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Automated Trucks and the Future of Logistics – A Delphi-Based Scenario Study

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ABSTRACT

The logistics industry is facing a transformation. Automated driving has been gaining importance in the commercial vehicle industry and trucks with SAE L4 are expected by 2030 for the hub-to-hub scenario. Driven by the research question of what the direct logistics environment of automated trucks will look like in 2030 a two-round Delphi-based scenario study was conducted for domestic goods transport in Germany. 19 projections were developed and evaluated by 27 experts from different industries. With complete-linkage clustering, four logistics scenarios for 2030 were created. The results show that environmental and social sustainability as well as digitalization are expected to be the most important drivers. These include the shift to electric drive systems, improved working conditions, and increasing transparency and connectivity of the supply chain. The experts forecast an increase in the importance of software services and a continuing shortage of skilled workers. Rather controversial are the topics of charging infrastructure for electrified transport and the degree of automation of loading systems. Overall, the results provide a reliable basis for strategic decision-making in order to ensure the introduction of automated trucks into the logistics of the future and their surrounding environment.

KEYWORDS: Automated Trucks · Future · Logistics · Trends · Delphi Study · Delphi-based Scenario Study

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1. INTRODUCTION

Increasing vehicle automation is playing a significant role in the commercial vehicle industry [22, 56]. With its share of 73 %, the truck is the most important means of freight transport in Germany. Consequently, automation in this area has great potential on an economic, ecological and social level [20, 49]. Through automation at SAE Level 4 [77], improved fuel efficiency and reduced driver costs for instance can reduce total cost of ownership in the long term [20, 54, 86]. Further, automated trucks are expected to optimize traffic flow, reduce the occurrence of traffic jams and therefore enable improved planning of transport times for the parties involved in logistics [20]. In view of these advantages, companies in the commercial vehicle sector are focusing on developing the necessary technologies for automated driving. However, it should not be forgotten that the truck is only one part of the entire logistics chain. Therefore, it is just as important to investigate the future logistics environment of automated trucks to ensure that the logistic processes can also be implemented with automated vehicles.

Just how the logistics industry will change in the coming years has been widely discussed [99, 103]. Several authors assume that the logistics value chain will be restructured by increasing digitalization and strict emissions regulations [43, 61]. Moreover, it can be assumed that further platform-based logistics business models will develop in the course of digitalization, driven in particular by start-ups [50, 93]. Increased global competition and demographic change are also cited as factors influencing logistics systems [55, 103]. Faced by these developments, it is of great importance not only to shape the technical progress of automation, but also to consider the future framework conditions in which automated trucks will operate because their use may be fundamentally influenced by possible future trends and developments in logistics.

1.1. Research question and scope of study

By 2030, automated trucks are expected to be in use for long-distance transport between main transshipment hubs outside conurbations [62]. At automation level 4 the system takes over complete control of the vehicle for pre-defined routes. In the limiting case, the system is able to assume a risk-minimizing state without the need for human interaction [77]. Therefore, it is not necessary for a driver to be inside the vehicle on these defined routes. However, currently truck drivers are responsible for many other tasks in addition to driving that integrate them deeply in the logistics process. These tasks include, for example, inspecting the truck, route planning or loading and unloading the vehicle [19]. Since it must be ensured that logistics processes function with automated trucks in the future, it is important to investigate what the future logistics environment of automated trucks in hub-to-hub scenario will look like. This will allow the truck to be developed in such a way that it can meet its future requirements and be integrated into future logistics processes.

To be able to make statements about the future, suitable forecasting instruments from futurology are needed [39]. Scenarios are a helpful means of gaining a deeper understanding of potential future business environments [78]. Therefore, the aim of this study is to develop differentiated future scenarios for the logistics of domestic hub-to-hub transport in Germany, and thus to provide reliable statements about the future framework conditions for the logistics of automated trucks.

Research Question: What will the direct logistics environment of automated trucks look like in 2030?

