*Coordinating and Controlling Autonomous Driving Business Ecosystems*

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# Index of Research Papers

This thesis comprises the following research papers:

**Research paper 1:**
**(Chapter 4)**

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# Acknowledgements

The economy, politics and society are bound to face a huge revolution of change in order to develop and realize the autonomous driving (AD) ecosystem, which is one of the most strategically significant and financially promising developing industries in the future. The maturity of autonomous driving technology means the arrival of high-tech intelligent era. Therefore, various industries, organizations and institutions are bound to have an impact, especially the traditional automotive industry is definitely facing a reshuffle which makes the theme extremely relevant and sensitive.

During this time, as a mechatronics engineer who has worked by a German hidden champion in the automotive industry for several years, it is my great honor and luck to receive the opportunity to begin my PhD life by the Chair of International Management at the University of Bayreuth. In the beginning, I would like to express my deepest appreciation to my doctor father Professor Dr. Reinhard Meckl for his remarkable guidance and support. What is most memorable and engraved in my mind is Prof. Meckl's rigorous academic discipline, pragmatic and realistic scientific research style, profound knowledge and the principle of treating people with discipline and generosity, which is a valuable asset for my future life and will benefit me for the rest of my life.

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# Abstract

It is widely recognised that autonomous driving (AD) ecosystems represent a fundamental disruption in the automotive industry and will be a key driver of future innovation. The benefits achieved through innovation, such as increasing the efficiency and safety of the transport system, avoiding traffic accidents, assisting (e.g., in case of driver fatigue or driver impairment) the driver, and optimising traffic flow, demonstrate the disruptive nature of this new technology. In addition, AD ecosystems will also be a very important business model in the future and many innovative companies will be benefited from the transformation. In order to achieve a high level of acceptance, overcome insurance problems and meet high ethical requirements, the requirements on the reliability of autonomous driving systems are dramatically higher than in the driver-based automotive industry. Furthermore, the predicted sustainability of the AD ecosystem integrates not only technological aspects, but will also influence and be affected by non-technological factors such as the environment, climate change as well as the use of space (AD will create efficiencies that require fewer cars on the road or parked on city streets). Consequently, AD ecosystems have proven to be the focus of research activities in the automotive industry and public institutions, as well as in business and academic circles.

Building on three research articles, this thesis contributes to business research by (1) exploring a model to identify the structure and evaluate the critical success factors (CSFs) of total quality management (TQM) in AD business models. (2) highlighting a framework to determine the needed capabilities for the orchestrator of an AD ecosystem and discuss who should be the orchestrator (s). The first part includes two published research articles that define an ecosystem of autonomous driving, provide the new potential CSFs of AD-TQM according to the Verband der Automobilindutrie (VDA) and International Automotive Task Force (IATF) 16949 standards, as well as the more than 100 theoretical papers about TQM in journals, conduct a quantitative empirical study to prioritise the new potential CSFs of AD-TQM between Germany and China as two of the most strategic marketing of autonomous driving in the world. The second part consists of a published research article that determines the needed capabilities for the orchestrator and discusses who could be the orchestrator of an AD ecosystem.

This thesis shows that different layers must be integrated to implement a successful AD ecosystem. Therefore, new CSFs of TQM, especially based on the interactions between different layers must be considered. In addition, the understandings and the plannings for a reliable AD-TQM as well as the AD ecosystem could be different because of the culture difference, for example between Germany and China. To lead and implement the AD ecosystem, different layers, especially the Internet of Things Platform Providers (IoTPPs), the traditional original equipment manufacturers (OEMs) and the government would have different dominations based on the different needed capabilities as well as different cultures. The thesis highlights the need for further research on collecting many more interviews and data to identify how the new CSFs of AD-TQM could be realized and who exactly should take the orchestrator responsibilities in AD ecosystems (both) under considering of different country specifications.

## Zusammenfassung

Es ist weithin bekannt, dass die Ökosysteme des autonomen Fahrens (AD) einen grundlegenden Umbruch in der Automobilindustrie darstellen und ein wichtiger Motor für künftige Innovationen sein werden. Die durch die Innovation erzielten Vorteile, wie die Erhöhung der Effizienz und Sicherheit des Verkehrssystems, die Vermeidung von Verkehrsunfällen, die Unterstützung des Fahrers (z. B. bei Übermüdung oder Beeinträchtigung des Fahrers) und die Optimierung des Verkehrsflusses, zeigen den disruptiven Charakter dieser neuen Technologie. Darüber hinaus werden AD-Ökosysteme ein sehr wichtiges Geschäftsmodell in der Zukunft sein. Viele innovative Unternehmen werden von der Umstellung profitiert. Um eine hohe Akzeptanz zu erreichen, Versicherungsprobleme zu überwinden und hohe ethische Anforderungen zu erfüllen, sind die Anforderungen an die Zuverlässigkeit autonomer Fahrsysteme dramatisch höher als die der fahrerbasierten Automobilindustrie. Darüber hinaus umfasst die prognostizierte Nachhaltigkeit des Ökosystems des autonomen Fahrens nicht nur technologische Aspekte, sondern wird auch nicht technologischen Faktoren wie Umwelt, Klimawandel und Raumnutzung beeinflussen und davon beeinflusst werden (autonomes Fahren wird zu Effizienzsteigerungen führen, die weniger Autos auf der Straße oder in den Städten notwendig sind). Deswegen haben sich AD-Ökosysteme als Schwerpunkt der Forschungsaktivitäten in der Automobilindustrie und in öffentlichen Einrichtungen sowie in der Wirtschaft und in akademischen Kreisen erwiesen.

Diese Arbeit leistet einen Beitrag zur Wirtschaftsforschung mit drei Forschungsartikeln im Journal, indem sie (1) ein Modell zur Identifizierung der Struktur und Bewertung der kritischen Erfolgsfaktoren (CSFs) des Total Quality Management (TQM) in AD-Geschäftsmodellen untersucht. (2) einen Rahmen zur Bestimmung der erforderlichen Fähigkeiten für den Orchestrator eines AD-Ökosystems aufzeigt. Der erste Teil umfasst zwei veröffentlichte Forschungsartikel, die ein Ökosystem des autonomen Fahrens darstellen, die neuen potenziellen CSFs des AD-TQM gemäß den Standards des Verbandes der Automobilindutrie (VDA) und der International Automotive Task Force (IATF) 16949 sowie den mehr als 100 theoretischen Artikeln über TQM in Fachzeitschriften bereitstellen und eine quantitative empirische Studie durchführen, um die neuen potenziellen CSFs des AD-TQM zwischen Deutschland und China als zwei der wichtigsten strategischen Marketing der Welt für autonomes Fahren zu priorisieren. Der zweite Teil besteht aus einem veröffentlichten Forschungsartikel, der die benötigten Fähigkeiten des Orchestrators bestimmt und diskutiert, wer der Orchestrator eines AD-Ökosystems sein könnte.

Diese Arbeit zeigt, dass verschiedene Teilnehmer integriert werden müssen, um ein erfolgreiches AD-Ökosystem zu implementieren. Daher müssen neue CSFs des TQM, insbesondere basierend auf den Interaktionen zwischen den verschiedenen Teilnehmer, berücksichtigt werden. Darüber hinaus können das Verständnis und die Planungen für ein verlässliches AD-TQM sowie das AD-Ökosystem aufgrund

kultureller Unterschiede, zum Beispiel zwischen Deutschland und China, unterschiedlich sein. Um das AD-Ökosystem zu leiten und zu implementieren, würden verschiedene Teilnehmer, insbesondere die Plattform-Anbieter für das Internet der Dinge (IoTPPs), die traditionellen Erstausrüster (OEMs) der Automobilindustrie und die Regierung unterschiedliche Dominanzen haben, die auf den verschiedenen benötigten Fähigkeiten sowie den unterschiedlichen Kulturen basieren. Die Doktorarbeit unterstreicht die Notwendigkeit weiterer Forschungen, dass mehr Interviews und Daten gesammelt werden sollen, um herauszufinden, wie die neuen CSFs von AD-TQM realisiert werden können und wer genau die Orchestrator-Verantwortung in AD-Ökosystemen unter Berücksichtigung der verschiedenen Länder-spezifikationen übernehmen sollte.

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# 1 Introduction

## 1.1 Motivation and Research Context

At present, a new round of global scientific and technological revolution as well as industrial change is emerging. The scientific and technological innovation is accelerating and deeply integrated into all aspects of human society, becoming a leading force in reshaping the world landscape and creating the future of humanity.

During the phase, the digitalization has become a new lever for leveraging economic growth by driving a high level of integration with data, digital transformation with innovation, and high-quality development with intelligence, and has become a key choice for countries to seize the initiative of future development. The “Internet Plus/Big Data” will change human production and life in all aspects. The development of a new generation of information technology and the practicalisation of technologies such as wireless transmission and wireless charging will provide rich, efficient tools and platforms for the interconnection of people with people, people with things, things with things and people with services. With the popularisation of the big data, human activities will become fully data-driven. Cloud computing provides the basis for large-scale production, sharing and application of the data. New network forms such as the Industrial Internet, the Energy Internet, the Autonomous Driving ecosystem, the Internet of Things and the Space Internet are emerging. The application technologies such as Smart Earth, Smart City, Smart Logistics and Smart Life are expanding, creating an ever-present and ubiquitous information network environment that will respond to people's communication, education, transportation, healthcare, logistics, finance and other work and life needs in a timely and comprehensive manner. It will drive profound changes in human production methods, business models, lifestyles, learning and thinking styles. Therefore, the power of the Internet Plus and Big Data will be used to comprehensively reshape the world and society, enabling human civilisation to move towards a new era of "intellectual revolution" following the agricultural and industrial revolutions.

Autonomous vehicles will be a part of this next innovation revolution. They will lead to so many advantages such as increasing the efficiency and safety of the transport system, avoiding traffic accidents, covering the need for assistance (e.g., overtiredness, lack of motivation to drive, influence of medication) of drivers and the optimisation of traffic flow that the autonomous driving (AD) ecosystems have proven to be the focus of research activities of the automotive industry and of public institutions, as well as in economic and academic circles (Mauer et al., 2015, pp.151–73; Mora et al., 2020). On the other hand, in order to convince the marketing to accept the new, unfamiliar industry, the AD ecosystems must overcome the insurance issues and meet high ethical standards, whereby a very high level of reliability is necessary. In addition, the non-technical factors such as environment, climate change as well as the use of space (AD will create efficiencies that require less cars on the road or parked on city streets) will also influence the development and implementation of AD ecosystems (Mauer et al., 2015, pp.151–73; Mora et al., 2020).

In order to exhibit a maximum level of reliability, the implementation of the “Total Quality Management (TQM)” as a comprehensive process that optimizes the quality of an institution’s products and services in all functional areas and at all levels through the participation of all employees which aims to increase customer satisfaction is high necessary (Kumar et al., 2009; Rothlauf, 2014). Aquilani et al. (2017) has summarized 103 academic papers covering the critical success factors (CSFs) of TQM and shows the evidence, that the academic research has paid little attention to the AD-TQM up to now, which derives the first part of the thesis (CSFs of AD-TQM).

The necessary cooperation between different players of an AD-system will take place in the form of a network in which every member contributes to a product/service. Such a network is often referred to in literature as a business ecosystem (Moore 1993, p.76; Hakala et al., 2020). To realize a reliable AD ecosystem with an integrated AD-TQM system, it is necessary to determine the organizations which will have the dominant role in this ecosystem. These organizations will in this thesis be called the “orchestrator”. As the core coordinator of the business ecosystem, the orchestrator coordinates and controls the other members of the ecosystem to bring contributions in the necessary quality and quantity. In addition, the standards and rules of the business ecosystems (for example, the TQM system) will be defined and controlled by the orchestrator. From research perspective, the analyse of the orchestrator for an innovative ecosystem is generally not a new issue (Gardet and Mothe, 2011; Ritala *et al.,* 2012). Therefore, the second part of the thesis has been defined as the discussion of who will be the orchestrator(s) of the AD ecosystem.

Thus, this thesis answers the following overarching research question (RQ): RQ: **Which critical success of factors of total quality management in autonomous driving ecosystem can be derived from the academic literature as well as from practical observations and who should take the orchestrator role to realize and manage a reliable autonomous driving ecosystem?**

## 1.2 Thesis and Results

This thesis consists of three research articles that investigate the new CSFs of AD-TQM, implement a quantitative empirical study to prioritise the CSFs under the consideration of country specifications and derivate a framework to identify who, by which needed capacities, could be the orchestrators of AD ecosystem. Every research paper addresses its own research question. The three research articles consist of three journal publications

The first research article, “Critical success factors of total quality management in autonomous driving business models”, was published on the Cogent Engineering, Taylor & Francis. This research paper explores an AD ecosystem, which layers with which responsibilities should be integrated. Then it summarizes an overview of the CSFs of TQM from published research papers and explains what are the new challenges under AD ecosystem. At the end, this paper shows 15 CSFs of AD-TQM using qualitative empirical studies and offers a first perspective on how the AD-TQM should be implemented.

*This research paper is authored by Zinan Wang and Reinhard Meckl. Zinan Wang especially contributed to the development of the theoretical background, derivation of the hypotheses and implementation of the discussion sections.*

The second research article, “Prioritising critical success factors of total quality management in autonomous driving business models: A comparison between Germany and China”, was published in the Cogent Business & Management, Taylor & Francis. This paper prioritises the CSFs of AD-TQM quantitatively as well as implements a comparison between Germany and China as two of the most important places in the world for strategic marketing for autonomous driving. Furthermore, the reasons of the difference between Germany and China are discussed in details with qualitative empirical studies.

*This research paper is authored by Zinan Wang and Reinhard Meckl. Zinan Wang especially contributed to the development of the theoretical background, conducting the empirical data and analysis, systematizing the results and implementing of the discussion sections.*

The third research article, “Who will be the orchestrator in an Autonomous Driving (AD) Business Ecosystem?” – The Position Of The Internet Of Things Platform Providers (IoTPPs) Versus Traditional Original Equipment Manufacturers (OEMs) Of The Automotive Industry, was published in the Journal of System and Management Sciences. This article determines the needed capabilities as the orchestrator of an AD ecosystem based on the framework which paper 1 and paper 2 have researched. The possibilities of three layers, the IoTPPs, OEMs and Government as the orchestrators are discussed based on different needed capabilities.

*This research paper is authored by Zinan Wang and Reinhard Meckl. The authors contributed equally to all parts of the paper.*

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# 2 Theoretical Foundation

## 2.1 Autonomous Driving

An autonomous driving vehicle is a vehicle that only requires from only driver assistance (half autonomous driving) to total no personal control at all (full autonomous driving). It can sense its environment and navigate itself using technologies such as radar, integrated smart maps and computer programming without the need of a human operation. The decisions as how to behave in traffic can be made continually by autonomous driving vehicle itself based on the rules and constraints which the people have programmed and ruled. Unmanned fleets of multiple autonomous driving vehicles can effectively reduce traffic pressure and therefore increase the efficiency of the transport system. (Mauer et al., 2015, p 2; Levinson et al., 2011; Geiger et al., 2012; Datta et al., 2017)

Since the topic is very new and innovative with lack of maturity, the Mauer et al. (2015) has stated that the analysis and implementation of the autonomous driving should be considered based on six aspects, which derivate many open questions and have been defined as the basis for the present thesis.

### 2.1.1 Ethical Aspect

If the autonomous driving vehicle is allowed to take the responsibility on our daily life, they must at least replicate, or do better than the human-drive process (Mauer et al., 2015, p. 69). But by some extremely cases, the decisions should not be only made according to the traffic laws but require a sense of ethics, which could lead to many difficult tasks to be programed into algorithms for a computer to follow.

Some reference papers have already determined a famous scenario for the ethical dilemma (Lin, 2014; IEEE, 2022):

Which choice should be made if the AD vehicle must either swerve left and crash an eight-year-old girl or swerve right and strike an 80-year old grandmother and if it does not swerve, both will be killed.

Since the key point of the ethic should be that all persons must be treated fairly independent on age, gender, disability, religion etc. Therefore, to solve the ethical dilemma, ethical frameworks and rules derived for human behavior should be integrated and programmed as control algorithms and systems in autonomous driving vehicles (Mauer et al., 2015, p. 88).

### 2.1.2 Mobility (Industry) Aspect

The autonomous driving is a revolutionary innovation process including actors and actor networks, institutional framework as well as technological development (Nagi, 2014; Mauer et al., 2015, p. 150; Bernhart & Winterhoff, 2016). It will influence and be influenced from political, legal, social and sustainability dimensions (Geiger, 2012; Mauer et al., 2015, pp 149-171). Since the political developments, national discourses and support strategies for autonomous driving are different, the discussions of the cooperation and coordination between different countries should be implemented for a success AD business model (Wang & Meckl, 2022a; Lee and David, 2020). New business model such as "Carsharing" as the use of the vehicles could appear in essence possible (BASt, 2012). Since each key player has his own competencies advantages, the comparison of the various key players such as automobile industry, non-automotive technology companies as well as high-tech start-ups should be analysed in details who can take the dominate role and responsibilities in autonomous driving business models (Wang & Meckl, 2022b; Mauer et al., 2015, pp 205-208). In order to implement a successful autonomous driving business model, the intelligent/smart city with needed integrated infrastructure should be one of the preconditions (Cugurullo, 2020; Nikitas, 2020). Although the future of autonomous driving is so attractive, the product costs and cost of ownership should be considered as an important factor during the development (Futschick et al., 2013, pp. 119-219).

### 2.1.3 Traffic Aspect

The traffic management system involves to develop a model based on the model of human-controlled vehicles with only minor modifications for autonomous driving vehicles (Mauer et al., 2015, p 301). Therefore, the analysis of how autonomous driving vehicles could affect the traffic management or might impact an entire city is high necessary which several reference papers have already researched (Kesting, 2008; Treiber and Kesting, 2012). Therefore, all the other connected participants such as persons, non-autonomous driving vehicles/motor bikes, road with or without autonomous driving sensors etc. should be integrated and considered for the analysis (Gopalswamy and Rathinam, 2018; Seif and Xu, 2016). Furthermore, the autonomous driving vehicles covers all modes of transport both on public traffic as well as in-house logistic within company grounds to improve the productivity, reliability and flexibility of the company which should be also considered for the further research (Kristoffersson and Pernestål, 2018; Daduna, 2020).

### 2.1.4 Safety Aspect

In order to receive the high safety requirements of autonomous driving vehicles, the limitations of their machine perception as well as the associated functional limitations to react during the real driving activities must be recognized (Mauer et al., 2015, p. 407). The limitations are depended on the integrated various sensors (cameras and radar sensors), digital maps and the associated self-localization functional module for the map matching of the autonomous driving vehicles as well as the interactions between autonomous driving vehicles and all other road participants including all the relevant infrastructure elements (Winner et al., 2012; Mauer et al., 2015, p. 407). A successful implementation of AD business models requires a large scale in series production of AD vehicles. Therefore, a release process to investigate whether the defined requirements have been fulfilled during the series production must be implemented (Felkai and Beiderwieden, 2013, pp. 7-49). Since the autonomous driving vehicles will take the safety responsibilities by themselves, new constructive safety requirements and safety concepts as well as release process for the specification, design, development and function test in comparison with the processes in current automotive industry must be defined (Maaref et al., 2020; Koschuch et al., 2019). In addition, the integration of the machine learning algorithm is one of the core factors to ensure the safety of autonomous driving vehicles (Fujiyoshi et al., 2019; Dogan et al., 2011). Because of the big data exchange in the AD ecosystem, the data protection principle should be also specified (Mauer et al., 2015, pp. 497-517).

