ecosystem?
2. An emergency plan for products, processes, services and systems that incorporates all five layers must be integrated into the ecosystem.	Not confirmed	How can the AD-ecosystem be 100% guaranteed and tested under the environment with all the possibilities before it really goes to the market?
3. Top management´s involvement with all actors for all five layers in the ecosystem of autonomous driving is a necessary precondition for a high-level AD-TQM system.	Confirmed	Not exactly stated
4. Employees should be trained and involved in the processes of the ecosystem of autonomous driving.	Confirmed	1 How should the universities develop a major with the integration of different technical and business aspects for students to understand the AD-ecosystem? 2 How should the employees be encouraged to build up an ecosystem who is able to optimize by itself?
5. Process approach remains the same: Organisations should be built as systems with interlinked processes, of which the key ones of TQM should be identified.	In doubt	Is the current process approach really sensible for AD-ecosystem with current thin integration of software aspect?
6. Digital curriculum vitae processing should be realized and implemented for all components in the ecosystem.	In doubt	Is the digital curriculum sensible for AD-ecosystem taking into account of complex technology as well as huge cost pressure?
7. Predictive maintenance processing should be realized and implemented for all components in the ecosystem.	Confirmed	How should the predictive maintenance be realized in AD-ecosystem
8. Data and information exchange for all five layers in the ecosystem should be coordinated and monitored.	Confirmed	How a file folder system can be built up so that the 5 layers can attach, exchange, communicate and analyze the data to implement the CSF?
9. A production process and product release procedure should be defined for all five layers in the ecosystem.	Confirmed	How can a simulation process under the environment with all the possibilities be realized as a release process for the end AD-ecosystem?
10. The audit process should be performed for all five layers in the ecosystem.	Confirmed	How should the software and programming process be integrated and extended in the quality norms, especially in the IATF, for the audit of AD-ecosystem?
11. The responsibilities of the public and private organisations for the processing of the components in the ecosystem must be defined and a legal framework must be established.	Confirmed	What should the central certification organisatinon look like?
12. A suitable application environment (temperature range, dampness range, visual clarity, road condition, etc.) with integrated automated measurements and a stop (no drive) function, which operates when environmental factors are out of application range, should be implemented for the S-Cars.	Confirmed	How can such an automatic stop process/out of service status of AD-ecosystem be realized?
13. Different quality requirements for special important characteristics of all five layers in the ecosystem should be classified, realized, and controlled.	Confirmed	How should the important characteristics be defined (what are the special characteristics?) Should the method FMEA be considered for the implementation?

(*Continued*)

Table 6. (*Continued*)

CSFs as hypotheses of AD-TQM in this study	Result	Further research to implement the CSFs
14. The data protection principles should be defined and implemented in the ecosystem.	Confirmed	Not exactly stated
15. The platform, frameworks and interlinks in the ecosystem must be standardised.	In doubt	Not exactly stated

industry and the ecosystem of autonomous driving, as well as the VDA and IATF 16,949 quality-standards, were defined as 15 corresponding hypotheses (see for an overview Table 3).

A procedure for confirming these CSFs theoretically and empirically was applied (Figure 2). As a first step in empirical validation, a pretest was conducted using the qualitative cognitive expert interviews (Mellahi & Eyuboglu, 2001; Mensah et al., 2012; Niu & Fan, 2015) by interviewing four experts with the intent of gaining first knowledge of a maybe necessary adaptation of the hypotheses before entering a large scale in further research. The optimized and adapted questionnaire (see the appendix questionnaire) during the interviews can be defined as the basis for further research.

In addition, during the interviews, 11 hypotheses have been confirmed, 3 hypotheses are in doubt and 1 hypothesis has been rejected. The opinions of the interviewees for further research have also been conducted (see Table 6).

The summary of the results of the interviews in Table 6 shows one clear trend: the bilateral relations that prevail in the present automobile quality management system must be replaced, or rather, restructured with a view to multilateral relations within the ecosystem. This means that ample thought should be given to organise and optimise the coordination and match of several players in an interdependent relational system.