2. LITERATURE REVIEW: TRENDS IN LOGISTICS

To approach the future environment of automated trucks, current trends in logistics next to automation play a crucial role. The extent and influence of these trends are widely debated in the literature. Conclusions for the logistics and transport sector are derived from various global developments. Therefore, various factors influencing the environment of the logistics sector can be identified, many of which are interlinked and mutually dependent. Figure 1 illustrates the trend areas and developments in logistics that are particularly relevant in the context of this research question. In the following, possible development trends in different areas are described and their effects on the logistics industry are explained.

2.1. Globalization

Global trade relations are growing due to the increasing cross-border flows of goods as well as to intra-company trade between globally distributed production sites and subsidiaries. This development is driven by the decline in prices for international transport [103]. Automated trucks and the associated drop in transport costs are expected to further increase globalization [72]. Due to the internationalization of online commerce, global trade flows and logistics networks are steadily increasing in importance [5, 99]. In globalized markets, competitive pressure increases and new growth opportunities are generated, at the same time existing drivers for the logistics industry, such as cost pressure, are further intensified [5]. Global competition therefore demands new business processes in logistics [45].

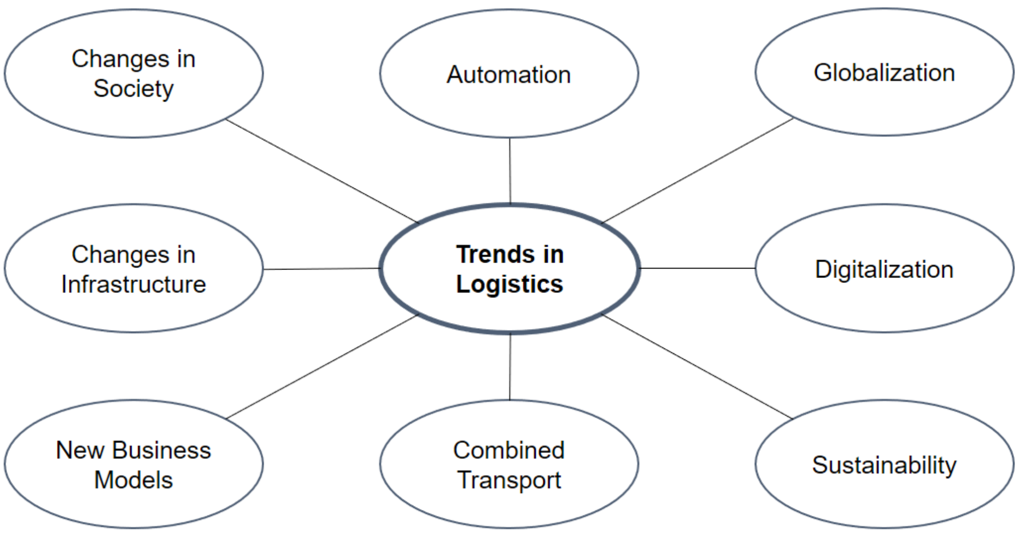


Figure 1: Selection of interrelated trends in logistics.

For instance, those companies offering value-added services beyond transport have a competitive advantage relative to traditional transport companies [5].

2.2. Digitalization

Advancing digitization is often cited as a key driver of change in the truck and logistics industry [37, 43, 79, 102]. Driverless transport systems, tracking and tracing, and platform-based freight and loading exchanges have long been established solutions in the logistics industry [93]. A frequently described topic in respect of Industry 4.0 is networking and connectivity in the value and supply chain. The trend is towards connected intelligent systems and communication throughout the whole supply chain, linking suppliers, manufacturers, and service providers [37, 45, 93, 102]. Further, identification and localization technologies such as GPS and RFID offer increasing transparency and control capabilities thus enabling efficient transportation [99, 102, 103]. The benefits are greatest with real-time transmission [103], because automatically transmitted environmental data extend traditional tracking and tracing to include ongoing information thus enabling possible intervention in the transport process [102].