### 2.1.5 Legal And Liability Aspect

Currently, very few legal systems represent the implementation of autonomous driving vehicles on public roads for the day-to-day life. Because the role of the vehicles has been changed not only performance of the drive activities but also observation of the traffic situation with associated decision, the "driver person" would not be represented as the "vehicles user" with "dominance" and "authority" from legal aspect. Therefore, it is especially important to define the allowance level of the decisions of the autonomous driving vehicles so that the delimitation of the responsibilities between the "driver" and the vehicles could be recognized. In addition, the laws should elucidate the liability of the product manufacturers during the whole product lifetime. Under the consideration of the ethical dilemma, the law should make clear descriptions as introductions which reactions should be done so that the algorithms can be integrated in purpose. The autonomous driving vehicles should own the automatic error compensation capability to realize the "Principle of Trust" in the marketing. In addition, the associated insurances should be expanded to help reduce the financial burden. (Beiker, 2012; Eugensson et al., 2013; Imai, 2019; Mauer et al., 2015, pp. 523-589).

### 2.1.6 Acceptance Aspect

Since the acceptance level of autonomous driving will decide the marketing success of the autonomous vehicles, the analysis on consumer perceptions of autonomous driving vehicles, although the present knowledge is sparse, is extremely important (Carlson et al., 2013, Burns, 2013). In this new innovative industry, not only automobile manufactures and suppliers will make the further development and footprint, bu8t also the technology firms such as Google or Apple are showing their huge motivations and ability to make a competition and cooperation

(Lutin et al, 2013; KPMG, 2012; 2013). Because the branding should be one of the critical success factors for the successful acceptance of autonomous driving vehicles, the analysis, especially the comparison between the automobile manufactures and technology firms should be implemented in details (Cairns et al., 2014). In addition, how to convince the drivers who have huge motivations for the manual driving activities; how to persuade the consumers to trust the autonomous driving technology with their lives; how to assure that the society will not be idler and idler because of the high automated (no person activities needed) technology and the associated lack of communications and cooperation between people and how to avoid the job losses in several various sectors (for example taxi driver, delivery services, etc.) can be defined as he further critical success factors for the next research (Mauer et al., 2015, pp. 665-685).

## 2.2 Critical Success Factors of Total Quality Management

Total Quality Management (TQM) describes a management system in which a company achieves the customer requirements through their organizational progresses with the engagement. A company meets these requirements by integrating every employee from every department to follow high standards and strive for continuous improvement (Bigwood, 1997; Barua, 2021; Hasim et al., 2022). According to several scientific studies, implementing a TQM philosophy can help a company: 1. Ensure excellent customer satisfaction and customer relationship. 2. increase sales volume and productivity; 3. Reduce waste and inventory; 4. Improve design capabilities and acceptance; 5. Adapt to changing markets and regulatory environments; 7. Improve market image; 8. Eliminate defects and waste; 9. Increase job security; 10. Improve employee morale; 11. Reduce costs; 12. Increase profitability (Kumar et al., 2009; Corredor and Goñi, 2011). Because of the relevance of the theme, many scholars have researched the CSFs of TQM based on different industries also under different countries specifications as well as culture influence over the past few decades. In accorded with several systematic literature review papers of TQM, following top ten critical success factors/dimensions have been extracted (Aquilani et al., 2017; Nadine et al., 2014; Karuppusami and Gandhinathan, 2006; Powell, 1995; Sila and Ebrahimpour, 2002; Ebrahimi and Sadeghi, 2013; Thiagarajan and Zairi, 1997):

### 2.2.1 Human Resource/Team Work/Involvement of Employees

To enable the creation of a total quality management culture, the organizations should build up a standard reward system to involve all the employees as a part of the TQM system (Zhang et al., 2000; Rao et al., 1999). This involvement will encourage the employees to acquire new knowledge, recognise errors actively and solve the problems more efficiently for continuous quality improvement (Welikala and Sohal, 2008). In addition, through the active participation, the employee empowerment should be defined so that a bottom-up identification of quality problems with associated solutions system can be implemented. With this empowerment, the employees can and will make an efficient and fast decision to solve the (potential) errors which could also recue the need of supervisors and experts who are normally require high costs (Mehra et al., 2001; Ahire et al., 1996). With the high motivation, a team work culture will be developed that the employees share the information with high trust to identify the quality errors and work out the associated solutions together (Rahman and Bullock, 2005; Vouzas and Psychologios, 2007).

### 2.2.2 Leadership/Involvement of Top Management

As a management philosophy, the first initiation of quality activities should be performed from the leadership level with clear policies, standards and enough resources (Grover et al., 2006). To clarify the importance of TQM and integrate the favour of high-quality performance, some research papers have stated that the leadership should be one of the most important CSFs of TQM (Das et al., 2008; Chin et al., 2002; Yusof and Aspinwall, 2000). Under the involvement of top management, the employees will be encouraged and the associated resource will be prepared with goal orientation for the implementation of TQM system (Zhang et al., 2000; Nair, 2016; Brah et al., 2002).

### 2.2.3 Supplier Partnership

The failure of the supplier parts is one of the main reasons of quality problems which could lead to extra costs and the damage of the image of a product or even the entire organization (Zhang et al., 2000; Lee and Li, 2018) Therefore, excellent strategic long-term relationships between the organization and the suppliers could orient the TQM goals and ensure that only the components with competent quality can be delivered and used (Das et al., 2008). Several research have presented that this CSF is especially significant for the manufacturing firms/industries (Kaynak 2003; Rahman and Bullock 2005).

### 2.2.4 Customer Focus

A management process for an open relationship with customers should be established in order to identify the customer needs, develop and deliver the products or services which meet the requirements and receive the feedback how and whether the customer requirements are realised (Nair, 2006; Das et al., 2008; Flynn et al., 1995). The customer needs should be researched and integrated in each stage of the product development process in order to develop a customer-oriented products/services to acquire the marketing success (Singh and Smith, 2004). Since the customer satisfaction is one of the critical success factors for the success of a company, a quickly response to change the customer demands is necessary (Mehra et al., 2001; Das et al., 2008). The complaint management, prioritisation of customer focus as well as the measurement of customer satisfaction could help the organizations to implement the CSF (Samson and Terzikvski, 1999; Zhang et al., 2000).

### 2.2.5 Training and Learning

A successful TQM system requirements capable employees so that the employees should be trained continuously for better quality understandings. It is a precondition that only employees with quality knowledge can make constructive contributions for building up a TQM system (Ahire et al., 1996; Rao et al., 1999). In addition, several researches have also studied a strong correlation between the quality performance and the training of employees (Solis et al., 2000; Rahman and Bullock, 2005). Therefore, the training budget should be viewed as investment instead of only costs so that a continuous training standard can be integrated easily (Das et al., 2008).

### 2.2.6 Evidence-based decision making/Information and data analysis

Organizations require a persistent flow of reliable information and data to manage and improve the quality continuously which makes an innovative and suitable information system as a key part of the infrastructure for a success TQM system (Rao et al., 1999; Saraph et al., 1989). The appropriate data should be always defined as the evidence basis for a decision making and also to measure the status of quality before and after the improvement activities to keep the objectivity of the decision and evaluations (Jayaram et al., 2010; Lakhal et al., 2006; Choi and Eboch, 1998).

### 2.2.7 Strategy Quality Planning

The TQM should be planned as a long-term management strategy in the organizations to achieve the expected excellence (Lee et al, 2003). With a clearly strategy quality plan, the employees can determine and track the vison of the company's quality future (Solis et al, 2000). This planning helps the organizations to establish clear objectives and prioritise the quality strategy orientation with targets description and definitions as well as the associated activities (Rao et al., 1999; Malik et al., 2012; Saraph et al., 1989).

### 2.2.8 Culture and Communication

The spread of the quality philosophy as TQM culture orients strong quality performance (Maletič et al., 2014; Welikala and Sohal, 2008; Antony et al., 2004). In addition, the TQM culture oriented effective communication, which are based on the quality goals and policies, encourages the commitment to the TQM program and establishes the quality awareness linked closely (Baidoun, 2003; Kanji and Asher, 1993; Welikala and Sohal, 2008). In the past decades, several research papers have already stated the significant correlation of the quality culture and the associated effective communication to the performance of TQM system (Powell, 1995; Antony et al., 2004; Valmohammadi, 2011).

### 2.2.9 Improvement

The CIP method (continuous improvement process/KAIZEN) is defined as knowing current situation of quality, implementing improvement activities to achieve the quality requirements and remaining the improved quality status (Brunet and New, 2003; Sanchez and Blanco, 2014). The method can be integrated in both product and process characters. The CIP should not be only viewed as a short-time method to solve the signal problem. It is rather defined as a process-oriented strategy in daily working life, that the employees should systematically analyse the current status of quality and develop suggestions for the continuous improvement of the quality level in the organizations (Jung and Wang, 2006; Brunet and New, 2003; Sanchez and Blanco, 2014). Therefore, the suggestions don’t have to be always big changes or huge innovations but rather in small steps as long-term daily activities which are divided into different phases. The PDCA (Plan-Do-Check-Act, details see Johnson, 2002; Realyvásquez-Vargas et al., 2018) is one of the most integrated methods to implement the CIP strategy of TQM.

### 2.2.10 Benchmarking

To analysis of the reference/best leading competitors in the same industry or the other organizations with similar processes can make the organization increase their performance by learning from external reference examples (Ahire et al., 1996; Das et al., 2008; Rao et al., 1999). Through the benchmarking, the organization could know their own position and identify the open points to be improved, also from quality perspective, which makes it as one of the CSFs of TQM (Rao et al., 1999). Therefore, several research papers have already confirmed the significant influence of benchmarking for a successful TQM system (Rao et al., 1999; Sun, 2000; Das et al., 2008).

### 2.2.11 Practical Quality Standards Of Automobile Industry – IATF 16949 and VDA

As two of the most relevant and integrated quality management norms in the automotive industry, the International Automotive Task Force (IATF) 16949 as well as the Verband der Automobioindustrie (VDA) have defined the necessary quality principles as well as the associated instruments and evaluation/audit criterions how the organizations in the automotive industry should build up a success TQM system both on management system as well as product and process perspectives (Franceschini et.al., 2011; IATF, 2016; VDA2, 2012). In the practice, the companies are able to orient a long-term strategic relationship in meeting and satisfying the customers' requirements by implementing the IATF 16949 and VDA programs. For many business activities in automotive industry, the certifications and evidence that the organizations can have an excellent understanding as well as implementation of these quality standards have been defined as one of the preconditions to receive the quotation request so that they are allowed to entrance the business competitions. Therefore, these quality standards have been defined as the main focus of all the organizations and institutions in the automotive industry.

As a future technology which is pushing the limits of automation, efficiency and luxury of the current vehicles, the autonomous driving innovation may become a torrent of inconsistency and potential risk which needs a suitable quality management system to prevent the potential failures. Therefore, the deep understanding as well as the continuous update and extending of these quality standards in the current automotive industry are essential for developing the AD ecosystems.

## 2.3 Orchestrator Of A Business Ecosystem

### 2.3.1 Autonomous Driving As A Business Ecosystem

Mäntymäki et al. (2018) has summarized a synthesis of different business networks as Industry, Population, Inter Organizational Network, Cluster, Value Network and Business ecosystem which made a clear description what are the reference characters and the associated applicability of every network form.

| | Industry | Population | Inter-organizational network | Cluster | Value network | Business ecosystem |
|---|---|---|---|---|---|---|
| Definition of group borders | Established and potential competitors; firm borders | Homogeneity of organizational forms; firm borders | Multiple organizations linked through multilateral ties; network borders | A geographically proximate group; distance border | Exchange of intangible assets between individuals, groups and organization; borders of experienced value constellations of network | Loosely connected firms who depend on each other for their mutual effectiveness and survival; an entity and a system with borders |
| Primary relationship between firms | Competition; including latent competition | Competition; among diverse organizations forms | Collaborative ties that facilitate reaching a common goal | Loose collaborative ties within a region that assist in global competition | Competition and collaboration in value creation | Competitive and collaborative ties |
| Sources of transformation and change | Selection through competition; large number of competitive factors; 'The best fit wins.' | Selection through competition; competition for limited resources; 'The strongest benefiter wins., | Formally, established governance processes between network parties; 'The best networker wins.' | Selection of most viable regions through global competition; 'The strongest collaborator/adapter wins.' | System's capacity to create tangible and intangible value constellations beyond product components. Ability to generate value from intangible resources. 'The best negotiator wins' | New products and customer needs incorporate the next round of innovations; 'The dominant player attracting contributors, such as platform player wins.' |
| Applicability | Explaining success and viability of individual companies | Explaining success and viability of populations of companies | Explaining evolution and success of inter-organizational networks | Explaining success of geographic regions | Explaining success and failures of companies and new products. Predictive analysis. | Explaining simultaneous evolution/disruption of markets and networks |
| Existing Business cases | Games industry | Supercell's Clash of Clans or King's Candy Crush Saga | Collaboration between game companies and movie studios | Silicon Valley; Seattle region | Hard disk manufacturer in 'Innovators dilemma'. | Apple, Amazon, Facebook. Alibaba |

Table 2-1 Concepts depicting business networks

From the definitions described in the section 2.1, the autonomous driving is a revolutionary innovation. Because of the simultaneous evolution, a total new concept and business logic with new customer needs will be implemented based on the actors and actor networks, institutional framework as well as technological development innovation. Since a business ecosystem could represent the most framework conditions above, the autonomous driving network will be viewed as a business ecosystem in the present paper which consists of the dominate players and loosely connection between different firms (participants).

Under a business ecosystem, the network of different organizations such as suppliers, distributors, customers, competitors, governments etc. will be implemented in order to deliver a specific product or service through both competition and cooperation. Each participants of the ecosystem affects and will be affected by the others with interacted correlations (Peltoniemi and Vuori, 2004; Kamargianni and Matyas, 2017). Orchestrator Concept of A Business Ecosystem

In a business ecosystem, the essential cooperation among different players arises in a networking form which every member contributes a product/service that the dominant participant as the orchestrator can interlink the other participants (Mäntymäki et al., 2018; Mukhopadhyay and Bouwman, 2019). As the central network actors of a business ecosystem, orchestrators implement the necessary activities to make the value creation with explicit goals and timetables (Dhanaraj and Parkhe, 2006; Dollet and Matalobos, 2010; Hurmelinna-Laukkanen and Nätti, 2018). The standards, business logic as well as the TQM system should be coordinated and derived by the orchestrators (Perks et al., 2017; Götz et al., 2020; Dessaigne and Pardo, 2020).

The business ecosystem and network research have a long tradition in the B2B field with nuanced literature on ecosystem orchestration:

Ritala et al. (2012) have suggested that orchestrations motivate the actors to join the ecosystems as well as ensure the knowledge sharing and transparent communication between different actors. In addition, the orchestrations orchestrate the ecosystem structure and innovation appropriability. They have defined the orchestrations as one of the key aspects of coordination of innovation-generating business ecosystems using the case studies in development of finnish mobile TV industry.

Hurmelinna-Laukkanen and Nätti (2018) has stated that the orchestrators of innovative ecosystems need:

- operation role implementation capabilities to ease and success of executing role-specific activities on a daily basis.
- role switching capabilities as similar to the dynamic capabilities, which enable the orchestrators to create, extend and modify themselves for living through alterations in their resources, the scale and scope of business, products, customers, ecosystems and other features of their external environments (Teece et al., 1997)

- role augmentation capabilities that enable the orchestrator to change itself and acquire new capabilities based on new situations and development innovations.

Hara and Kobayashi (2015) has conducted that even the peripheral actors, for example the governments, could block the orchestration so that the ecosystem implementation could be failed if the integration and cooperation are not successful.

Dessaigne and Pardo (2020) has summarized four norms as an orchestration practice based on the Electrical Equipment (E/E) industry:

- End-user centrality: the key purpose of the orchestrations for all the actors of ecosystem should fulfil the customer expectations and achieve customer satisfactions
- Inclusivity: the opinions and motivations of all the actors should be integrated that every actor could participant to create value in the ecosystem with end customers
- Collaboration: every actor has its own role and value to be integrated in the ecosystem and should not be replaced by another one.
- A “common enemy”: all the actors from E/E industry face the same enemy against the big internet of things platform providers (IoTPPs) such as Google, Amazon, Facebook etc. because they are so powerful in the cash flow and investment power that no manufacturers in the E/E industry can even dream of.

Perks et al (2017) has presented four orchestration mechanisms:

- Envisioning: the orchestrator should envision the potential value of the ecosystem for each actor and understand how the collaboration should be build up to achieve the potential value.
- Inducing innovativeness: the orchestrator must have the power and readiness/motivation to support and invest the innovation activities of the ecosystem in order to achieve the potential values and purpose.
- Legitimizing: the orchestrator should build and realize the legitimacy for the ecosyetem and the associated values.
- Adjusting: the orchestrator should adjust the internal organizations and structure continuously towards the development of the ecosystem and the change of the external environment.

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# 3 Derivation of Research Gaps, Research Questions and Research Methodology

Based on the theoretical basis, two research areas have been implemented, which have their own goals but also correlations with each other: “Critical success factors of total quality management in autonomous driving” (research filed one) and “Orchestrator of an AD ecosystem” (research filed two).

For each field, there is a research goal (RG) with several research questions (RQ), which addresses a particular research perspective of these research fields. The research paper 1 has been presented as a concept paper with qualitative empirical investigations (conducting interviews) to build up an AD-TQM system as a new conception. The research paper 2 has been implemented as an in-depth investigation with quantitative empirical analyses based on the frame conditions of the research paper 1. Furthermore, the research paper 3 has been introduced as another concept paper with conducting interviews to discuss the orchestration of AD ecosystem, which has made further research for the AD-TQM as well as reflected a new research topic for who could be the orchestrator of an AD ecosystem.

## 3.1 CSFs of AD-TQM

Although the CSFs of TQM have been researched as a main focus both from theoretical and practical sides in different industries under different country specifications, there are only few research papers, which have made a focus on the CSFs of TQM in the current automotive industry (Aquilani et al., 2017; Sinha et al., 2016; Arumugam et al., 2011; Mojtahedzadeh and Arumugam, 2011). Since the IATF 16949 and VDA have associated an excellent practical TQM system in the automotive industry from practical side with many CSFs in detailed descriptions, it is necessary to summarize an overview based on both theoretical and practical perspectives. Therefore, the first RQ has been derived as:

**a) What are the CSFs of TQM in the current automotive industry?**

For this RQ, we conducted a structured literature review to summarize an overview of the CSFs of TQM. Firstly, we have determined seven quality principles according to the IATF 16949. Then, we have integrated the keywords “CSF of TQM” and “TQM” by the Google Scholar as the main database, as well as reviewed the 103 reference literatures by Aquilani et al. (2017) as the latest literature review about the theme. Under considerations of both IATF and VDA standards as well as the research papers, an overview and descriptions about the CSFs of the current automotive industry have been implemented.