One of the next steps in research and practical implementation is to confirm and evaluate the interdependencies and the implementations of the CSFs on a larger quantitative empirical scale, for which proven methods, such as regression analysis and structural equation models, should be employed. For this research, the last methodology, the quantitative empirical study in the papers about the CSF of TQM will be performed (Saraph et al., 1989; Agus & Hassen, 2000; Baidoun, 2003; Kutlu & Kadaifci, 2014; Das et al., 2008; Yusof & Aspinwall, 2000; Black & Porter, 1996) using the adopted questionnaire.

Furthermore, research on AD-TQM requires a multi- and interdisciplinary approach. The technical side is the core but must be amended by business considerations with the main view being the establishment of AD-TQM within a profitable autonomous driving business model. As mentioned above, the management and coordination of the actors in the five layers with respect to TQM pose a central task for AD-TQM. Instruments, processes, and structures to coordinate the relations efficiently, often with the necessity of taking into account intercultural aspects, are preconditions to the successfully launching of autonomous driving. The coordination of multiple company relations has a long tradition in academic economic literature. Company networks, strategic alliances, coopetition, and virtual companies are all terms for optimising approaches to such coordination (Ciborra, 1996; Katz & Shapiro, 1985; Nalebuff & Brandenburger, 1996; Simonin, 1999). Organisational, decision theory or strategic literature address the problem (Adner, 2017; Ceccagnoli et al., 2010; Mcintyre & Srinivasan, 2017). The direction and challenge of other future research are the examination of the possibility of transferring the knowledge that could be gained from such research and practical experience to the new constellation of digital ecosystems, and in our case, that of AD-TQM (Aarikka-Stenroos & Ritala, 2017; Wareham et al., 2014) for enabling the introduction of AD as one of the most important technical changes in the coming years.

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Appendix

Questionnaire

I.: General questions for the AD-system: (for senior TQM expert as well as senior technical expert)

(I.1).Taking these participants of an AD-system, which would you rate most to least important? Please give the reasons.

(I.2) Do you expect a centrally coordinated or a decentral AD-TQM? Why?

(I.3) What do you expect to be the coordinating layer in the AD-System for the AD-TQM? Or will there be none?

(I.4) Which means and instruments for coordination do you expect?

(I.5) Do you expect the AD-System and the AD-TQM System a “closed shop”, which means that no outside company in the industry may easily enter that network of companies of the different layers? (“Proprietary systems”)

II.: Organisational issues:

1. What should be the difference between the current process of system-failures and complaints management **(“VDA-Schadteilanalyse Feld”; VDA-Standardisierter Reklamationsprozess” etc**.) and the process of system-failures and complaints management in an AD-system?

5. What are the differences between the current process management of the **APQP** and **IATF** and the process management of the AD-system?

9. Should the release process be defined for all the five layers in the AD-system? How should it be implemented? What are the differences between the current release process in the automotive industry (“**PPAP”; “PPF”; “APQP” etc**.) and the new release process for all the five layers?

10. What should be the difference between the current audit process in the automotive industry (**"VDA 6,3"; "VDA 6,7"; "VDA-SPICE" etc**.) and the audit process for the AD-system?

11. Which organisations should release which components and processes? Who should take the audit by whom in the ecosystem?

13. What should be the difference between the current definition of "special characteristics" in the automotive industry (**"IATF"; "VDA-Prozessbeschreibung Besondere Merkmale" etc**.) and the definition of "special characteristics" for the AD-system?

III.: Technological issues:

2. What should the critical incident-cascade in an AD-system and the emergency plan look like?
6. How can failures of the components in the ecosystem be automatically predicted? Is the implementation of the digital curriculum vitae processing of all the layers in the AD-ecosystem necessary? How should it be implemented?
7. Is the realization of the predictive maintenance processing of all the layers in the AD-ecosystem necessary? How should it be implemented?
8. How should the data and information on quality be measured and analysed in the AD-ecosystem?
12. How can the safety and security of the end users be implemented in the AD-ecosystem in considering the influence of the extreme environment?
14. Is the implementation of the data protection principle necessary in the AD-ecosystem. Why?
15. Should the platform, frameworks, and interlinks of the AD-ecosystem be defined as standard or non-standard? Why?

IV.: Human-resources and management issues:

3. How is the top management currently integrated for the TQM in your company? What should be the change of the integration of the top management for the TQM of AD-ecosystem?

4. Which capabilities of the employees should be trained to implement an excellent AD-TQM? How are the employees currently integrated for the TQM in your company? What should be the change in the integration of the employees for the TQM of AD-ecosystem?