The digitization of products and services is becoming a differentiating feature because of the increase in technology relating to Big Data (BD), Cloud Computing, Internet of Things, Artificial Intelligence (AI) and Machine Learning [45, 84, 99, 102]. Fifth-generation mobile communications (5G) is seen as a key technology for the networking and integration of large sensor networks, which enables monitoring of the entire intralogistics and production logistics [38, 76]. It is assumed to have innovative potential for logistics efficiency in terms of time- and failure-critical communication with or between automated vehicles and machines [50, 76]. Moreover, intelligent logistics robots and autonomous vehicles are increasingly in demand because of higher wage costs and demographic change [73, 101, 102]. Intelligent networking that goes beyond the direct vehicle environment is additionally changing processes at depots. Thus, it is possible to integrate trucks into a dynamic control system that controls the coordination of vehicles as well as the assignment of tasks at the depot [55].

In addition to AI, blockchain (BC) technology offers potential for crucial efficiency-enhancements and secure applications [33]. With the use of this innovative technology, smart contracts can be realized in the form of the automated execution of contracts between different parties [26] and thus the digital waybill (eCMR; 9, 16, 59). However, BC is still in a developmental state and further research is needed prior to widespread application of the technology [26, 33]. In addition, the legal framework for the use of BC as well as AI remains unclear [26]. Either way, traditional logistics players will need to invest highly in digitalization if they wish to remain competitive [70, 81].

As a result of the growing connectivity between logistics players, uniform platform models and defined interfaces are required, which represents a major hurdle in complex value chains [37, 81]. Lack of trust and a lack of standardization among the many participating supply chain members are preventing data exchange, especially in the heterogeneous European logistics market [81, 102]. Trends toward the elimination of manual work steps through eCMR, an increasingly automated process at depots or robot-assisted logistics processes will not only influence the working world of truck drivers, but will also bring about a redistribution of tasks in different logistics processes.

An overlying trend in this field is the trend toward intelligent transport systems (ITS). ITS are smart systems using innovative developments in information and communication technologies [75] to „enable more intelligent use of infrastructure and vehicles and to enhance the management of traffic and mobility" [23]. There are multiple components to the system such as an overall communication infrastructure, sensor technology, the digital transmission of data and navigation satellite systems for locating the vehicle [3, 94]. ITS include and make use of the above mentioned trends such as the digital connection of the parties involved or the real-time transmission of data. The introduction of ITS however is dependent on the infrastructure as sensors, cameras, etc. have to be integrated in the road transport network [75]. Thus, ITS can provide information on e.g. traffic conditions and traffic flows [36] and among others can be used for fleet management in order to react dynamically to disturbances and increase the fleet efficiency [3]. Therefore, ITS can have a positive influence on CO^2 efficiency and sustainability [2].

2.3. Sustainability

Environmental sustainability is considered to be a significant driver in the need for transformation in logistics [66, 76, 103]. Due to the increasing acceptance of and demand for green products and services, players in the logistics industry are being forced to address this issue [76]. Environmental, transport and economic policies are also indicative of the consensus in the public debate [76]. EU regulation [18] for reduced CO_2 emissions from new trucks is resulting in far-reaching changes in the trucking industry [25]. Platooning and automation can contribute to environmental sustainability [63] and truck manufacturers are increasingly pursuing the use of alternative drive systems. However, the further development of batteries, the associated prices [46], and current limited storage capacities [99] are a source of major uncertainties in this field. The high electricity demand as well as the lack of space for suitable electric charging stations along main traffic arteries are further obstacles opposing electrification in long-distance transport [25]. Therefore, Fuel Cell Electric Vehicles could also play an important role [21]. The 2030 innovation program of the German Federal Ministry of Transport and Digital Infrastructure (BMVI) addresses the topics of fuel cell technology, electromobility, and the expansion of charging infrastructure [7].

Moreover, the demand for the social sustainability of logistic players is increasing due to public discussion about drivers' working conditions [99, 103]. Repeated criticism concerns issues such as low wages, partly precarious employment conditions, and the lack of a work-life balance [99]. Through quality seals such as FairTruck, logistics service providers and freight forwarders are demonstrating an increased appreciation of their employees [7, 69, 99]. Accordingly, these will continue to act as a differentiator between logistics companies in the future.