Since the autonomous driving ecosystem should be one of the critical innovations which can lead so many advantages that the topic has been already researched from both academic and practical literatures in the past years (Mauer et al., 2015; Mora et al.,2020; Levinson et al., 2011). However, the literature on an autonomous driving ecosystem is quite rare. Lima et al. (2016) has stated that there are five actors (S-Car; Road-Side Unit; S-Components; Trusted Authority; Environment) in the AD ecosystem which will face the end users (the drivers) directly. An overview of which layers by which industries should be integrated in the AD ecosystem and which responsibilities should they have, is sparse but highly necessary. Therefore, the second RQs (group) has been defined:

**b) How should an AD ecosystem be built up?**

**b.1. Which layers should be integrated in an AD ecosystem?**

**b.2. Which functions/roles/responsibilities should they access?**

**b.3. Which connections should they have (also between the actors for end users)?**

In order to research the above mentioned RQs, we also conducted a structured literature review to summarize an overview of the current status of autonomous driving in the context of ecosystem theories. After integrating the several keywords such as autonomous driving ecosystem, autonomous driving and self-driving vehicles/cars by the Google Scholar as the main database, as well as reviewing the 1006 reference literatures by Mauer et al., (2015) as the main theoretical basis of autonomous driving, it has been determined that only few papers have discussed such a topic but none of them have really made a clear presentation to build up an AD ecosystem with participants, roles and responsibilities (Lima et al., 2016; Campolo et al., 2018). Therefore, we have expanded the key words to another comparable ecosystem, the "Industrial Internet of Things", also with the consideration of the practical papers from the famous consulting companies such as McKinsey; Boston; Bain and Roland Berger. Finally, some practical papers have stated an ecosystem with the participants and the associated responsibilities by the Industrial Internet of Things Ecosystem (Rauen et al., 2017; Lüers et al., 2017). Based on the literature review, we created an autonomous driving ecosystem to introduce the potential participants, their responsibilities and roles as well as their interactions.

After identification of the CSFs of TQM in the current automotive industry as well as an AD ecosystem, the framework for conducting the hypotheses of the CSFs of AD-TQM has been prepared with following conducted RQs.

**c) What are the main challenges in the innovation from the current automotive industry to the autonomous driving ecosystem from TQM perspective under the consideration**

**of the six research aspects?**

**d) How should the CSFs in the automotive industry be adopted because of the main challenges?**

**e) Which new CSFs should be integrated for a successful TQM system in AD ecosystem and why?**

The Saraph et al. (1989) has defined an instrument to identify the CSFs of TQM independent of industries. This instrument has been integrated as the basis of the methodology to research the RQs. Since the AD-TQM is very new, innovative and sensitive as an unstructured field of research with few really cases, the case studies are not applicable. Therefore, we have started an empirical study with a pretesting for gaining first knowledge of a necessary adaptation of the hypotheses before entering into a large scale analysis. We conducted four cognitive expert interviews to make the first adoption of 15 CSFs of AD-TQM as the first step to research CSFs of AD-TQM as research paper 1:

**CRITICAL SUCCESS FACTORS OF TOTAL QUALITY MANAGEMENT IN AUTONOMOUS DRIVING BUSINESS MODELS**

Based on the research results of the research paper 1, we carried out a quantitative empirical study in research paper 2 to further analyse the CSFs of AD-TQM. The survey data come from Germany and China as two of the most important and strategic countries of AD ecosystem. According to a structured literature review, we determined that almost all the papers with quantitative empirical studies about CSFs of TQM have been implemented with the method likert-scale with validity, reliability, unidimensionality as well as the associated regression analysis (Saraph et al., 1989; Shrivastava et al., 2006; Sohail and Hoong, 2003; Wali et al., 2003). Although the likert-scale seems to be extremely suitable, we decided not to integrate the method in our present research. Because different with the previous research industries, the CSFs of AD-TQM is a very new, innovative theme with actually no successful cases yet. The respondents, although as experts, can’t have reference examples to understand so that they can’t really make a structured evaluations based on their own practical experiences. Therefore, for such a theme, the respondents could tend to agree to the public political statements as an acquiescence bias (Kuru and Pasek, 2016; Qasem and Gull, 2014). For our case, it means that there could be a tendenz, that the respondents could evaluate all the CSFs as very important to stay a political correctness so that the likert-scale analysis can’t be implemented successfully.

Therefore, we decided to prioritise the CSFs using quantitative empirical data which, according to a structed literature review, the “analytic hierarchy process (AHP)” approach could be integrated. As a widely employed methodology for creating ranking lists, the AHP provides a procedural flow of how to prioritise the elements (Saaty, 1994; Golden et al., 1989; Wasil and Golden, 2003), which by the present research, as the CSFs (“elements”) of the AD-ecosystem. In addition, also some few research papers about CSFs of TQM have used the AHP to implement a general prioritizing (Rezazadeh et al., 2012).

After the decision of the suitable method, the next RQs should be:

**f) What are the rankings of the CSFs of AD-TQM in Germany and China?**

**g) What are the main reasons of the difference of the rankings between Germany and China?**

Since AHP does not need a large number of survey (Cheng & Li, 2001), We selected the experts by all the five layers of AD ecosystem from personal contacts ensuring the trust and readiness for the sensitive theme as well as the possibilities for the further interviews. Then we chose six experts with interesting and reference evaluations to finish six cognitive qualitative interviews for conducting the main reasons in order to answer the RQ 7.2.

All the research results have been summarized in the research paper 2:

**Prioritising critical success factors of total quality management in autonomous driving business models: A comparison between Germany and China**

Therefore, the first RG (research filed one), “**Critical success factors of total quality management in autonomous driving**” consists of the seven RQs above with two research papers.

### 3.2 Orchestrator of an AD ecosystem

After the discussions of the research filed one, one of the future research projects could be to determine the orchestrators as well as their exact roles of an AD ecosystem. Based on the AD ecosystem from RQb, we selected two layers as the most possible orchestrators of an AD ecosystem and made an analysis about why could they take the responsibilities.

One of the layers is the original equipment of manufacturers of vehicles (OEMs) such as Damiler, who are the orchestrators which own the successful orchestration experience of the complex supply chain risk management as well as the high complicated total quality management system in the current automotive industry. The other layer is the internet of things platform providers (IoTPPs) such as Google who own very excellent successful orchestration experience of other reference ecosystem (for example, the smart mobile phone ecosystem) and at the same time, have enormous resource for investment and support of the further innovation development (Hyrynsalmi et al., 2012; Dessaigne and Pardo, 2020).

As the first step for this research filed, the RQ h has been defined as:

**h) What are the needed capabilities in orchestration of a business ecosystem?**

For this RQ we conducted a structured literature review to summarize an overview of orchestration of an ecosystem using the theoretical foundation of the section 2.3.2.

After determination of the needed capabilities in orchestration, the RQi has been implemented as:

**i) Who will take the dominate responsibilities by each needed capability and why?**

Firstly, we derived the preliminary hypotheses for each needed capabilities of the orchestration. The same as the research paper 1, since the theme is a very new and innovative topic with no real cases, therefore, we started an empirical study with a pretesting instead of case study to adapt to the preliminary hypotheses using cognitive expert interviews before entrance into a quantitative empirical study with large scale. Based on the protocol of the interviews, we used the Gioia Method (Gioia 2004) by analyzing the correlation of the records to derive the aggregate hypotheses as the final results of the research paper 3:

**"Who Will Be The Orchestrator In An Autonomous Driving (AD) Business Ecosystem?"– The Position Of The Internet Of Things Platform Providers (IoTPPs) Versus Traditional Original Equipment Manufacturers (OEMs) Of The Automotive Industry**

Which builds up the research the second RG (research field two), **the orchestration of an AD ecosystem.**

## 3.3 Research Methodology

As described above, we conducted a structured literature review to determine the current research status since all the reference papers in the relevant themes have integrated such a method. Following information and results have been determined:

- The CSFs of TQM in the current automotive industry
- The overview of the current status of autonomous driving in the context of ecosystem theories.
- The participants of an Industrial Internet of Things ecosystem.
- The methodology of quantitative empirical studies about CSFs of TQM

- The overview of orchestration of an ecosystem

Both AD-TQM and AD-orchestration are according to the literature review very new, innovative and sensitive as unstructured fields of research with no real successful cases, the case studies are not applicable. With the help of qualitative methods, new aspects and opinions can be discovered through open approach as well as the adoption and optimization of the hypotheses can be implemented immediately if the interviewers have open points and misunderstandings with high flexibility (Borrego et al., 2009). Therefore, we have started an empirical study with a qualitative pretesting for gaining first knowledge of a necessary adaptation of the hypotheses before entering into a large scale analysis in the research paper 1 and 3.

Although the likert-scale analysis has been implemented as the most implemented quantitative method in the current papers about CSFs of TQM, we have integrated the method "analytic hierarchy process (AHP)" approach to make a quantitative empirical study of the CSFs of AD-TQM by research paper 2 to prevent the acquiescence bias trend of likert-scale analysis. The further analysis have been already discussed in the section 3.1.

Furthermore, in order to analyse the reasons of the different evaluations between Germany and China, we chose six experts with reference evaluations to finish six cognitive qualitative interviews which the new aspects and opinions have been discovered.

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# 4 Research Paper 1: Critical success factors of total quality management in autonomous driving business models

*With Reinhard Meckl (2020)*

*Published in the Journal Cogent Engineering (SJR: Q2)*

## 4.1 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**

## 4.2 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.

## 4.3 CSF 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. 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 4-1 (own representation according to IATF 16949, 2016; Kumar and 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 commit-ment/role of top management (1) |
| Engagement of Pe-ople | Linking with HR practices (SN 3) | Training of education (3)<br>Employee commitment and attitude/involve-ment (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 infor-mation and analysis/quality data and report-ing (4) |
| Relationship ma-nagement | Quality Management (SN 4)—Supplier Quality Management | Supplier collaboration/management/supplier quality (management) (5) |

Table 4-1 Matrix between the quality principles of IATF 19040 and the CSFs of TQM

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).

***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 require-ments 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. Cus-tomer satisfaction, as well as any complaints and feedback from the customer on the quality levels of currently available products and services, should be measured and taken into account so that the organisationorganization can improve its performance.

***CSF 2. Leadership (Involvement of leadership and top management)***:

The top management should plan the strategy and develop the politics of TQM for the organization. Thus, top-management must have the ability to influence and help others in the organization 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.

***CSF 3. Engagement of people***:

In TQM, every member of the organization 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. A 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.

***CSF 4. Process approach***:

Organizations 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.

***CSF 5. Improvement (Continuous improvement process as CIP)***:

CIP implies that the organization 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.

***CSF 6. Evidence-based decision making***:

By measuring quality data information (supplier quality levels, process capability, cost of quality, etc.), the organization 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.

***CSF 7. Relationship management***:

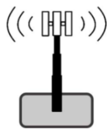
Successes in TQM, such as reduction in quality costs, ensuring lasting provisions of components with the required quality, and finding the right reasons for complaints in time can be implemented through partnerships between the customers and their suppliers in the supply chain. All major suppliers must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

## 4.4 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 (Iansiti and Levien, 2004; Adner, 2006; Fjeldstad et al., 2012).

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 organizations 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 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 4-1). These layers are also adaptable to 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). 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 (Iansiti and Levien, 2004; Adner, 2006; Fjeldstad et al., 2012).

| 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 organization that certify the RSUs, S-Cars, and S-Components |
| Layer 5 | Producers, which manufacture S-Cars, S-Components and RSUs | Produce the sentient components with active sensors and actuators in the ecosystem |

Table 4-2 The five layers of an autonomous driving ecosystem

Figure 4-1 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.t, 2017; Lima et al., 2016; Matthaeia et al., 2015, 9-36), in a graphical description.

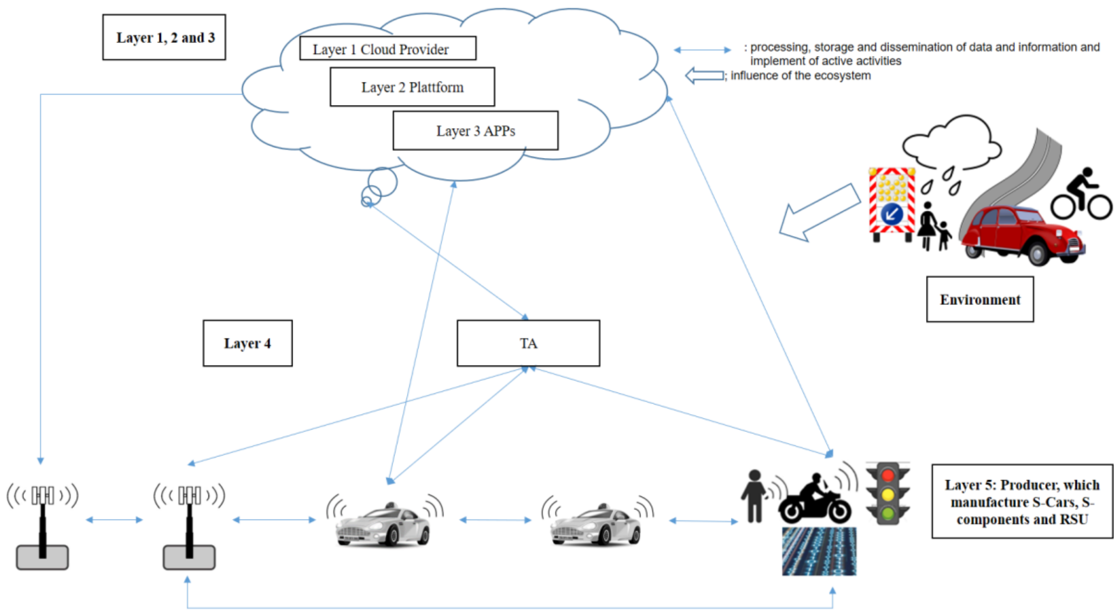



Figure 4-1 The ecosystem of autonomous driving

## 4.5 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 et al., 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 organizations. 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 (Lima et al., 2016; Datta et al., 2017; Matthaeia et al., 2015; Aquilani et al., 2017; Sinha et al., 2016; Arumugam and Mojtahedzadeh, 2011; Mojtahedzadeh and Arumugam, 2011), 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)

## 4.6 CSFs of AD-TQM based on VDA and IATF 16949 quality standards

The Verband der Automobilindustrie (VDA) and International Automotive Task Force (IATF) 16949 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, fifteen CSFs of TQM have been identified from VDA and IATF 16949 standards, as well as form theoretical papers in journals, to represent suitable CSFs of AD-TQM.

***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 the 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:

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

Both the VDA and IATF 16949 standards have defined emergency planning as a CSF for a quality management system (IATF, 2016; VDA6.3, 2016; VDA2, 2012; 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 16949 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; VDA6.3, 2016; VDA2, 2012; 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:

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

***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 organizations (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, 16949). 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:

***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***

***Engagement of people of AD-TQM***

The organization 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 organization 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 organization should define and document the processes for motivating the employees to improve the TQM system continuously (IATF, 2016). All employees in the organization should be integrated into TQM so that they can understand and fulfil their responsibilities (VDA6.1, 2016). Employee satisfaction in the organization 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:

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

***Process approach of AD-TQM***

The respective organization must determine the processes required for the quality management system and their applications in the organization 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).

***5. 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)***

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

The organization 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 16949 (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 (Thorsten, 2016; Rexroth, 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; 2017b; 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:

***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.***

***Evidence-based decision making of AD-TQM***

The organization 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; VDA6,3, 2016; VDA6,7, 2016; VDA2 2016). Regarding the increasing importance and necessity of processing the data and information in the ecosystem (Matthaeia et al., 2015; Datta et al., 2017; Lima et al., 2016), the hypothesis for CSF 8 of TP 3 can be stated as:

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

***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 is 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 the 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 organizations 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:

***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 organizations 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 (VDAZ, 2016; VDAR, 2009; VDAB, 2011). 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:

***12. 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 (VDAB, 2011; VDAR, 2009; VDA2, 2012; IATF, 2016; VDA6.3, 2016; VDASi, 2010). Currently, Layer 5 takes the main responsibility for defining and controlling the characteristics (VDAB, 2011; VDAR, 2009; VDA2, 2012; IATF, 2016; VDA6.3, 2016; 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:

***13. 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 29100 “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:

***14. 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 (Lima et al., 2016; Datta et al., 2017). Therefore, the hypothesis of CSF 17 for TP 6 can be stated as:

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

The overview of the fifteen corresponding hypotheses is shown in table 4-3.

| ***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: Organizations 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 organizations 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. |

Table 4-3 Hypotheses of the CSFs of AD-TQM

## 4.7 Empirical testing of the CSF-hypotheses – a first approach

### 4.7.1 The empirical research design

As mentioned above, research on TQM in AD is a relatively new field of research. Figure 4-2 presents a typical process of logical steps of how the new CSFs of AD-TQM can be implemented in science. (own representation according to Saraph et al.,1989; Hietschold et al., 2014; Sen and Taylor, 2007; Black and Porter, 1996).

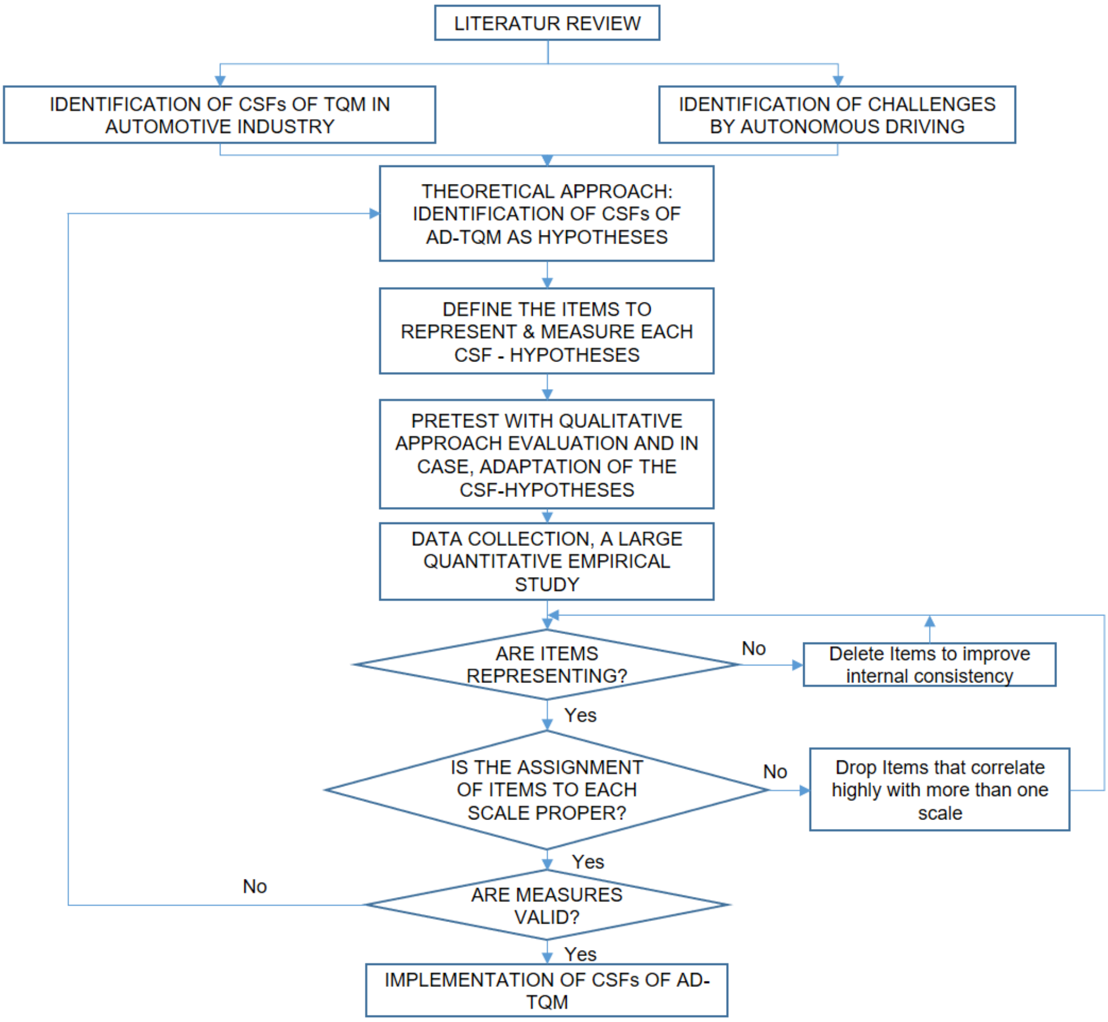



Figure 4-2 A proposed research path for AD-TQM

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 (Talib and Rahmann, 2010; Seetharaman et al., 2006; Mustafa and Bon, 2012; Idris and Zairi, 2006; Arumugam et al., 2011; Mandava and Bach, 2015; Soltani et al., 2005). The procedure was as following.