2.4. Combined Transport

With the aim of being able to meet the increasing demand for road freight traffic volumes and ongoing sustainability requirements, the cooperation between different transport modes such as rail, water and road, so-called combined transport (CT), is being promoted [6] in order to achieve optimum performance, economic efficiency and environmental friendliness in the transport sector [6, 45, 103]. The related trend of synchromodality focuses on the combination of different transportation modes in a structured and synchronized way with the aim of increasing intermodal transportation [15, 44, 65]. The idea of synchromodality is that actors along the supply chain are interconnected and cooperatively plan the flow of goods being able to flexibly switch between the available means of transport [44, 68]. Despite the strong growth in CT, freight transport continues to remain significantly concentrated on roads, accounting for over 70% of total transit volume, and this share is continuing to increase [26, 45, 103]. This is because of the many current advantages of road transport over other modes including dense road network, shorter transport times, high adaptability to customers' requirements [45]. The use of automated trucks could also deepen the focus on road transportation [17]. The main obstacle for CT is interface problems for the transshipment of intermodal transport goods [103]. Therefore, it remains questionable as to whether a breakthrough in CT and thus a change of use of trucks in freight transport can be expected.

2.5. Competition and new business models

Truck manufacturers must prepare for increasing consolidation among the logistics players: smaller customer numbers with greater purchasing power. A concentration process and increasing fleet sizes are to be expected in the next ten years, especially in long-distance transport [79]. In addition, it is likely that truck manufacturers will be repositioned in the future, as digital reinvention will be a prerequisite for future success [40]. For example, OEMs could offer flexible rental and sharing concepts [79] and move from manufacturer to service provider to respond to the changing market [43, 49, 79]. With the use of automated trucks, manufacturers are already working on so-called "Transport as a Service" (TaaS) concepts [70]. Trends are also moving towards a transformation of truck manufacturers into hardware and software companies, emphasizing the development of "Software as a Service" (SaaS) areas by OEMs [49, 79]. Furthermore, collaborations and strategic partnerships will be necessary, especially with digital players, as they can offer complex logistics services based on their expertise in digital processes as well as their data assets in respect of consumer and consumption behavior and thus be able to advance further into logistics with their own transport capacities [84, 85].

Digitalization is also enabling the entry of numerous logistics start-ups, in the form of digital freight forwarders or digital platforms [93]. Digital freight forwarders are gaining in importance and are competing with large, traditional freight forwarders [81, 93, 102] by handling the traditional brokerage service of exporting goods exclusively digitally [102]. Furthermore, with the help of collected route planning and freight data as well as the use of AI, optimal routes can be identified, thus reducing empty runs up to 20% resulting in enormous cost savings [70, 96]. Also, the growing collaborative use (sharing) of transport, storage and truck capacities via digital platforms highlights the trend towards the "access over ownership" principle [47].

2.6. Logistic processes and infrastructure

As part of urbanization, large distribution centers are becoming increasingly close to conurbations and thus to consumers. The goal is to shorten the last mile, which in the future will be limited by access restrictions [79]. Nowak et al. [61] assume a future hub-to-hub delivery executed by automated trucks. In this context, highway routes between hubs are suitable as an application area for automated trucks because the transport is highly standardized [31, 42, 62]. Also, according to Ritz [72], a network of automated hubs is possible in that automatic loading and unloading systems make the arrivals of automated trucks independent of on-site personnel. Deliveries from the hubs to urban areas can then be made using light commercial vehicles [61, 79]. Factors such as dwindling transport space are becoming an increasing challenge for logistics processes, especially near metropolitan areas [26, 57]. Schuckmann et al. [82] conclude from their futures study that insufficient availability of funding could lead to poor transport infrastructure because government investment will be concentrated in urban areas. To counteract this and finance the required transport infrastructure or its maintenance, private investors could become more involved [82].

2.7. Society and risks

Demographic change is causing labor shortages in many places, from unskilled workers to qualified

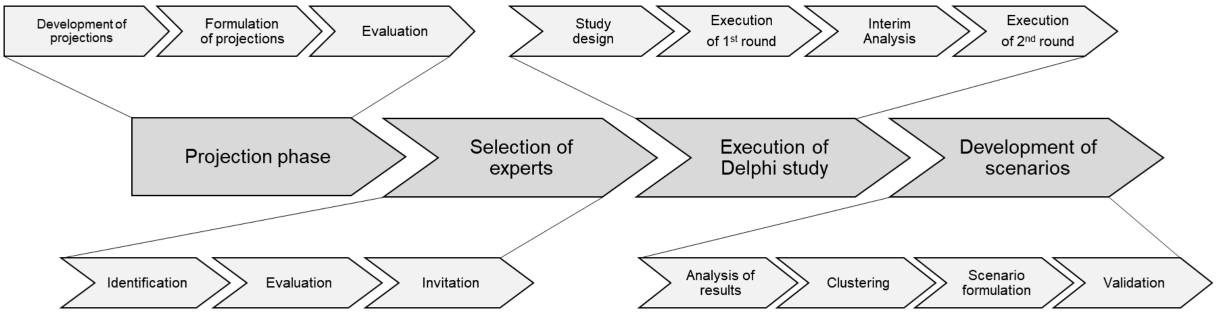


Figure 2: Study design adapted from Gracht & Darkow [22] and Fritschy & Spinler [15]

specialists, as well as a shortage of truck drivers [37, 81, 99]. By 2030, the logistics work environment will have changed as a result of digitalization and automation [7, 37]. As a result of the use of automated trucks and new driving methods such as platooning, it will be possible for vehicle drivers to carry out new tasks [7, 61, 83]. It may be possible to account for the time when the driver is not driver (passive journey part) differently to periods of active driving. This would result in an enormous increase in efficiency for logistics companies [83].

Furthermore, crime represents a major risk for the logistics industry [37, 41]. In addition to cargo theft, cyber attacks on IT infrastructure in particular are increasingly occurring [41]. As a result, cyber security is becoming an important part of the service portfolio for logistics companies [11, 97]. In addition, extreme weather events are cited as a growing disruptive factor for closely timed supply chains [41]. Trade conflicts, rising tariffs, sanctions, and political instability are also disrupting established supply chains worldwide, so that supply chain volatility must always be taken into consideration [8, 37, 41].

2.8. Summary

The trends in logistics show that hub-to-hub traffic will be a suitable application area for automated trucks in 2030. Important drivers such as digitalization and sustainability indicate a clear direction of development for the logistics industry, whereas other factors such as the future role of CT, for instance, remain questionable based on the literature. As automated trucks will have to be integrated in the future logistics processes of 2030, clarification is required as to which of the trends will prevail, what state they will be in by 2030 and whether these trends will have an influence on the direct logistics environment of the automated trucks.

3. METHODOLOGY AND RESEARCH DESIGN

Since there is often insufficient quantitative data available for futures studies, experts have to be consulted. As a powerful research technique, the Delphi method can be used to collect expert knowledge in a structured way [13, 29] with the aim of reaching a reliable consensus within an expert group about future developments and events [28, 32, 90]. At the same time, the scenario method is particularly suitable for estimating future developments and long-term planning, and is useful in strategic decision making in an uncertain, rapidly changing environment [89, 95]. The scenario technique is often used in combination with the Delphi method, as it can increase the quality of the study in terms of creativity, objectivity and credibility [20, 60]. Therefore, a Delphi-based scenario study was conducted for the year 2030 following a standard phase-based procedure [28] visualized in Figure 2. The study focuses on hub-to-hub transport in Germany using automated trucks of level 4 or higher according to the classification of SAE International [77].