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 were presented in the table 4-3.

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 and Blair, 1994). The same method was also conducted by some papers about CSFs of TQM (Mellahi and Eyuboglu, 2001; Mensah et al., 2012; Niu and 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 a research in the early development efficiently and successfully (Mellahi and 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 can´t 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 of 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 4-4).

| 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 |

Table 4-4 Three categories and the associated CSFs

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 are the 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 current automotive industry to an AD-system. The main interviewees should be senior technical experts, whose research main focus is the autonomous driving.

The third category are 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 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 4-3.

Ordered according to every 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 the in-depth knowledge for the comprehensive interviews (Niu and 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 were 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 the 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 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 as well as the working organizations are reported in table 4-5.

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.

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

Table 4-5 Profile of the experts as well as the working organizations

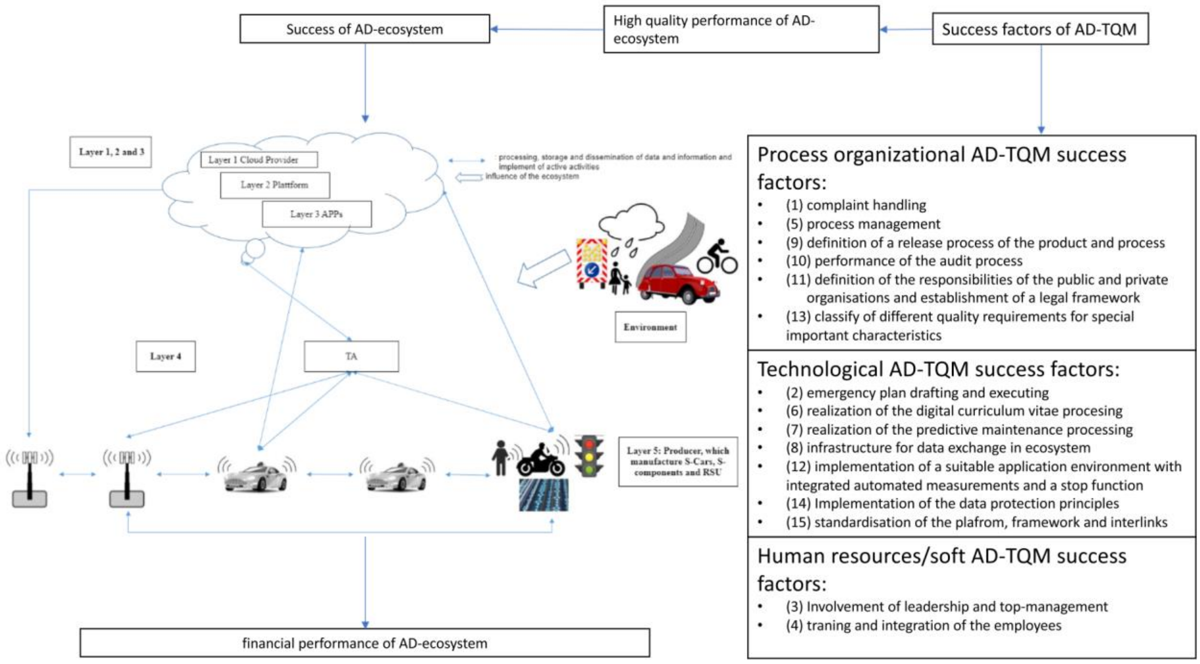



Figure 4-3 Integration of the 15 CSFs of AD-TQM in the AD-ecosystem

### 4.7.2 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:

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

**Hypotheses is 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 opinions, the software and programming process should be in particular integrated and considered in the handling process. According to their opinions, the further research should be focused on how to handle complaints 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.**

**Hypotheses is 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.

**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.**

**Hypotheses is 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 in different arears and different layers so that they can communicate and cooperate with each other. Then the company can ensure their own innovations and competitiveness in the AD-ecosystem.

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

**Hypotheses is 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 the 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 which 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.

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

**Hypotheses is 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 need 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 in the process approach. But the basic logic is actually similar.

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

**Hypotheses is 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 considering, 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.

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

**Hypotheses is 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 is 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.

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

**Hypotheses is 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.

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

**Hypotheses is 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 analysis 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.

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

**Hypotheses is 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 16949 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.

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

**Hypotheses is 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 organization to coordinate the release process which doesn´t belong to any layers in the AD-ecosystem. The reason is that every layers in the ecosystem would have their own interests and that there is also a conflict of interest with each other. A central certification/coordination organization can stay neutral in this case and coordinate the system fairly. For the further research, it is necessary to identify what should the central organization 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.**

**Hypotheses is 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 the 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 arear, 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.

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

**Hypotheses is 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, the 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 for the lives of people. The special characteristics, which is 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.

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

**Hypotheses is 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.

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

**Hypotheses is 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 the further research by conducting a large quantitative empirical study.

Eleven CSFs (5 CSFs by organizational issues; 4 CSFs by technological issues and 2 CSFs by Human-resource and management issues) were confirmed. By one confirmed CSF of organizational 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 organizational 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 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 organizational issues and 2 CSFs by technological issues) are in doubt. By CSF 5 (organizational issues), the main doubt is that the current process approach should integrate the software aspect more specifically for the 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 the further implementation. By CSF 15 (technological issues), the experts have not stated the exactly 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. The 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 4-6.

Table 4-6 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 harmonized 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 con-firmed | How can the AD-ecosystem be 100% guaranteed and tested under the environment with all the pos-sibilities 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-ecosys-tem?<br>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: Organizations 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 soft-ware aspect? |
| 6. Digital curriculum vitae processing should be real-ized and implemented for all components in the eco-system. | 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 real-ized and implemented for all components in the eco-system. | 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 environ-ment with all the possibilities be realized as a re-lease 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 pro-cess 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 organ-izations 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 organization 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 environ-mental 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 im-portant characteristics of all five layers in the ecosys-tem should be classified, realized, and controlled. | confirmed | How should the important characteristics be de-fined (what are the special characteristics?)<br>Should the method FMEA be considered for the implementation? |
| 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 eco-system must be standardized. | in doubt | not exactly stated |

## 4.8 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 (Talib and Rahmann, 2010; Seetharaman et al., 2006; Mustafa and Bon, 2012; Idris and Zairi, 2006; Arumugam et al., 2011; Mandava and Bach, 2015; Soltani et al., 2005) based on the current CSFs of TQM in the automotive industry and the ecosystem of autonomous driving, as well as the VDA and IATF 16949 quality-standards, were defined as fifteen 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 and Eyuboglu, 2001; Mensah et al., 2012; Niu and 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 the 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 et al., 2000; Baidoun, 2003; Kutlu and Kadaifci, 2014; Das et al., 2008; Yusof and Aspinwall, 2000; Mazd, 2015;

Black and 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 5 layers with respect to TQM poses 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 (Katz and Shapiro, 1985; Simonin, 1999; Nalebuff and Brandenburger, 2007; Ciborra, 1996). Organizational, decision theory or strategic literature address the problem (McIntyre and Srinivasan, 2017; Adner, 2017; Ceccagnol et al., 2010). 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 (Wareham et al., 2014; Aarikka-Stenroos and Ritala, 2017) for enabling the introduction of AD as one of the most important technical changes in the coming years.

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## 4.10 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.: Organizational 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 organizations 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?

# 5 Research Paper 2: Prioritising critical success factors of total quality management in autonomous driving business models: A comparison between Germany and China

*With Reinhard Meckl (2022)*

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## 5.1 Abstract

As one of the most strategically relevant and financially promising developing industries, the requirements for autonomous driving (AD) systems´ reliability are dramatically higher than in the driver-based car industry. Using the analytic hierarchy process method, this study conducts a quantitative empirical study to prioritise the 15 critical success factors (CSFs) of total quality management (TQM) in the AD-ecosystem. The CSFs are derived from VDA and IATF 16949, two widely accepted TQM-frameworks in the car industry. Comparisons are made between Germany and China as two of the most important places in the world for strategic marketing for autonomous driving.

**Subjects: Engineering Economics; Strategic Management; Management of Technology & Innovation; Marketing Management; Industry & Industrial Studies**

**Keywords: total quality management; autonomous driving; automotive industry; IATF 16949; VDA; analytic hierarchy process**

## 5.2 Introduction

Total Quality Management (TQM) is a holistic concept for integrating quality as the core purpose for all levels of an organization (company, institution, etc.). All processes are optimised continuously with the participation of all employees to ensure that the products and services are characterised by high quality (Musenze & Thomas, 2020; Rothlauf, 2014). TQM is therefore a management approach that aims to achieve a permanent optimisation of processes and procedures (Alanazi, 2020; Yusof & Aspinwall, 2000). According to a literature review by Aquilani et al. (2017), p. 103 academic papers covering the critical success factors (CSF)s of TQM are described, which shows that the topic has been already developed with certain prescriptions over the past few decades.

It is generally accepted that autonomous driving (AD)-ecosystems will be a fundamental disruption in the car industry and that it is a major impetus for future innovation (Mauer et al., 2015; Wang & Meckl, 2020). The advantages achieved through innovation, such as increasing the efficiency and safety of the transport system, preventing traffic accidents, providing assistance (e.g., in the case of driver fatigue or driver impairment) to drivers as well as optimising the traffic flow, show the disruptive character of this new technology. In addition, the predicted sustainability of the AD ecosystem integrates not only technology aspects but also will influence and be influenced by non-technical factors such as environment, climate change as well as the use of space (AD will create efficiencies that require less cars on the road or parked on city streets) (Mauer et al., 2015, pp.151–73; Mora et al., 2020). Consequently, AD-ecosystems have proven to be the focus of research activities of the automotive industry and of public institutions, as well as in economic and academic circles (Mauer et al., 2015, p.4).

The necessity for a very high level of reliability within the AD-ecosystem is obvious (Wang & Meckl, 2020). In such a highly automated system, deficits in quality from the steering algorithm up to the sensor detection may cause severe damage to lives and material property. Wang and Meckl (2020) have identified 15 CSFs of AD-TQM with a qualitative empirical study as a pre-test for identifying and adapting the relevant factors in this new field. The next step should be prioritising the CSFs to support the players in the AD-ecosystem in implementing a highly reliable and successful ecosystem (Chin et al., 2008). Therefore, in this paper, we aim to contribute to the prioritising of CSFs in an AD-TQM-system with a quantitative scale analysis to establish highly reliable technical systems for AD-ecosystems.

Several research studies have already posited that China has the potential to become the world's largest market for AD vehicles (see e.g., Beiker et al., 2016; Pizzuto et al., 2019). With huge potential and excellent motivations, new high innovative technologies for AD ecosystem must be integrated in China because of the complex traffic environment and safety requirements (Pizzuto et al., 2019; West, 2016). Since Germany is already an innovative technology leader at the international level with an excellent image and market acceptance, especially for the automotive industry (Dilk et al., 2008; Keck, 1993), Germany will also take a leading role in developing and establishing AD-ecosystems (Kaltenhäuser et al., 2020). With the big market potential and the high innovation capacity of both countries, it is interesting from a research point of view to compare the strategies the relevant players are implementing in the two countries, also as a means to identify potential ways of cooperation, which may accelerate the success of AD-ecosystem (Schlobach & Retzer, 2018). Therefore, a comparison model for understanding the CSFs of AD-TQM between Germany and China will be implemented for advancing research results on that topic, which have been missing up to now.

## 5.3 The Autonomous Driving (AD) ecosystem

To identify the CSFs, it is necessary to define and describe a typical AD-ecosystem in its most relevant components. Lima et al. (2016; also see Wang & Meckl, 2020) have stated that there are five factors which face the end users (in this case, the drivers) directly in an AD-ecosystem.

S-Car: The autonomous driving car that can communicate with other S-Cars and S-components with CPU, sensors, and driving robots. (Lima et al., 2016; Datta et al., 2017; Mauer et al., 2015, pp. 9–36).

S-Components: Other sentient components, such as motorcycles or the roads and traffic lights with CPU, sensors, and driving robots in the ecosystem which communicate with each other and actively react according to the received information (Lima et al., 2016; Datta et al., 2017; Mauer et al., 2015, pp. 9–36).

Road-Side Units (RSUs): RSUs implement the communication between S-Cars and roads. The data will be acquired and controlled to coordinate the necessary information for the S-Cars about the traffic situations. Near-real-time images of the state of traffic in an area can be generated (Lima et al., 2016; Datta et al., 2017; Mauer et al., 2015, pp. 9–36).

Trusted Authorities (TAs): TAs are public and private organizations such as the government, Technical Inspection Association (TÜV) and National Highway Traffic Safety Administration (NHTSA) for certifying the RSUs, S-Cars, and S-components (Lima et al., 2016).

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

Based on this definition of players in the ecosystem, the five layers presented in Table 5-1 are identified:

As Layer 1, the cloud infrastructure providers implement the computing ability and storage capacity to process, store, and disseminate Big Data in near-real time (Datta et al., 2017; Lima et al., 2016; Lüers et al., 2017; Rauen et al., 2017)

The IoT platform providers (IoTPPs), as Layer 2, enable the digital connections of physical objects, as well as the transactions over the IoT via a coordinating platform (Lüers et al., 2017; Rauen et al., 2017).

The applications and software developers are located in Layer 3. They provide software services and solutions on the platform (Lüers et al., 2017; Rauen et al., 2017).

The trusted authorities as Layer 4 provide the institutional platform for autonomous driving and certify the components such as roadside units (RSUs), S-Cars, and S-components based on national laws and policies (Datta et al., 2017; Lima et al., 2016; Lüers et al., 2017; Rauen et al., 2017).

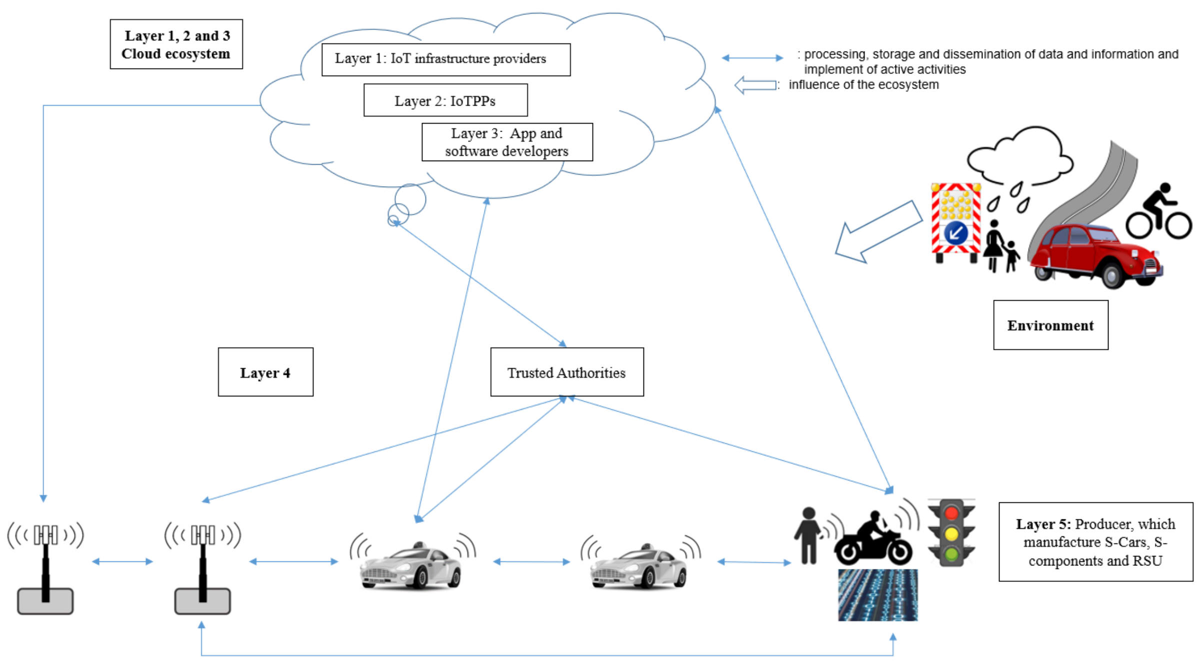
The producers that manufacture the S-Cars, S-components and RSUs with active sensors and actuators are located in Layer 5 (Lima et al., 2016; Lüers et al., 2017; Rauen et al., 2017, 2017)

| 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 organization that certify the RSUs, S-Cars, and S-components |
| Layer 5 | Producers, which manufacture S-Cars, S-Components and RSUs | Produce the sentient components with active sensors and actuators in the ecosystem |

Table 5-1 The five layers of an autonomous driving ecosystem

(Lüers *et al.*, 2017; Rauen *et al.*, 2017; Datta *et al.*, 2017; Lima *et al.*, 2016; Mauer *et al.*, 2015, 9-36; Wang and Meckl, 2020)

Figure 5-1 The ecosystem of autonomous driving in a graph (Wang & Meckl, 2020)



## 5.4 CSFs of AD-TQM

The CSFs of TQM have been discussed by many scholars, who have advocated certain prescriptions in different industries over the past few decades. Vimal Kumar and Sharma (2014) have identified 36 CSFs of TQM. According to Aquilani et al. (2017), ten CSFs in TQM have been defined as “most important”. The IATF has integrated seven of the most core CSFs for the automotive industry. Wang and Meckl (2020) have summarized the resulting matrix as Table 5-2:

| Quality principles of IATF 16949 | CSFs of Kumar and Sharma 2014 | CSFs of Aquilani, Silvestri, and Ruggiere 2017 |
|---|---|---|
| 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 and 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) |

Table 5-2 Matrix of the quality principles of IATF 16949 and the CSFs of TQM

Based on the matrix table, also considering the integration of the German Association of the Automotive Industry (VDA), another relevant and integrated quality management system in the automotive industry, and using the 103 research papers about the CSFs of TQM by Aquilani et al. (2017) as the basis and starting point, Wang and Meckl have developed 15 CSFs of AD-TQM (Franceschini et al., 2011; Qualitätsmanagementsystem-, 2016; VDA2, 2012; Wang & Meckl, 2020).