3.1. Development of projections

The projection phase included three processes consisting of the development, formulation and evaluation of the projections. For the development of projections, we first identified the current trends, drivers and developments in the logistics industry, digitalization and society by conducting a broad literature research. For this literature research, scientific publications, current draft legislation, governmental regulations, current future studies, company and association reports as well as press releases were consulted. Further, we used a variety of data bases including Web of Science, Scopus and Google Scholar. The search string initially included the keywords *trends in logistic, trends in digitalization* and *trends in society.* Based on the results the following key words were chosen more precisely on the identified topics and included *digitalization in logistics*, *globalization*, *competition in logistics*, *business models in logistics*, *sustainability*, *individualization*, *alternative drives*, *freight transport*, *infrastructure*, *society*, and *criminality*. The identified trends were categorized into suitable thematic areas and initially 45 future theses were developed.

Furthermore, we conducted five explorative workshops with experts from logistics and the commercial vehicle industry. Their areas of expertise concentrated on innovation research, product strategy, logistic processes and telematics services. Each workshop consisted of a free brainstorming on the driving trends in logistics by the experts followed by an evaluative assessment of the so far identified trend areas and future theses from the literature review. This two way approach via literature and expert knowledge allowed us to ensure that no relevant trend area was overlooked for our specific research question [29].

To filter the core theses, redundancies were removed and the initial 45 future theses were reduced to the final 19 projections by the experts' prioritization of trends and relevance for the research topic. In a further step, these projections were formulated with concrete and precise wording. Irrelevant information and conditional statements were eliminated and an appropriate question length was ensured [20, 29, 51, 74]. Each projection was introduced with "In 2030 ..." to always remind participants of the targeted time period [80]. Finally, the projections were evaluated regarding consistency, ambiguity and content validity by three experts from the fields of psychology, foresight in the commercial vehicle industry, and academic research in logistics. Based on their feedback, the projections were adjusted and, thus, their suitability for the research purpose was ensured. For better structure and understanding for the reader, the 19 projections were grouped into four thematic areas: Society, Environment and Freight Transport (SEF), Infrastructure and Alternative Drives (IAD), Digitalization in Logistics (DIL), and Business Models and Competition (BMC). The projections as well as their underlying sources are presented in Table 1. Please note, that the projections were originally formulated in German for this study and were only translated for use in this paper.

Table 1: Formulated projections with included sources from literature and expert workshops.

No.	Projections for 2030	Source
Society, Environment and Freight Transport (SEF)		
1	In 2030, automated trucks will partially redistribute tasks along the logistics process. The shortage of qualified personnel persists as an unsolved problem.	[7, 37, 61, 69, 81, 99]; Workshop
2	In 2030, driving in an automated truck will be divided into active manual and passive automated driving time. Passive automated driving will count differently towards the prescribed driving time.	[83]; Workshop
3	In 2030, social and environmental sustainability will become increasingly important for logistics players e.g. as manifested by improved working conditions and climate neutrality.	[14, 18, 25, 37, 69, 76, 99, 103]; Workshop
4	In 2030, combined transport consisting of land transport and other modes of transport (e.g. rail or water) will still be held back by factors such as a lack of infrastructure for reloading goods. Freight traffic will continue to be concentrated on the roads.	[6, 26, 45, 59, 92, 103]; Workshop
Infrastructure and Alternative Drives (IAD)		
5	In 2030, automated trucks will mainly be used for transportation between logistics centers connected by major roads or highways.	[42, 61, 62, 72, 79]; Workshop
6	In 2030, the condition of the transport infrastructure between logistics centers will largely be unchanged from today.	[82]; Workshop
7	In 2030, it will be possible to use electric drive systems based on battery and fuel cell technology for long-distance transportation.	[7, 21, 25, 46, 67, 99]; Workshop
8	In 2030, an adequate charging infrastructure with sufficient charging stations will enable the expansion of electrified transport between logistics centers.	[7]; Workshop
Digitalization in Logistics (DIL)		
9	In 2030, a large part of the logistics chain will be digitalized. This will enable cross-modal and cross-company connectivity between all players in the supply chain (customer, service provider, supplier, etc.).	[7, 37, 45, 81, 93, 102]; Workshop
10	In 2030, transport and environmental data will be recorded automatically and transmitted in real time along the entire supply chain. This will enable the seamless tracking of goods.	[7, 99, 102, 103]; Workshop
11	In 2030, coordination of trucks at logistic centres will be automated and digital. The loading or unloading position, as well as the route to it will be transmitted digitally to the truck.	[55]; Workshop

12	In 2030, delivery and export process in logistics centers will be automated. This includes the automated loading and unloading of trucks as well as the automated identification and allocation of goods.	[61, 72]; Workshop
13	In 2030, freight and customs documents will be widely digitalized and will no longer need to be carried in paper form.	[7, 8, 26, 33, 59]; Workshop
Business Models and Competition (BMC)		
14	In 2030, digital players such as Amazon or Google will increasingly be competing in the logistics field by also offering transport and logistics services and, where applicable, owning their own truck fleets.	[7, 61, 81, 84, 85]; Workshop
15	In 2030, the transport of goods between logistics centers will be carried out by a few logistics service providers with very large truck fleets, rather than by a large number of small logistics service providers with very small fleets.	[79, 93, 102]; Workshop
16	In 2030, OEMs are also increasingly offering transportation services. OEMs thus own fleets of automated trucks and offer transport as a service.	[43, 49, 70]; Workshop
17	In 2030, OEMs have evolved into hardware and software service providers. In addition to the automated truck, they also offer other telematics systems by means of their own platforms and interfaces.	[49, 79]; Workshop
18	In 2030, digital freight forwarders will play a significant role in logistics. They will take over the brokerage of transport services and offer further services in planning and controlling logistics processes.	[70, 81, 84, 85, 93, 102]; Workshop
19	In 2030, sharing of truck fleets and storage areas will be becoming increasingly established as a way of avoiding empty runs and vacant storage areas to the greatest extent possible.	[14, 79, 84, 96]; Workshop

3.2. Selection of Experts

Correct selection of experts is of great importance for the validity and reliability and thus for the success of a Delphi study [30, 48, 87]. Principles for the selection of experts include heterogeneity, an appropriate level of knowledge and the size of the group [74]. Therefore, following Schuckmann et al. [82], potential representatives of all relevant stakeholder groups were identified for this study: Academic research, logistics players, politics and associations, consulting companies active in the field of logistics and transport, automotive industry with representatives of commercial vehicle manufacturers and tier 1 suppliers, and digital logistics services. The recommended panel size of a group of 20 – 30 experts [64] was aimed for. Following the approach of Fritschy and Spinler [20] and Kluge et al. [39], the qualification of the experts was measured on the basis of their affiliation to the respective industry, their position, professional experience in years, and their self-assessment of their own expertise.

In total, we considered 63 experts for this study. They were contacted via email or LinkedIn message with information on the research topic, study design, timing, and the invitation to participate. 30 experts agreed to participate and completed the questionnaire of the first round of the Delphi study. In round two 27 out of the original 30 experts took part. This dropout rate is below average [60] and speaks for the quality of the survey design and the experts' interest in the research topic. The 27 final participants of both Delphi rounds represent different stakeholder groups and industries. The panel composition is shown in Figure 3. Half of the expert panel has more than 15 years of professional experience in their industry (M = 15.41, SD = 9.68). On average, each of the experts holds three to four competency areas amongst the named subject profiles (M = 3.56, SD = 1.87). Thus, an appropriate heterogeneity across the involved stakeholder groups and knowledge areas was ensured. Furthermore, the average overall expertise is rated as rather high (Likert Scale 1-5; M = 3.96, SD = 0.80). None of the experts rated their expertise as low (worse than 3), and therefore no one had to be excluded from the results analysis due to a lack of expertise.