The 15 CSFs are first identified as 15 corresponding hypotheses using conceptual methodology without an empirical study (Arumugam et al., 2011; Idris & Zairi, 2006; Mandava & Bach, 2015; Mustafa & Abdul, 2012; Soltani et al., 2005; Talib & Rahman, 2010). A pre-test was conducted using qualitative cognitive expert interviews (Mellahi & Eyuboglu, 2001; Mensah et al., 2012;

Niu & Fan, 2015), so that the 15 CSFs are generated (see Table 5-3; for details on the CSFs see Wang & Meckl, 2020).

| ***Current CSFs of TQM in the automotive industry*** | ***CSFs as hypotheses of AD-TQM*** |
|---|---|
| 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: Organizations should be built as systems with interlinked processes, of which the key TQM processes 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 organizations 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 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. |
| 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. |

Table 5-3 15 CSFs of AD-TQM

## 5.5 Methology: quantitative analytic hierarchy process

To prioritise CSFs, the analytic hierarchy process (AHP) approach can be implemented (for details on AHP see e.g., Saaty). The AHP is "hierarchical" because the criteria that are used to solve a problem are always placed in a ranking, i.e., a hierarchical structure. The elements of a hierarchy can be divided into groups, whereby each group only influences one other ("higher") group of hierarchy elements and is only influenced by one other ("lower") group (Saaty, 1994; Golden et al., 1989). It is called "analytical" because it is suitable for comprehensively analysing a complex problem constellation in all its dependencies (Saaty, 1994; Golden et al., 1989). In addition, the AHP provides a procedural flow of how to prioritise the elements (Saaty, 1994; Golden et al., 1989), which is also the objective of this paper with the CSFs ("elements") of an AD-ecosystem. Due to these characteristics, the AHP has become a widely employed methodology for creating ranking lists. According to Wasil and Golden (2003), thousands of AHP applications have been used to support the generation of strategies of ecosystems in more than 30 diverse areas. It has also been employed in research papers (see for example, Rezazadeh et al., 2012) for prioritising the general CSFs of TQM. The common approach, adapted to the research focus of this paper, should be executed as follows (Cheng & Li, 2002; Saaty, 1994; Lam & Chin, 2005; Golden et al., 1989):

(1) Identifying the CSFs of AD-TQM

(2) Defining the questionnaire as well as the profile of the experts

(3) Collecting the data by pair-wise comparisons of the CSFs

(4) Calculating the consistency ratio (CR) of the judgments

(5) Representing the weights of the CSFs of AD-TQM

(6) Implementing the comparison between Germany and China, using additional qualitative cognitive expert interviews.

Step 1 has been adopted from prior research, as explained above.

For Step 2, it is important that the questionnaire survey focuses on experts from all five layers. To guarantee high-quality answers, the experts must have direct project experience in connection with an AD-ecosystem. The quantity of the experts from each layer between Germany and China should be the same for a fair comparison. The referencing organizations by each layer, for example, Nokia in infrastructure, Baidu in IoTPPs, Fraunhofer Institute in app developers and software, the provincial government in trusted authorities as well as e.g., Audi in automotive

OEMs should be included, so that the results are more convincing. Since AHP does not require the involvement of a large number of experts (Cheng & Li, 2001), all the participants interviewees have been reached by personal contacts of the authors, ensuring that the experts have the trust and readiness to express their real opinions of the new, unfamiliar, and sensitive theme instead of issuing statements made with a view to mere political correctness.

Therefore, eight experts in IoT infrastructure providers, 10 experts in IoTPPs, 10 experts in software and app developers, eight experts in trusted authorities, as well as 28 experts in automotive OEMs and system suppliers were sought out in Germany and China. The experts are either senior engineers who are deeply integrated in AD-ecosystem projects or senior managers (CXOs) who must focus on the business strategy of the whole ecosystem. The profile of the participants as well as their employers are reported in Table 5-4. Due to confidentiality, the names of the companies/institutions have been replaced by a description of institutions' position in the ecosystem and their respective industry.

Through a pair-wise comparison (procedure in detail see also Kou et al., 2016; Ramík & Korviny, 2010), the AHP can rate the CSFs quantitatively. Summing up Step 3, 64 questionnaires were sent to the participants, and all of them responded with the quantitative pairwise comparisons mainly because their permission to do so has been cleared beforehand. In the questionnaires, the responses should evaluate how important they think the 15 CSFs will be for the success of AD-TQM. The participants should assign points (the more points, the more important is the respective factor for the success of AD-TQM) to each factor. As a control condition, the points in total for the 15 CSFs must be 100. A side-document including an explanation of the method and giving background information proved useful since no follow-up inquiries from the participants were made. To ensure that all the judgments were consistent, the consistency tests of each data set were calculated in the fourth step with the formal CR = CI/RI (see also Chu and Liu, 2002). The RI is the random index and should be defined as 1.58 based on n (CSFs of TQM) = 15 (Yap et al., 2018) in this paper. With the formal CI (consistency index) = $\frac{\lambda \max - n}{n-1}$ that λmax is calculated by averaging the value of the consistency vector (procedure in detail also see Alonso & Lamata, 2006; Geoff, 2004). The consistency ratios CR of these 64 data sets are all below 0.1, which means these data are consistent and reliable (Saaty). The norming of the total points which could be assigned to 100 ensures a high consistency. The consistency indices of each data set are shown in Table 5-7 (Appendix).

| Layers | China | Referencing organizations | Germany | Referencing organizations |
|---|---|---|---|---|
| **IoT infrastructure providers** | 5G senior expert | one of the largest 5 G infrastructure providers (IPs) in the world (two responses); One of the largest 5 G IPs in the world; the China business unit (CBU) of the world's largest semiconductor chip manufacturer | Professor | a research institute for 5 G of a technology university; a system supplier for the hardware of 5G equipment; Germany business unit (GBU) of one of the largest 5 G IPs in the world; one of the largest internet infrastructure providers in the world |
| | 5G senior expert | | Head of business development | |
| | 5G senior expert | | CEO | |
| | Project leader 5 G and cloud technology | | CTO | |
| **IoT platform providers** | Senior expert AD ecosystem | one of the largest AI and internet companies (AIICs) in the world; one of the largest AIICs in the world; one of the largest AIICs in the world; an electric vehicle manufacturer based on the investments of several AIICs; an electric vehicle manufacturer based on the investments of several AIICs | Senior expert AD ecosystem | GBU of one of the largest AIICs in the world; an IoT ecosystem-oriented consulting company (four responses) |
| | Project leader expert AD smart suspension | | Vice president Europa | |
| | Senior expert AD ecosystem | | Senior expert AD ecosystem | |
| | Project leader expert AD smart suspension | | Senior expert AD ecosystem | |
| | Senior expert AD cloud technology | | Senior expert AD ecosystem | |
| **Software and app developers** | Programming and software engineer big Data | A big data institute of a technology university; a big data department of a multinational home appliances and consumer electronics company; a big data-oriented consulting and programming company (three responds) | Programming expert for AD ecosystem | A big data institute of Europe's largest application-oriented research organization; a former start-up of developing affordable electric vehicles; a big data institute of a technology university; a big data-oriented consulting company; one of the largest enterprise software companies |
| | Project expert big data | | Programming expert for smart logistic system | |
| | Vice president | | Programming expert for big data | |
| | Product and architecture design | | Senior expert for big data | |
| | CTO China | | Vice president | |
| **Trusted authorities** | Vice director | an economy office of a province government; an IT research and strategy centre of a province government; an analytical strategy centre of a province government; an advisory and strategy centre of a province government | Board of director | a traffic planning office of a city government; a famous economy association; a research and strategy centre of a country government; a transport planning office of a city government |
| | Senior manager | | President | |
| | Senior manager | | Director | |
| | Senior manager and advisory board | | Project leader for AD ecosystem | |
| **Automotive OEMs and system suppliers** | CEO | OEMs: one of the "Big Four" Chinese automakers (two responses); a Chinese multinational automotive company; China's largest SUV and pickup manufacturer; The CBU of one of the largest worldwide OEM SYSTEM SUPPLIERS: a system supplier for smart suspension system (SSS) (three responses); a system supplier for SSS; The CBU of an Europa system supplier for SSS; the CBU of an Europa system supplier for SSS; the CBU of an Europa system supplier for injection moulding; the CBU of one of the largest worldwide system supplier; a research institute of a technology university | CEO | OEMs: one of the largest premium car manufactures in the world; one of the largest worldwide OEM SYSTEM SUPPLIERS: a system supplier for SSS (two responses); a system supplier for SSS (three responses); one of the largest worldwide system supplier (two responses); one of the largest worldwide system supplier (two responses); a system supplier for precision machining; a GBU of a Asia system supplier for injection moulding; a system supplier of special production equipment |
| | CEO | | Deputy vice president of quality | |
| | General manager of AD smart suspension system | | Quality planning director | |
| | Vice president | | Quality manufacturing expert | |
| | Smart suspension director | | Vice president of sales | |
| | Smart suspension expert | | Senior development expert | |
| | Project director smart suspension system | | Innovation management expert | |
| | AD expert | | Vice president | |
| | Quality expert of smart suspension system | | CTO | |
| | Sales manager | | Sales manager | |
| | Sales director | | Senior development expert | |
| | Smart suspension expert | | Senior development expert | |
| | Senior purchasing manager | | Project leader | |
| | Senior expert for automotive architecture | | Senior development expert | |

Table 5-4 The profile of the interviewees as well as the working organizations

Therefore, the weighting of the 15 CSFs of AD-TQM can be implemented based on all the 64 questionnaires, which appear in Table  in t5-8he Appendix (from highest to lowest weighting). The weighting from the German point of view based on the data of the 32 German experts appears in Table 5-9 in appendix and from the Chinese point of view, based on the data of the 32 Chinese experts, Table A 5-10 in the Appendix shows the weights.

For Step 6, qualitative interviews were conducted as the main approach to an innovative, i.e., unstructured field of research (Bethann et al., 2019; Wang & Meckl, 2020; Willis, 2004, 2015). The same method was also integrated by other cited papers about the CSFs of TQM (Mellahi & Eyuboglu, 2001; Mensah et al., 2012; Niu & Fan, 2015). In this paper, this method has been used to interview some of the 64 experts from both Germany and China after the quantitative AHP. This supports the researchers in identifying the unrealised potential interdependencies as well as determining the main reasons for the differences in the prioritising of the CSFs of AD-TQM between Germany and China. The results were meant to highlight the reasons for some big differences in the evaluations of experts from both countries. Therefore, in the present paper, six experts from Germany and China were interviewed. Their evaluated points as well as the correlations are shown in Table 5-5 (n/a is the abbreviation for "not available").

| Different prioritising of CSFs | German point | Chinese point | Expert 1 from Germany | Expert 2 from China | Expert 3 from Germany | Expert 4 from China | Expert 5 from Germany | Expert 6 from China |
|---|---|---|---|---|---|---|---|---|
| CSF 11 | 6.81% | 7.66% | 5% | 10% | n/a | n/a | 6% | 8% |
| CSF 9 | 6.94% | 7.38% | 7% | 8% | 7% | 10% | 6% | 7% |
| CSF 2 | 6.94% | 7.34% | n/a | n/a | 6% | 10% | 4% | 7% |
| CSF 7 | 7.03% | 6.53% | 8% | 5% | n/a | 4% | 10% | n/a |
| CSF 12 | 7.00% | 6.56% | 8% | 5% | 7% | 5% | n/a | 4% |
| CSF 6 | 5.72% | 6.53% | n/a | n/a | 6% | 7% | 2% | 8% |
| CSF 1 | 6.00% | 5.94% | 6% | 5% | 6% | n/a | n/a | 5% |

Table 5-5 Evaluations of the six responses from the interviews

In addition, the interviews were a chance to discuss with the experts whether and why they want to add new factors to the CSF list of AD-TQM. The proposed new CSFs were discussed until both experts and authors agreed on the new ideas.

## 5.6 Results and discussion

We ranked the weights of the CSFs along four levels:

(1) Very important (8% ≤ normalised priority weight)

(2) Important (7% ≤ normalised priority weight < 8%)

(3) Neutral (6% ≤ normalised priority weight < 7%)

(4) Less important (normalised priority weight < 6%)

Taking the four levels, the German and Chinese experts have the same opinion on CSF 8 (Data and information exchange procedure). It is the only "very important" CSF of AD-TQM. Collecting, analysing, and exchanging the relevant data and information between the five layers to reach a conformity of products and services, customer needs and satisfaction, as well as the implementation and performance of the TQM system does make the most relevant contribution to a high level of an AD-TQM-system. As a consequence, the building up of such an exchange procedure should be one of the critical challenges in an AD-ecosystem. With players from very different backgrounds (see Table 7), solving this task requires high capabilities in ecosystem governance and coordination.

Several previous research studies have already stated that the implementation of the Big Data has significant implications for sustainability with the excellent understanding of operations, determining the environment (energy) risks, optimising the resource implementation, as well as establishing better regulation (see e.g., Dubey et al., 2019;).The present research has proved that these considerations are also suitable for building up an AD-TQM system.

The six CSFs 15, 13, 10, 3, 5, and 14 are evaluated from both sides, Germany and China as "neutral" CSFs, which means these factors should be considered for building up the AD-TQM but are not the highest priorities.

From both Germany and China, it is stated that CSF 4, to involve and train all the employees for AD-TQM, seems to be a "less important" CSF, which is somehow surprising, regarding the high relevance of the human factor in traditional TQM-systems. Further interviews with the experts (Experts 2, 4, 5, and 6, whose points are all less than 6% by CSF 4) show that the experts doubt there are enough resources to train all the employees of every player because of the high complexity and innovation of the AD-ecosystem. In addition, the level of the automation of the AD ecosystem will be extremely high, which means that not all employees significantly influence the success of the AD-ecosystem. Some reference roles such as the technology and marketing are very important. Therefore, it makes more sense to train solely the target employees who are highly relevant for the performance of the ecosystem.

The enterprise resource management theory, especially the resource capacity, as well as resource prioritisation and allocation in sustainable development (see e.g., Hoch & Dulebohn, 2013; K.

Kumar & van Hillegerberg, 2020; Parris & Kates, 2013), could be the theoretical basis for explaining the very surprising result that most resources should be planned and placed for the most important tasks, in this case, to train the target and relevant employees of the AD ecosystem with limited resources.

In further discussion with the interviewees, they all agreed that resource management could be a new important CSF of AD-TQM with the explanation that in practice, the relevant resources are always limited. With the integration of such considerations in the CSFs, the implementation of an AD-TQM can be planned and considered in a more practical way.

Therefore, a new CSF (CSF 16) of AD-TQM could be defined as:

**16. The participants of all five layers should plan and prioritise their limited resources for the most important processes of AD-TQM.**

Because of the massive difference between Germany and China, CSF 11 (legal framework and sharing of competences between public and private institutions) is discussed ambiguously. It is (only) ranked as a middle "neutral" CSF for Germany but scored as the highest "important" CSF for China. Because of the high scoring on the Chinese side, it is considered as the highest "important" (one level below the "very important") CSF of AD-TQM in total.

According to the further discussions with the experts referenced, the biggest difference is to define/integrate the role and responsibility of the government for the AD-ecosystem. German eperts recognise no priority and stay quite neutral on whether the government should be really integrated to realise AD technology. Chinese experts believe that one of the most important parts should be the legal framework which cannot be realised without the government. In addition, the government may take on the orchestrator role to coordinate other layers based on the law and policy aspects.

Several papers have already asserted that in general, a good government should develop and maintain strategies, policies, and programs to promote sustainability (Bell, 2002; Saha, 2009). Specifically for AD ecosystems, research studies have also discussed that the government may offer support to build up the necessary infrastructure as well as to define new laws and a regulatory framework (Mauer et al., 2015, pp. 151–73). This paper has contributed to further discussion, clarifying that the exact role and position of the government should be defined clearly and will be very different based on diverse countries with varying cultural backgrounds in AD-ecosystem.

CSF 9 (a standard and consistent release process for product and production in the ecosystem) is also in discussion because the evaluations are ranked as a “neutral” CSF by Germany but as an “important” CSF by China, which leads to an “important” CSF of AD-TQM in total. For German experts, this CSF is a support process to ensure that the integrated technologies from different layers are reliable. Therefore, the technologies should be most important instead of the release process itself. On the other hand, the Chinese experts prefer to have an AD-ecosystem in the market in which the technology is perhaps not so mature at first but can be developed continuously, based on the feedback from the market and Big Data analytics. Therefore, a standard release process to ensure the security of the AD-ecosystem is important.

A similar discussion can also be seen in CSF 2 (implemented emergency plan): the German viewpoint is a “neutral” but CSF 2 is defined as “important” by China, the same as the ranking in total. During the further interviews, the German experts have the similar statement that a mature technology of the AD-ecosystem (both products and production) should be developed, which means a complex emergency plan is not needed. In contrast, China prefers the same as CSF 9: to have an AD-system in the market first without the (“over required”) full maturity so that an emergency plan to ensure the security and reliability of the AD-ecosystem is needed. Therefore, it is judged as “important”.

The discussion of CSF 7 (predictive maintenance processing) is critical, since to the Germans it is “important” while it is ranked as a middle “neutral” CSF by China. It is considered to be as a “neutral” CSF of AD-TQM in total. Based on the further interviews of the experts, the different understandings (similar to CSFs 9 and 2) for “technology first” in Germany and “market first” in China are also the main reasons here. The German experts have stated that automatic predictive maintenance should be one of the innovative new technologies to ensure the matureness of the AD-ecosystem during the whole system life, which leads it to be an “important” CSF. On the other hand, the experts in China prefer to concentrate on the development of the AD-ecosystem itself instead of investing many resources to integrate an automatic predictive maintenance technology, which could slow the market entrance because of the high investment required and a too-long development period.

The CSF 12 (automated environment application) is ranked from the German side as “important”. From China, it is judged as the highest “neutral” CSF, where the CSF is also ranked as “neutral” in the total overview. A similar justification of this difference is also the “technology first” reasoning from Germany or “market first” from China. In German opinion, the start-stop function based on the suitable application environment of an AD-ecosystem should be one of the interesting new and innovative technologies to be implemented in the AD-ecosystem, whereas the Chinese experts agree with this statement but at the same time they also fear that the suitable application environment cannot be determined correctly. As a consequence, there could be too many "stops based on fake false environment", so that the driver experience of the AD-ecosystem could be negatively influenced. Therefore, CSF 12 is ranked as "neutral".

Because of the huge difference between Germany and China, the CSF 6 (digital curriculum vitae) is also in discussion. It is ranked as the lowest "less important" (5.72%) CSF for Germany but scored as a middle "neutral" (6.53%) CSF for China. In sum, it is judged as a "neutral" CSF of AD-TQM. During the further interviews, the German experts stated that the digital curriculum vitae for all the components of an AD-ecosystem is only an excellent theoretical idea. In practice, they cannot image which technologies can be integrated to realise such a complex innovative approach. In addition, there is uncertainty about whether it makes sense to invest so many resources regarding the risk that, due to the high complexity of such a system, the performance of the AD technology is not improved by a digital curriculum vitae. Therefore, it is ranked as the lowest "less important". In contrast, the China experts have the opinion that such a technology could help to define the responsibility of the potential failures and improve the trust of the end users for the AD-ecosystem. Of course, to produce all the components with such a complex and expensive technology is not possible, but it can be implemented for the important parts (for example, the algorithm of AD software). It could be a huge advantage for the marketing side to show the industry's innovation to the customers. Thus, it is weighted as a middle "neutral" CSF.

According to previous research (see e.g., Hall & Vredenburg, 2003; Kolk & Van Tulder, 2010; Lubin & Esty, 2010), it can be stated that both technological innovation and marketing development are the critical factors, which have close interactions (innovation could create a sustainable marketing profit and a sustainable marketing profit would encourage the continuous technical investments and motivations) for the sustainability of a business ecosystem. With regard to this phenomenon, the present paper has demonstrated the significant difference in the understanding and prioritisation of the two critical factors from Germany and China and opened a further discussion to analyse the reasons for the difference as well as to achieve a balance between the two factors to develop a reliable AD-TQM.

In further discussions with the interviewees, they have stated that the significant difference is because of the different understanding from Germany and China regarding new innovative business ecosystems. It should not be defined as a new CSF of AD-TQM because the cultural difference could influence many other aspects and can't be considered as a separate factor.

For the CSF 1, the handling of complaints in the AD-ecosystem, the total rating is scored as “less important”. The ratings between Germany and China are different but both ratings (Germany: 6.00%; China: 5.94%) are at the borderline between “neutral” and “less important” with similar understandings. The summary of the analysis is shown in Table 5-6.

| CSFs of AD-TQM | Ranking (total) | Ranking (Germany) | Ranking (China) |
|---|---|---|---|
| 8. Data and information exchange for all five layers in the ecosystem should be coordinated and monitored. | Very important | Very important | Very important |
| 11. The responsibilities of the public and private organizations for the processing of the components in the ecosystem must be defined and a legal framework must be established. | Important | Neutral | Important |
| 9. A production process and product release procedure should be defined for all five layers in the ecosystem. | Important | Neutral | Important |
| 2. An emergency plan for products, processes, services, and systems that incorporates all five layers must be integrated into the ecosystem. | Important | Neutral | Important |
| 7. Predictive maintenance processing should be realised and implemented for all components in the ecosystem. | Neutral | Important | Neutral |
| 12. 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. | Neutral | Important | Neutral |
| 15. The platform, frameworks, and interlinks in the ecosystem must be standardised. | Neutral | Neutral | Neutral |
| 13. Different quality requirements for special important characteristics of all five layers in the ecosystem should be classified, realised, and controlled. | Neutral | Neutral | Neutral |
| 10. The audit process should be performed for all five layers in the ecosystem. | Neutral | Neutral | Neutral |
| 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. | Neutral | Neutral | Neutral |
| 5. Process approach remains the same: Organizations should be built as systems with interlinked processes, of which the key ones of TQM should be identified. | Neutral | Neutral | Neutral |
| 14. The data protection principles should be defined and implemented in the ecosystem. | Neutral | Neutral | Neutral |
| 6. Digital curriculum vitae processing should be realised and implemented for all components in the ecosystem. | Neutral | Less important | Neutral |
| 1. Handling of complaints must be harmonised in the whole ecosystem, i.e., for all five layers. | Less important | Neutral | Less important |
| 4. Employees should be trained and involved in the processes of the ecosystem of autonomous driving. | Less important | Less important | Less important |
| 16.The participants of all five layers should plan and prioritise their limited resources for the most important processes of AD-TQM. | new CSF | new CSF | new CSF |

Table 5-6 Weights of the CSFs of AD-TQM according to the four levels of importance in total and between Germany and China

## 5.7 Conclusions, Limitations and Outlook

The purpose of this study is to prioritise the 15 CSFs of AD-TQM quantitatively and implement a comparison between Germany and China.

The AHP method was adopted. 64 experts from all five layers of an AD-ecosystem from Germany and China who are either senior experts of AD-projects or the senior managers who must focus on the strategy of the new ecosystem were selected. The 64 experts completed 64 quantitative pair wise questionnaires to weight the 15 CSFs of an AD-TQM-system. The consistency ratios are all below 0.1, which means that all the data sets are reliable for further analysis. Six experts were interviewed for the further explanations of the differences in results between Germany and China.

Four levels of the weights as “very important”, “important”, “neutral”, and “less important” were defined based on the scorings of the CSFs.

The CSF 8, data and information exchange and analysis in the AD-ecosystem, proved to be the only “very important” CSF for the success of the AD-TQM.As theoretical explanations, several previous research studies have already stated the theory of Big Data for sustainability. The CSFs 11, 9, and 2, to define the responsibilities of the public and private organizations to certify the layers in AD-ecosystem, define a release process of product and production, as well as to integrate an emergency plan of application, have been defined as the “important” CSFs of AD-TQM. The CSFs 7, 12, 15, 13, 10, 3, 5, 14 and 6 have been judged as the “neutral” CSFs. The CSF 1, handling of the complaints, as well as the CSF 4, involving and training of all the employees, have been ranked as the two “less important” CSFs. For the surprising evaluation of CSF 4, the enterprise resource management theory in sustainable development could be a theoretical basis for an explanation. Additionally, it has been selected as a new important CSF during the interviews for a practical reliable implementation of an AD-TQM.

Seven CSFs showed different evaluations between Germany and China. One of the biggest differences of understanding between Germany and China is the role and responsibilities of the government in the AD-ecosystem (CSF 11) which has been also discussed by other referenced research. The German experts stayed neutral and had no preference whether government, or generally speaking public authorities, should be tightly integrated in the ecosystem, whereas the Chinese experts determined that the participation of government authorities is a precondition for a successful AD-TQM, based on law and policy aspects. According to some Chinese experts interviewed (Expert 2, 4, and 6), the government should even take the orchestrator role to coordinate other participants to realise the AD-TQM. The basic result thus is that CSF 11, the responsibilities of the public organizations, does not correspond between Germany and China. The Germans ranked it as “neutral”, while the Chinese scored it as the highest “important” CSF.

The other big difference of understanding of how to develop the AD-ecosystem between Germany and China is the “technology first” attitude in Germany versus the “market first” attitude in China. The German experts interviewed (Expert 1, 3, and 5) preferred to have a mature technology before the market rollout, so that the applications of the AD-ecosystem could be secure and reliable for the long-term stable development of the industry. On the other hand, the Chinese experts interviewed (Expert 2, 4, and 6) had the idea to roll out the AD technology to the market without introducing “overly required” matureness. Afterwards, the AD-ecosystem can be developed and optimised continuously and efficiently based on the feedback from the customers and on Big Data analytics for the applications. Because of this basic difference, the CSFs 9, 2, 7, 12, 6 and 1 are differently ranked from the German and Chinese sides. These two factors (“technology first” and “market first”) have close interactions and should be realized with an feasible balance for a sustainable AD-TQM.

Furthermore, an important contribution of this study is in relation to sustainability and generally with compliance to ESG-related management. Our study contributes to promoting an environmentally important and socially desirable new system of mobility. Identifying and empirically validating CSFs are preconditions for establishing the future environment-central mobility system. It helps to efficiently operate this system and to ensure a long-lasting survival of an AD ecosystem that helps make mobility cheaper and easier to use.

The limitations of this approach may be found on the methodological level. In the AHP approach, the subjective factor in filling out the questionnaires and thus determining the hierarchical structure are obvious (see also Kaliyamurthi, 2017; Oguztimur, 2011). What is more, the sample consisted of 64 experts as well as six interviewed experts from two different countries, which means that for each layer and each country, the number of experts may be too low to guarantee a generally valid result. Experts from all five layers, and also from other interesting countries such as the USA or Japan, should be integrated in future studies to reach a higher level of empirical verification. In this case, the present research can be defined as a starting basis and an official introduction toward beginning a research project for acquiring the experience of the experts in all five layers and all relevant countries without depending upon personal contacts.

Furthermore, multi-level sample sizes are required since variations in results may occur depending on different criteria or different groups such as gender, age, ethnic group, etc. Therefore, the CSF list should be a dynamic construct with the idea that the CSFs have been defined and prioritised according to the current technology based on the present surveys. New CSFs with new prioritising resulting, e.g., from technological developments, could be stated with further quantitative research and interviews.

Future research should also focus on the analysis and implementation of the new CSF "resource management". Moreover, an interesting result is the differing opinion on the role of the government in AD-ecosystems. Future research should develop types of AD-ecosystems with different levels of government involvement and evaluate the effects on TQM. Furthermore, it is also necessary to study the phenomenon and the associated meanings of the "technology first" approach in Germany and "market first" in China for building up a successful AD-TQM system in general. Such a study could help to define the orchestrators as well as their exact roles in order to see who will and should take which responsibilities (and how) to build up a reliable AD-TQM in the future. What is more, further relevant CSFs of AD-TQM should be integrated and prioritised continuously by further surveys with large quantitative data. In addition, the cooperation and coalition between Germany and China to build up an international standard AD-TQM could be implemented after analysing the differences in understanding for the complex innovative new ecosystem.

In summary, Wang and Meckl (2020) have identified 15 CSFs of AD-TQM as the first step with a qualitative pre-test according to (only) four interviews of experts by only two layers (three by layer 5 and one by layer 3). As a further procedure, the present research has prioritised the 15 CSFs according to 64 quantitative empirical studies based on the data from all five layers as a critical further step. Moreover, six qualitative interviews have been conducted to analyse the reasons for the prioritising as well as to determine further potential new CSFs of AD-TQM. With this analysis, the understandings of the AD-TQM ecosystem have been implemented more comprehensively (all the layers have participated) and deeply (much more experts have participated with quantitative evaluations). The importance and sensitivity of the topic has been also widely extended from both the theoretical and practical side (several senior managers for example, the president, the CEO and the CMO of several very famous institutional organizations have been quantitative questioned and qualitative interviewed). Several further research directions such as discussing the orchestrators of the AD ecosystem and defining the exact role and responsibilities of the government in the AD ecosystem have been specified much more clearly.

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## 5.9 Appendix

| Expert | Layer | Country | CR | Expert | Layer | Country | CR |
|---|---|---|---|---|---|---|---|
| 1 | Infrastructure | CN | 0.00 | 33 | TA | GE | 0.01 |
| 2 | Infrastructure | CN | 0.02 | 34 | TA | GE | 0.01 |
| 3 | Infrastructure | CN | 0.01 | 35 | TA | GE | 0.05 |
| 4 | Infrastructure | CN | 0.00 | 36 | TA | GE | 0.00 |
| 5 | Infrastructure | GE | 0.00 | 37 | Automotive | CN | 0.00 |
| 6 | Infrastructure | GE | 0.00 | 38 | Automotive | CN | 0.00 |
| 7 | Infrastructure | GE | 0.01 | 39 | Automotive | CN | 0.00 |
| 8 | Infrastructure | GE | 0.01 | 40 | Automotive | CN | 0.01 |
| 9 | IoTPP | CN | 0.01 | 41 | Automotive | CN | 0.00 |
| 10 | IoTPP | CN | 0.02 | 42 | Automotive | CN | 0.01 |
| 11 | IoTPP | CN | 0.01 | 43 | Automotive | CN | 0.00 |
| 12 | IoTPP | CN | 0.01 | 44 | Automotive | CN | 0.01 |
| 13 | IoTPP | CN | 0.01 | 45 | Automotive | CN | 0.00 |
| 14 | IoTPP | GE | 0.00 | 46 | Automotive | CN | 0.00 |
| 15 | IoTPP | GE | 0.00 | 47 | Automotive | CN | 0.00 |
| 16 | IoTPP | GE | 0.00 | 48 | Automotive | CN | 0.00 |
| 17 | IoTPP | GE | 0.00 | 49 | Automotive | CN | 0.00 |
| 18 | IoTPP | GE | 0.01 | 50 | Automotive | CN | 0.01 |
| 19 | Software | CN | 0.00 | 51 | Automotive | GE | 0.00 |
| 20 | Software | CN | 0.04 | 52 | Automotive | GE | 0.00 |
| 21 | Software | CN | 0.00 | 53 | Automotive | GE | 0.01 |
| 22 | Software | CN | 0.00 | 54 | Automotive | GE | 0.01 |
| 23 | Software | CN | 0.01 | 55 | Automotive | GE | 0.02 |
| 24 | Software | GE | 0.00 | 56 | Automotive | GE | 0.02 |
| 25 | Software | GE | 0.01 | 57 | Automotive | GE | 0.00 |
| 26 | Software | GE | 0.00 | 58 | Automotive | GE | 0.00 |
| 27 | Software | GE | 0.00 | 59 | Automotive | GE | 0.02 |
| 28 | Software | GE | 0.04 | 60 | Automotive | GE | 0.01 |
| 29 | TA | CN | 0.00 | 61 | Automotive | GE | 0.00 |
| 30 | TA | CN | 0.00 | 62 | Automotive | GE | 0.00 |
| 31 | TA | CN | 0.01 | 63 | Automotive | GE | 0.00 |
| 32 | TA | CN | 0.02 | 64 | Automotive | GE | 0.00 |

Table 5-7 Consistency ratios of the 64 quantitative empirical studies.

| CSFs of AD-TQM | Normalised priority weights |
|---|---|
| 8. Data and information exchange for all five layers in the ecosystem should be coordinated and monitored. | 8.08% |
| 11. The responsibilities of the public and private organizations for the processing of the components in the ecosystem must be defined and a legal framework must be established. | 7.23% |
| 9. A production process and product release procedure should be defined for all five layers in the ecosystem. | 7.16% |
| 2. An emergency plan for products, processes, services, and systems that incorporates all five layers must be integrated into the ecosystem. | 7.14% |
| 7. Predictive maintenance processing should be realised and implemented for all components in the ecosystem. | 6.78% |
| 12. 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 S-Cars. | 6.78% |
| 15. The platform, frameworks, and interlinks in the ecosystem must be standardised. | 6.73% |
| 13. Different quality requirements for special important characteristics of all five layers in the ecosystem should be classified, realised, and controlled. | 6.69% |
| 10. The audit process should be performed for all five layers in the ecosystem. | 6.48% |
| 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. | 6.36% |
| 5. Process approach remains the same: Organizations should be built as systems with interlinked processes, of which the key ones of TQM should be identified. | 6.36% |
| 14. The data protection principles should be defined and implemented in the ecosystem. | 6.34% |
| 6. Digital curriculum vitae processing should be realised and implemented for all components in the ecosystem. | 6.13% |
| 1. Handling of complaints must be harmonised in the whole ecosystem, i.e., for all five layers. | 5.97% |
| 4. Employees should be trained and involved in the processes of the ecosystem of autonomous driving. | 5.77% |

Table 5-8: Weighting of 15 CSFs of AD- TQM (total)

| CSFs of AD-TQM | Normalised priority weights |
|---|---|
| 8. Data and information exchange for all five layers in the ecosystem should be coordinated and monitored. | 8.13% |
| 7. Predictive maintenance processing should be realised and implemented for all components in the ecosystem. | 7.03% |
| 12. 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. | 7.00% |
| 2. An emergency plan for products, processes, services, and systems that incorporates all five layers must be integrated into the ecosystem. | 6.94% |
| 9. A production process and product release procedure should be defined for all five layers in the ecosystem. | 6.94% |
| 15. The platform, frameworks, and interlinks in the ecosystem must be standardised. | 6.94% |
| 13. Different quality requirements for special important characteristics of all five layers in the ecosystem should be classified, realised, and controlled. | 6.84% |
| 11. The responsibilities of the public and private organizations for the processing of the components in the ecosystem must be defined and a legal framework must be established | 6.81% |
| 10. The audit process should be performed for all five layers in the ecosystem. | 6.78% |
| 14. The data protection principles should be defined and implemented in the ecosystem. | 6.50% |
| 5. Process approach remains the same: Organizations should be built as systems with interlinked processes, of which the key ones of TQM should be identified. | 6.47% |
| 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. | 6.03% |
| 1. Handling of complaints must be harmonised in the whole ecosystem, i.e., for all five layers. | 6.00% |
| 4. Employees should be trained and involved in the processes of the ecosystem of autonomous driving. | 5.88% |
| 6. Digital curriculum vitae processing should be realised and implemented for all components in the ecosystem. | 5.72% |

Table 5-9: Weighting of 15 CSFs of AD- TQM (Germany)

| CSFs of AD-TQM | Normalised priority weights |
|---|---|
| 8. Data and information exchange for all five layers in the ecosystem should be coordinated and monitored. | 8.03% |
| 11. The responsibilities of the public and private organizations for the processing of the components in the ecosystem must be defined and a legal framework must be established. | 7.66% |
| 9. A production process and product release procedure should be defined for all five layers in the ecosystem. | 7.38% |
| 2. An emergency plan for products, processes, services, and systems that incorporates all five layers must be integrated into the ecosystem. | 7.34% |
| 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. | 6.69% |
| 12. 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. | 6.56% |
| 6. Digital curriculum vitae processing should be realised and implemented for all components in the ecosystem. | 6.53% |
| 7. Predictive maintenance processing should be realised and implemented for all components in the ecosystem. | 6.53% |
| 13. Different quality requirements for special important characteristics of all five layers in the ecosystem should be classified, realised, and controlled. | 6.53% |
| 15. The platform, frameworks and interlinks in the ecosystem must be standardised. | 6.53% |
| 5. Process approach remains the same: Organizations should be built as systems with interlinked processes, of which the key ones of TQM should be identified. | 6.25% |
| 10. The audit process should be performed for all five layers in the ecosystem. | 6.19% |
| 14. The data protection principles should be defined and implemented in the ecosystem. | 6.19% |
| 1. Handling of complaints must be harmonised in the whole ecosystem, i.e., for all five layers. | 5.94% |
| 4. Employees should be trained and involved in the processes of the ecosystem of autonomous driving. | 5.66% |

Table 5-9: Weighting of 15 CSFs of AD- TQM (China)

# 6 Research Paper 3: Who Will Be The Orchestrator In An Autonomous Driving (AD) Business Ecosystem?" – The Position Of The Internet Of Things Platform Providers (IoTPPs) Versus Traditional Original Equipment Manufacturers (OEMs) Of The Automotive Industry

*With Reinhard Meckl (2022)*

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## 6.1 Abstract

As one of the most strategically significant and financially promising developing industries, autonomous driving (AD) ecosystems are facing challenging technical obstacles, organizational barriers, and financial requirements. The crucial question is which companies are most qualified to be the leaders of such ecosystems: to define the rules, and ultimately to reap the highest financial returns? This study defines a framework of an AD ecosystem, determines the needed capabilities for the orchestrator of an AD ecosystem, implements four qualitative interviews to make a first preliminary evaluation for the required capabilities of an orchestrator. Furthermore, hypotheses are derived and a questionnaire for the conducted pretest is developed which may also be used in a large quantitative empirical study asking what challenges the IoTPPs and AI-OEMs face in taking the dominating role compared to other referencing participants.

**Keywords:** business ecosystem; autonomous driving; automotive industry; Internet of things

## 6.2 Introduction

In order to improve the efficiency and safety of the transportation system, to prevent traffic accidents, to meet drivers' assistance needs, and to optimize the traffic flow, autonomous vehicles will actively participate in road traffic as a central feature as part of a mobile innovative revolution (Maurer et al., 2016, p. 2-4). There is no doubt that the resources of multiple participants will be combined to jointly develop and implement such a technologically challenging innovative autonomous driving (AD) ecosystem (Maurer et al., 2016; Datta et al., 2016; Wang and Meckl, 2020). From a strategic point of view, one of the crucial questions is, who is going to take the orchestrating role?

The answer is not obvious, since especially two types of companies of the new AD-value chain have the ambition and the means to compete as the "orchestrator." In the currently automotive business ecosystem, there are many papers which have already stated the huge complexity of the orchestration such as complex supply chain risk management and total quality management (Scannell et al., 2000; Sinha et al., 2016). The AI-OEMs are having the strongest position who design the quality standards such as IATF 16949 and VDA including the implementation process as well as define the customer specific requirements to orchestrate the automotive hardware suppliers and software suppliers for the innovation development as well as the high technical reliability in the automotive industry (Ding et al., 2019; Thun, 2018). From the other perspective, several researches have explored that in the future, cars could be defined as a smart movement centre on wheels while several leading IoTPPs are focusing to become the standard of applications (Beiker et al., 2016). IoTPPs like Google, Apple, Tencent, or Alibaba, who have already taken the core role by the smart mobile phone ecosystem to orchestrate the IoT infrastructure provider as well as software and app providers, could also take the same role in the AD ecosystem (Hyrynsalmi et al., 2012). Furthermore, targeted to the incumbents from the car industry, the answer to this question will determine whether they remain the dominant players in the car business or whether they will be degraded to suppliers of the core companies in this new constellation. For IoTPPs, this strategic window gives them the chance to enter a new era in their growth story with unprecedented possibilities to expand their dominant role in one of the most important industries.

In general, to manage and orchestrate an innovative ecosystem is not a new issue from different research perspective (Gardet and Mothe, 2011; Ritala et al., 2012). In the present paper, we focus on the the associated needed capabilities (Hurmelinna-Laukkanen and Nätti, 2018; Dessaigne and Pardo, 2020; Perks et al., 2017; Möller et al., 2005; Mitrega et al., 2012; Sullivan and Weerawardena, 2006). Our objective is to explicitly elaborate the orchestrator role in the AD-business ecosystem and to contribute to an industry framework based on this concept. In addition, as one of the best elements to avoid misunderstanding and the misuse of the survey process, especially for a very innovative, i.e., unstructured field of research, a pretest using qualitative technical interviews is implemented, firstly for gaining knowledge of a necessary adaptation of the hypotheses and secondly to generate the comprehensive questionnaire before entering into a large quantitative analysis (Presser and Blair, 1994; Buschle et al., 2021; Chigbu, 2019; Wang and Meckl, 2020).

## 6.3 Autonomous driving as a business ecosystem

A business ecosystem constellates different actors, including customers, suppliers, other partners, even competitors, whose resources are combined to create values through both competition and cooperation (Dessaigne and Pardo, 2020; Munksgaard and Freytag, 2011; Möller and Rajala, 2007). According to Wang and Meckl (2020), AD can be defined as an ecosystem which comprises five layers (see Figure 6-1): the cloud infrastructures, the IoTPPs, the applications and software developers, the trusted authorities, and the AI-OEMs including the system suppliers (see also Datta et al., 2017; Maurer et al., 2016; for a more detailed technical analysis see Pizzuto et al., 2019).

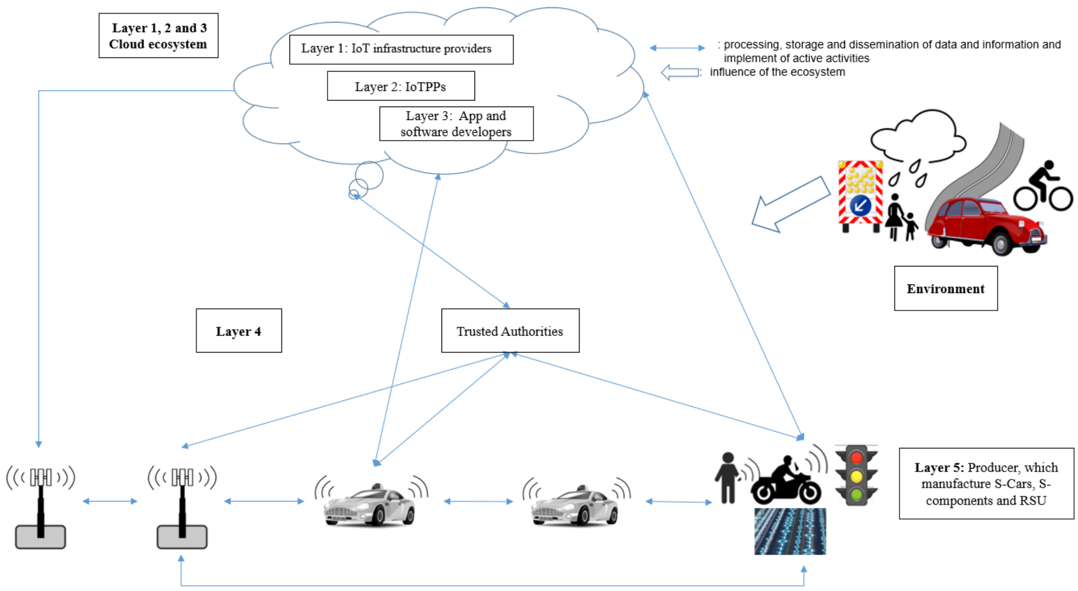


Figure 6-1 The ecosystem of autonomous driving

Cloud infrastructures as Layer 1 provide computing ability and storage capacity. The processing, storing, and disseminating in near-real time of Big Data in the ecosystem must be implemented in use (Lüers et al., 2016; Rauen et al., 2017; Datta et al., 2017; Lima et al., 2016).

The IoTPPs as Layer 2 enable the digital connections of physical objects, as well as the transactions over the IoT via a coordinating platform (Lüers et al., 2016; Rauen et al., 2017).

The applications and software developers (ASDs) as Layer 3 provide services and solutions on the Internet of Things platforms which is provided by IoTPPs (Lüers et al., 2016; Rauen et al., 2017).

The trusted authorities (TAs) as Layer 4 are public and private organizations which certify the Road Side Units (RSUs), autonomous cars (S-cars), and autonomous components (S-components) in order to provide the institutional framework (Lüers et al., 2016; Rauen et al., 2017; Datta et al., 2017; Lima et al., 2016) consisting of the rules and regulations, including system-suitable ethical standards (Wang and Meckl, 2020).

The AI-OEMs and the suppliers as Layer 5 manufacture the S-cars, S-components, and RSUs with active sensors and actuators (Lüers et al., 2016; Rauen et al., 2017; Lima et al., 2016; Wang and Meckl, 2020).

## 6.4 Theoretical grounding: the needed capabilities in orchestration

Orchestrators are the central network actors who coordinate purposeful actions to create and extract value from the ecosystem with explicit goals and timetables (Dhanaraj and Parkhe, 2006; Dollet and Matalobos, 2010; Hurmelinna-Laukkanen and Nätti, 2018). Orchestrators define standards and rules to organize the continuous improvement process (CIP) of the ecosystem. In addition, self-organizing and shared resources, protocols, processes, and infrastructures which enable collaboration should be implemented, allowing for the function of individual contributors and orchestrators as a loose network (Adner 2006; 2017; Fjeldstad et al., 2012; Lorenzoni and Lipparini, 1999).

In few academic articles such as Mitrega et al. (2012) and Sullivan and Weerawardena (2006), there are already discussions of the needed capabilities in an ecosystem orchestration (Hurmelinna-Laukkanen and Nätti, 2018). Although the challenge is still that "the Orchestrator capabilities have remained largely untapped" (Hurmelinna-Laukkanen and Nätti, 2018), the main focus of the present paper is to deal with who can and should be the orchestrator in the new technological AD-ecosystem instead of to research the general proposition of the capabilities needed as orchestrator. Therefore, the basis of the theoretical grounding are the existing described needed capabilities according to the few examples in the literature which have discussed orchestrators (Mitrega et al, 2012; Sullivan and Weerawardena, 2006; Ritter and Gemünden, 2003; Ritter et al., 2002):

1. Development capability (understanding, organization, and adaptation between cooperating organizations)

2. Initiation capability (search for new partners systematically to implement the benefits)

3. Proactive and innovative capability with high risk-taking abilities (readiness and openness to develop innovative products and solutions without clear marketing previews)

4. Decision capability (have the resources and powers to make decisions)

AD-ecosystems are theoretically a bundle of multiple alliances among participating organizations. The next topic to deal with, therefore, is the way multiple alliances are governed in an efficient way based on the needed development capability.

Establishing organizational standards and interfaces for communication and decision-making are main norms for the orchestrator to "govern" the ecosystem and exert its influence (Jacobides et al., 2018, pp. 2259, 2269-2270; Davis, 2014; Baldwin, 2012; Dakak and Alkhen, 2021). In some academic papers, the concept of "collaboration" is used as an organization of diverse interest groups that invest their resources to reach a common purpose which they are unable to deliver alone (Heuer, 2000; Lai, 2011). Thus, it is essential to determine the ability of the contender for the focal position to achieve structural management, i.e., to take all the five layers as a coalition in the AD-ecosystem.

One of the fundamental challenges is also the resolve (compared to the other ecosystem players) to implement those ruling structures. This is a time when another theoretical stream, the resource-based view (RBV) comes into play, which has also been used as the theoretical basis in a reference paper on needed capabilities in orchestration (Sullivan and Weerawardena, 2006).

The RBV is probably one of the most employed concepts in management theory (Mahoney and Pandian, 1992; Priem and Butler, 2001; Rugman and Verbeke, 2002; Brusoni and Prencipe, 2013). It is based on the idea that the quality and quantity of the resources in a company is the basis for its competitive advantage.

That the different resources of the players in an AD-ecosystem could combine to form a joint resource base allowing innovative serviced production is a promising view on value creation. Since an AD-ecosystem with problem-solving features and innovation survives only with its stable resource base, a dynamic approach is essential. Literature extended this static view by introducing the dynamic capability view (DCV) as an expansion of the RBV (Götz et al., 2020; Ambrosini and Bowman, 2009; also compare Teece et al., 2016; Teece et al., 1997; Teece, 2018). Dynamic capabilities are often characterized as those resources "that enable firms to create, extend and modify how they make a living, including through alterations in their resources (tangible and intangible assets), operating capabilities, scale and scope of business, products, customers, ecosystems and other features of their external environments" (Helfat and Raubitschek, 2018, p. 1393).

The subsequent question is, which dynamic capabilities are relevant to ensure the leading role of the orchestrator in an AD-ecosystem? How can the dynamic capabilities be synchronized with the needed capabilities in orchestration?

Considering resources like brand recognition and long-term customer loyalty are relevant for the competitive environment. The identification, assessment, and development of technical and business features satisfying customer needs is a precondition for the success of the ecosystem (Retkutė and Davidavičienė, 2021). This view is supported by, e.g., the marketing concept theory (Brady and Cronin, 2001). Hence, reputation would be classified as a "marketing competence" in an AD-ecosystem brand which can be synchronized to the theoretical basis "initiation capability."

Based on proactive and innovative capabilities, the central role of a working and innovative technology, the notion of "technological core competence" is essential to initiate and manage innovation. "Technological core competence" defines the key technological component for a current ecosystem which is competitive among the alliance-network and hard to imitate or replicate (March, 1997; Danneels, 2007).

Furthermore, to implement the decision capability, which requires extremely high upfront and regular capital investments necessary for building up, operating, and developing an AD-ecosystem, a solid ability in raising and providing capital seems to play an important role among dynamic capabilities. Moreover, the investor cannot expect a fast return and should make continuous large investments to compensate for an on-going negative cashflow. Regarding the AD-ecosystem as an innovation network, this assumption is very applicable and gives evidence for this “capital core competence” (Kupfer, 2019, pp. 11-40, p 253).

## 6.5 Derivation of the framework for the preliminary hypotheses

Based on the needed capabilities in orchestration after adaption, we identified four main factors concerning the preconditions and challenges which are necessary and have to be overcome to take the central role in AD-ecosystems:

1. Collaboration abilities (“organizational core competence”) based on development capability

2. Customer orientation (“marketing core competence”) based on initiation capability

3. Technological core competences based on proactive and innovative capability

4. Long-term investment motivation and resource capacities (“capital core competence”) based on decision capability

### 6.5.1 Collaboration abilities (“organizational core competence”)

In order to have a leading position in the collaboration, the contender should be able to integrate all the participants to agree to work together for building up a successful AD ecosystem in following aspects (Lai, 2011; Ordonez-Ponce et al., 2021).

1. Developing the relationships with every layer.

2. Resolve the conflicts of interest of different layers.

3. Win the respect, recommendations and support of other layers.

4. Be able to maintain the arranged lines, goals and relationships on a long-term basis.

5. Show the appreciation of the success of other layers.

Because of the successful collaboration experience of IoTPPS by the smart mobile phone ecosystem as well as the experience of OEMs by current automobile industry, the framework with the following two contrasting hypotheses-possibilities emerges can be defined with a view to the collaboration abilities:

1.1. The IoTPPs do have a stronger position with a view to collaboration abilities than the OEMs in AD-ecosystems because of their already long-term successful experience in other related digital business ecosystems.

1.2. The OEMs do have a stronger position with a view to collaboration abilities than the IoTPPs in AD-ecosystems because of the high technical complexity of automotive systems as well as the proven long-term successful experience of the current automobile industry.

### 6.5.2 Customer orientation ("marketing core competence")

The player in the business ecosystem who has the best customer orientation will determine the value creation and dominate the system.

The IoTPPs have a high brand recognition, even in the relevant sector of digital services. With their established customer access in other digital business ecosystems like search engines (Alphabet) or e-commerce (Alibaba), they are regarded as reliable providers of digital services among the large majority of potential customers. The capacity of the digital services provides them an edge in customer acceptance when buying AD-services for their vehicles.

Nevertheless, AD car driving will be to an extent a different "business transaction" than simply downloading a piece of music. End customers' (i.e., the drivers') expectations are similar to those in the non-AD car business. Vehicle ownership is not obsolete (Maurer et al. 2016, 633-634; Hajek and Hohensee 2020). In addition, repairing and maintenance services, emergency assistance, or advice on the secure handling of the technology of the "system car" (an intensive customer care) will still be expected by the large majority of the customers. The most effective customer care is done via direct contact.

The OEMs have a broad international physical sales network, where customers can easily get technical help and general assistance. Because of their long history, the OEMs have collected a huge quantity of contact data on potential customers. Consequently, OEMs are currently identified as the experts and contact partners with everything in connection with cars. Their brand recognition is indubitable.

Therefore, the framework for the preliminary hypotheses concerning customer orientation as an influencing variable for reaching the orchestrator position can be formulated:

2.1. The IoTPPs do have a stronger position with a view to customer orientation than the OEMs, since they are operating the digital platforms and have direct and well-established digital access to the AD-customers.

2.2. The OEMs do have a stronger position with a view to customer orientation than the IoTPPs since they provide direct, i.e., physical customer support as they use their large service systems.

### 6.5.3 Technological know-how ("technological core competence")

The player in the business ecosystem who contributes the most important technical component will be the orchestrator.

According to Krasniqi and Hajrizi (2016), the most important core competences for the AD-ecosystem can be found in a sophisticated software, accurate maps, and high-performing sensors (see also Figure 6-1).

The IoTPPs provide the algorithms, which represent the "intelligence" of the system for enabling the cars to find their way autonomously. In addition, the IoTPPs create and operate the Cloud soft- and hardware infrastructure in storing the real-time data. Furthermore, maps and mobility orientation services in general are also already established in the present service program. In current cooperation agreements, IoTPPs even share those technologies with traditional OEMs such as Baidu (Apollo) with FAW, and Google (Waymo) with Jaguar and Land Rover. For this reason, the IoTPPs´ technical know-how can cover at least two of the three most important core competencies in an AD-ecosystem.

Even more, complicated technology in the automotive industry such as massive production, lean management, and supply chain management should not be underestimated. It could be more difficult to integrate the hardware by the IoTPPs than for the OEMS to integrate software programming capacities. Under such conditions, the framework for the preliminary hypotheses-possibilities may be defined as:

3.1 The IoTPPs do have a stronger position with a view to technological core competences than the OEMs, because their technical know-how as software and algorithm providers can cover the most important core competency needs of an AD-ecosystem.

3.2 The OEMs do have a stronger position with a view to technological core competences than the IoTPPs, because their technical know-how is in development, mass lean production, and the assembly of huge quantities of hardware/physical parts which can´t be learned simply and quickly.

### 6.5.4 Long-term investment motivation and resource capacities (“capital core competence”)

The building up, operating, and continuing development of an AD-ecosystem requires a large and sustainable capital base. The player in the business ecosystem who has both a long-term investment motivation and the corresponding resource capacities has therefore a good chance to become the orchestrator (see Chapter 4.3).

The market capitalization of the referencing IoTPPs such as Google and Apple are at least five times larger than the referencing OEMs such as Toyota and Daimler. We believe the IoTPPs could have more power and more opportunities to raise funds from public capital markets or private investors to finance capital expenditure in the future potential capital acquisition (equity or loans).

Nevertheless, the OEMs’ capital expenditure could be generated to a positive cashflow from the traditional car business. Besides, governments in traditional strongholds may be tempted to infuse money into OEMS to accelerate their transformation as important players in the AD-ecosystem because of the strategic asset. Furthermore, the potential for OEMs to raise the necessary funds may be elevated to an adequate level by forming coalitions, e.g., with (big) automotive industries.

Therefore, the framework with two corresponding hypotheses-possibilities is defined as:

4.1 The IoTPPs do have a stronger position with a view to long-term investment motivation and capital resource capabilities because of the huge market capitalization and excellent experience for raising funds.

4.2. The OEMs do have a stronger position with a view to view to long-term investment motivation and capital resource capabilities by using the cashflow from the traditional car business and by forming strategic alliances.

So far, the main frameworks with opposing hypotheses have been formulated. By using the qualitative technical interviews, the hypotheses are generated and the questionnaire is developed in the following sections.

## 6.6 Pretest to generate the hypotheses and develop the questionnaire

### 6.6.1 Design of the pretest study

The necessity for pretesting, especially for new concept development, has already been demonstrated by dozens of papers (Presser and Blair, 1994; Nelson, 1985; Reynolds and Diamantopoulos, 1998; Buschle et al., 2021):

1. To avoid misunderstood and misused elements of the survey

2. To evaluate and improve the questionnaire before the main fieldwork

3. To increase the response quote in a further large quantitative study with the design of an understandable questionnaire

The qualitative technical interviews have been developed as the main approach to implement the pretest method (Willis, 2004; 2015; Bethmann et al., 2019). In the present paper, there are three reasons why this method is an appropriate core (Presser and Blair, 1994; Mensah et al., 2012; Niu and Fan, 2015). Firstly, a standardized, questionnaire-based, anonymous study is not able to involve all the expert know-how and to elaborate on certain attitudes and new information. Secondly, since the topic is still sensitive and strategically "private" in the industries, the respondents may not have the willingness to share relevant information and knowledge without a well-established relationship network to the respondents. Thirdly, the expert interview can help the researchers to identify unrealized potential interdependencies (Mellahi and Eyuboglu, 2001; Beatty, 1995).

One main success factor in guided interviews is knowledge of the interviewees, i.e., the expert status of the persons interviewed (Niu and Fan, 2015). A number of authors have already commented on respondent characteristics with the general propositions (Martinez-Mesa et al., 2016; Hensher, 2006; Diamantopoulos et al., 1994; Terhanian and Bremer, 2012):

1. The respondents should have direct knowledge of the questionnaire topic.

2. The pretest sample size is suggested as "small" generally

In the present paper, more specifically based on the characteristics, the respondents should possess general strategic industry know-how and have direct project experience with both IoTPPs and OEMs of AD-ecosystems. Four experts have been selected to implement the first pretest procedure to keep the "small" sample size. In addition, the interviewees should hold a position at least at senior management level, such as Chief Executive Officers (CXOs) and have the responsibility to implement the strategic development direction of their organization. Two CEOs, one Chief Marketing Officer (CMO), and one Chief Technology Officer (CTO) have agreed to participate in an interview. The profile of the interviewees and their organizations are reported in Table 6-1.

With the approach "Qualitative Pretest Interview (QPI)", the interviews lasted between one to two hours and were tape-recorded. Guided interviews with preformulated questions were conducted (Buschle et al., 2021). Vague answers or new aspects have been discussed in more detail. The results are presented in the next chapter.

### 6.6.2 Pretest results and discussion

Based on the Gioia Method (Gioia, 2004), we have grouped the records into categories (open coding) as the first order (Van Maanen, 1979). As second procedure, we have analyzed the correlation of the records from one category and defined the second order themes. As the last process, we have generated similar themes from the second order categories and derived the aggregate hypotheses.

For the framework concerning the "collaboration abilities," an interesting aspect, or, in other words, a new "pattern" (for details of "flexible pattern matching" see e.g., Bouncken et al., 2021; Bouncken et al., 2021; Sinkovics, 2018), was presented by all the four experts concerning the definition and implementation of legal regulation. Legal questions like who should take the responsibilities for accidents, ethical questions like what would be the priority of the decisions in algorithm when it comes to contradicting life-saving decisions, and more down to earth questions like how the insurance system should be implemented, are of central importance. Neither executive can nor will take the responsibility for such sensitive legal questions alone, and without those, the AD-ecosystem cannot and will not be implemented. Thus, an important consideration would be whether other participants, such as governments (trusted authorities), need to take the coalition role because of the authority of the final definition in laws.

Therefore, the preliminary evaluation for the collaboration capability, also see as the hypothesis for future quantitative empirical studies should be defined as:

- **The governments (trusted authorities) as a neutral third party may have a stronger position with a view to collaboration because of the authority of law which is the precondition to implement the AD-ecosystem.**

For the framework concerning "customer orientation," all of the four experts brought into play a more accurate "pattern": they stated that the mobility platform providers like Uber or DiDi should be the most important target customers for AD vehicles, especially in big cities with an established infrastructure. If the end users assign responsibilities to the mobile platform providers, there is no need to consider costs such as parking, insurance, maintenance and repairs, nor other organizational activities.

| Interview No. | Job title | Revenue (2019) | Number of employees | Location of Headquarters | Location of globalizations | Potential system for AD vehicles | Reference customers |
|---|---|---|---|---|---|---|---|
| 1 | CEO | 200 M € | 950 | Germany | USA and China | Smart suspension system with programming/software integration | Daimler; Apple |
| 2 | CMO | 80 M € | 500 | China | Germany | Magnet | VW; Apple |
| 3 | CEO | 500 M € | 4200 | China | USA and Germany | Smart suspension system with programming/software integration | FAW; NIO |
| 4 | CTO | 357 M € | 1900 | China | Italy | Smart suspension system with programming/software integration | Geely; NIO |

Table 6-1 Profile of the experts and the respective company

All four experts have also emphasised that it is one of the most crucial success factors for an AD-ecosystem to set up a virtual platform with comfortable link and digital services embedded, whereas it is not essential when only building up a physical contact and face-to-face service. Three participants stated that the IoTPPs did have a stronger position if the target customers are mobility platform providers because of the capacities and experience. In contrast, the OEMs are losing value since their core competitive factor is the physical sale system. One expert held a neutral point of view that if the number of target customers is limited, both OEMs and IoTPPs could have an equal chance and ability to build up their customer orientation quickly and properly. Furthermore, two experts have argued in a more differentiated way concerning areas without a well-established customized infrastructure. The service density of mobile platform providers may be insufficient, to the extent that people have to wait a long time when necessary. In this case, to purchase a private vehicle is an alternative. Neither have confirmed whether the digital platform or physical distributions would be more important for those customers. In addition, one interviewee affirmed that "premium vehicle culture" is very popular and stable in some developed countries, such as Germany. The customers have a remarkable loyalty to the premium car manufacturers such as Daimler, BMW, or Porsche to show their social image. For these premium auto market segments, the OEMs do have a stronger position than IoTPPs. Therefore, the preliminary evaluation for the "customer orientation", also see as the hypotheses for further quantitative empirical studies should be defined, and should better differentiate between different market segments of the car industry, as:

- **The IoTPPs may have a stronger position with a view to customer orientation if the mobility platform providers are the main customers because of their digital capabilities as well as identical cultures.**
- **The OEMs may have a stronger position with a view to customer orientation for the premium car fans because of the remarkable loyalty.**
- **Neither IoTPPs nor OEMs may have a stronger position with a view to customer orientation for the customers who are private persons in the cities without an established infrastructure of the AD ecosystem. These customers will stay neutral.**

Regarding "technological know-how," all four experts have confirmed that the relevance of the software and the algorithms is higher than the hardware components since the former take command of the latter, who only operate the orders.

Therefore, three participants believed that the IoTPPs did have domination over the OEMs in technical core competence while the programming abilities are the core technical know-how with long-term experience and extensive expert resources. Nevertheless, it is time-consuming and labor-intensive to integrate the OEMs' technical competence to IoTPPs since OEMs contain complicated technologies such as development, massive lean production, assembly of a large number of products with a narrow quality tolerance, and excellent process stability. Instead, it may be easier for the OEMs to obtain the technical capacities of programming and algorithms, stated the other expert.

Thus, a cooperative approach with a focus on their respective strengths may be a solution. IoTPPs should take charge of the software and programming integrations, whereas OEMs could be responsible for hardware development and massive lean production.

Therefore, the preliminary evaluation for the "technological know-how", also see as the hypothesis for the further quantitative empirical studies should be defined as:

- **IoTPPs and OEMs should cooperate together to fulfil the technological know-how for the AD-ecosystem. IoTPPs may take the software parts and OEMs may take the hardware and production parts.**

With regard to "capital core competence," three experts are convinced that the reference IoTPPs such as Google and Apple have the advantage in both market capitalization and cashflow. The traditional OEMs are at this point far behind and are not comparable. Furthermore, one expert declared that the IoTPPs have less risk resilience because of their highly profitable future investments. The market caps and the general high evaluations of the IoTPPs may decline dramatically and bankrupt the IoTPPs under abnormal circumstances such as economic depression or war. In this case, OEMs would have dominance because of their greater risk resistance. Nevertheless, under normal circumstances, the IoTPPs are in the better position.

Therefore, the preliminary evaluation for the "capital core competence", also see as the hypothesis for the further quantitative empirical studies should be defined as:

- **IoTPPs may have a stronger position with a view to long-term investment motivation and capital resource capabilities because of the advantages in both market capitalization as well as cashflow based on other business units.**

Figure 6-2 presents the data structure and summarizes the matching between interview transcripts and theoretical patterns (generated hypotheses).

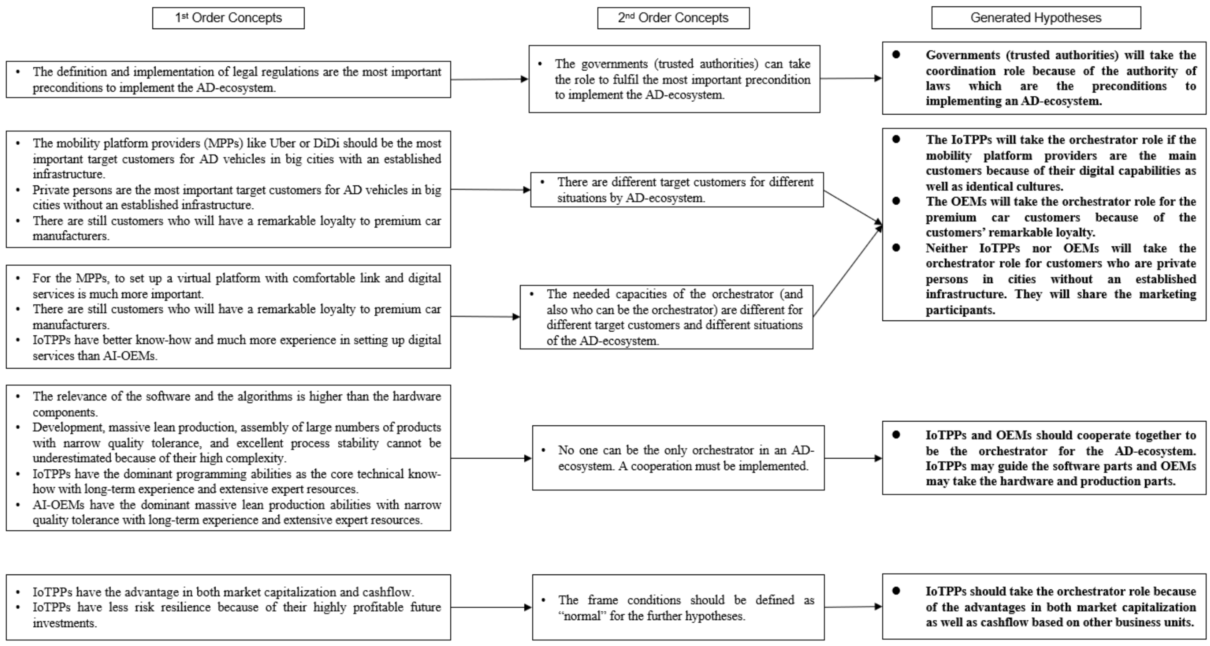


Figure 6-2 Data structure

(own presentation according to Gioia et al., 2010; Corley and Gioia, 2004; Langley and Abdallah, 2015; Nag et al., 2007)

## 6.7 Conclusion and outlook

The purpose of this study was to define a framework of an AD ecosystem, determine the needed capabilities for the orchestrator of AD ecosystem, implement four qualitative interviews to make a first preliminary evaluation for every capability the orchestrator needs, generate hypotheses as well as to develop a questionnaire as a preparation and pretest process for a large quantitative empirical study asking what challenges the IoTPPs and AI-OEMs face in taking on the dominating role compared to other referencing participants.

Five layers in AD ecosystem were defined and their responsibilities and roles in the AD ecosystem were descripted.

Four core competences (organizational, marketing, technical, and capital) were defined based on the theoretically needed capabilities in orchestration of the business ecosystem. The framework with four pairs of hypotheses based on the four core competences was defined.

By conducting a pretest by technical expert interviews, a preliminary evaluation for every core competence was discussed concerning the question who could be the orchestrator and why. Six generated hypotheses were discussed (see 4.6.2) for a future large quantitative empirical study and a questionnaire was developed (see Table 6-2).

| Core competence as orchestrator | Preliminary qualitative evaluation and the generated hypotheses | Further research |
|---|---|---|
| Organizational core competence | The governments (trusted authorities) as a neutral third party may have a stronger position with a view to collaboration because of the authority of law which is the precondition to implement the AD-ecosystem. | • What exactly should the government do for the collaboration?<br>• Is there some difference between different countries? |
| Marketing core competence | The IoTPPs may have a stronger position with a view to customer orientation if the mobility platform providers are the main customers because of their digital capabilities as well as identical cultures.<br><br>The OEMs may have a stronger position with a view to customer orientation for the premium car fans because of the remarkable loyalty.<br><br>Neither IoTPPs nor OEMs may have a stronger position with a view to customer orientation for the customers who are private persons in the cities without established infrastructures of the AD ecosystem. These customers will stay neutral. | • What exactly should the IoTPPs and OEMs do to implement their stronger customer orientations for the customers they may have the stronger role.<br>• What exactly should the IoTPPs and OEMs do to reverse the customer orientations for the customers they may have the weaker role.<br>• What exactly should the IoTPPs and OEMs do to win the customer orientation by private persons in the cities without established infrastructures of the AD ecosystem. |
| Technical core competence | IoTPPs and OEMs should cooperate together to fulfil the technological know-how for the AD-ecosystem. IoTPPs may take the software parts and OEMs may take the hardware and production parts. | How should the close cooperation be implemented? |
| Capital core competence | IoTPPs may have a stronger position with a view to long-term investment motivation and capital resource capabilities because of the advantages in both market capitalization as well as cashflow based on other business units. | How can an anti-risk capacity and high resilience for the AD-ecosystem be built up? |

Table 6-2 Summary of the results of the interviews

Many more interviews and data, especially from the experts of all five layers, in particular from

IoTPPs and OEMs, are needed for a clearer statement. Therefore, next research steps should be a well-defined evaluation and the implementation of the interactions among all the five layers of AD ecosystem on a larger quantitative empirical scale. In addition, the role of the regulating authorities and the effects of different legal frameworks are of central interest in the further study. Moreover, based on strategic moves and whether the cooperation of AI-OEMs and IoT-PPs is promising, e.g., by merging or by forming alliances which may allow them to develop a joint, industry-standard platform, is still under discussion. The limitation of the approach is the neglect of non-hypotheses aspects even though new ideas generated from the interviewees were considered. In addition, our sample consisted of only four CXOs of the AD-ecosystem. The experts from other layers of the AD-ecosystem must be integrated for the large quantitative study; thus, the hypotheses and questionnaire may not integrate all the aspects and factors generally and representatively. Furthermore, multi-level sample sizes are required since variation in results may occur depending on different criteria or different groups such as gender, age, nationality, and ethnic group, etc.

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# 7 Conclusion

## 7.1 Summary and Contribution

This thesis sets out to do research with view to the coordination and controlling of digital business ecosystems. The AD-business ecosystem is chosen as an important and highly suitable object of research in that respect. With the intent to cover main aspects of the research, the thesis investigates and prioritises the critical success factors of total quality management in autonomous driving ecosystem as well as determines who should take the responsibilities as the orchestrator of an AD ecosystem based on the needed capabilities theory of a business ecosystem.

From the theoretical perspective, the thesis has defined an AD-ecosystem with five different layers and made the descriptions in details for every layer (what are they and why should they be integrated in an AD ecosystem). With the investigation of the 16 CSFs of AD-TQM under the consideration of the correlations between the different layers, the current TQM theory has been successfully extended. In addition, it has been analysed the different understandings of the implementation of a successful AD-TQM system under the different country specifications between Germany and China as the two of the most important strategic marketing for AD vehicles in the future. Furthermore, the needed capabilities as well as the possibilities of IoTPPs, OEMs as well as the Governments as the orchestrators of an AD ecosystem are discussed, which is a valuable implementation and extension of the orchestrator theory for the business ecosystem. According to the theoretical research based on the reference literature review papers, all of these contents have been new studied as a further step to develop the TQM and orchestrator theory which the previous research have stated no details.

Besides the theoretical perspective, the thesis has also made a contribution to the practical side. Since many data come from the statements and interviews from the senior managers of the reference industries/companies, it will help the entrepreneurs from different industries, who are or want to go in the AD ecosystem to analyse who should be their target customers and what should they do to make successful value creations with reasonable data and figures (for example, to build up a reliable TQM system as an evidence of their capabilities). Furthermore, the thesis has published two extremely sensitive research fields (AD-TQM as well as the Orchestrator(s) of AD ecosystem) in public successfully. It helps the researchers from theory and experts from praxis without so many personal networking in AD ecosystem to implement the further discussions much easier. Because of the previous interviews with several senior experts from different famous layers as the excellent examples, the further interviewers should not state so many political correctness but with honest opinions to discuss the relevant and sensitive theme. It leads to that the thesis could be a start point to build up a global AD-TQM as well as to implement the orchestrations of the AD ecosystem. Moreover, it proves with data, facts and figures that the overview and understandings of AD-TQM as well as AD-ecosystem are very different between Germany and China as two of the most important marketing. The different opinions as "technology first" in Germany and "marketing first" in China should lead to different development policies to implement successful AD ecosystems in the both countries.

## 7.2 Limitations

The main limitation of the first two articles for AD-TQM, although already implemented with a quantitative empirical analysis, is that only 64 experts from two different countries were integrated for the research.

Therefore, larger quantitative empirical scales, especially a larger quantity of the experts from all five layers and also from other interesting relevant countries such as USA and Japan must be integrated to confirm and evaluate the interdependencies and the implementations of the CSFs with proven results such as regression analysis and structural equation models. Furthermore, multi-level sample sizes are required since variations in results may occur depending on different criteria or different groups such as gender, age, ethnic group, etc. In addition, since the CSF list of AD-TQM is dynamic according to the technology and business environment as well as based on the present surveys, new CSFs should always be considered and updated during the further research.

The main limitation of the third research paper as the orchestration of the AD ecosystem is that our sample consisted of only four CXOs of the AD-ecosystem.

Therefore, a quantitative empirical study with many more interviews and data for all five layers, in particular from IoTPPs, Government and OEMs, are necessary to evaluate and implement the interaction with a lager quantitative data. It should be also discussed that based on strategic decision whether the cooperation (and if yes, how) between different AD-layers and between different relevant countries should be the key to implement a successful AD-ecosystem.

## 7.3 Avenues for further research

After identification of the potential CSFs of AD-TQM, the next further interesting research could be to explore each CSF, how they could be implemented by each layer of the AD ecosystem with the associated test introductions and evaluation criteria (for example VDA 6.3 for process audit and release in the current automotive industry as reference). Especially the correlations and interactions between the different layers must be considered and analyzed. Moreover, the research of how exactly the dominant layer can fulfil the needed capabilities as the orchestrators and what exactly should they do to make the cooperation and integration to implement the orchestration of AD-ecosystem could be also extremely attractive in the future. Furthermore, the different understanding and strategy plan because of the culture difference by different countries, especially in the key marketing locations such as Europa, USA, Japan and China, can be also defined as a key focus of a further big research project.

In summary, the CSFs of AD-TQM as well as the orchestration of the AD ecosystem could be the core parts with many research potentials based on many different understanding perspectives under integration of many other research arears such as international management, information sciences, digitalization as well as innovation management.