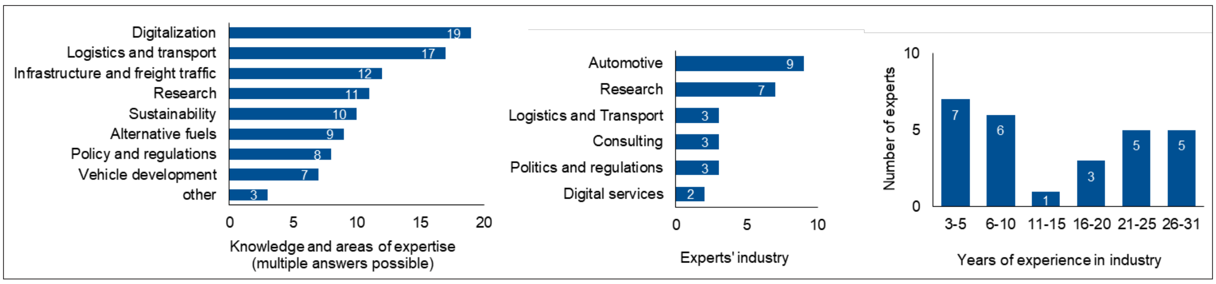


Figure 3: Characteristics of selected experts (N=27)

3.3. Execution of the Delphi study

The Delphi study took place as an online survey using a two-step process, as in numerous prior Delphi studies [see 20, 39, 52]. This is based on the fact that more than two rounds of interviews do little to improve the quality of the outcome and that most adjustments occur after the first iteration [91, 100].

3.3.1. Delphi Round 1

The first survey took place in July 2021. Participants had a period of three weeks to complete the survey. All 30 participants completed the questionnaire in full. The whole questionnaire can be found in the Appendix.

The first part of the questionnaire contained an initial explanation of data protection and the research objective, definitions of important constructs, instructions as well as an example question. In the main part, the 19 projections were to be evaluated. The experts rated the projections on an ordinal five-point Likert scale (1 to 5) in respect of the following criteria: probability of occurrence (P) by 2030 (*unlikely* to *likely*), impact (I) on the logistics environment of automated trucks if the projection were to occur in this way (*weak* to *strong*), and desirability (D) of the formulated projection (*undesirable* to *desirable*). For a balance between quantitative and qualitative data, experts were asked to give reasons for their probability assessments. Comments on effects and desirability were not requested, as this would have significantly lengthened the questionnaire [20]. After each thematic cluster, the experts gave a self-assessment of their expertise in the given subject area. In the third section of the questionnaire, sociodemographic data on position, industry, work experience, and a self-assessment on overall expertise were collected [39]. In each case, the self-assessment was given on a five-point Likert scale from *low* (1) to *high* (5). To ensure the quality of the questionnaire [24], a pretest was conducted with four persons who were not participating experts in the study. In order to guarantee anonymity as a core element of the Delphi study [60], the experts received a randomized access key to the survey.

The qualitative and quantitative results of the first round were analyzed and prepared as feedback for the second Delphi round. The distribution of the aggregated results was presented in the form of histograms and the median additionally marked. The coding method by Corbin and Strauss [12] was applied for the analysis of the comments and comments were divided into the three categories for a high, low, or neutral probability rating. Subsequently, those arguments for a neutral assessment were assigned to the high or low level depending on their salience and tendency, resulting in two groups for comments. Comments were categorized into codes within the groups to identify core factors and important arguments mentioned multiple times for a high or low probability rating [29].

3.3.2. Delphi Round 2

The second survey took place in August 2021. Participants were given a period of three weeks to respond. In total, 27 of the 30 participants from the first round completed the questionnaire.

The layout of the second round questionnaire included the summarized feedback as well as the experts' own individual answers from round one. Therefore, an individual questionnaire was created for each expert. In addition to the histogram, exemplary arguments of the other experts for a high or low probability assessment per projection were compiled from the codes derived in the coding phase. Based on the feedback given, the experts again assessed the same projections from round 1 in terms of probability. Desirability was not reassessed, as it is assumed that this factor would not change over this short time period [28]. However, impact was reassessed because this factor may change given the feedback presented [20]. No new arguments or comments were requested. Finally, the self-assessment on overall expertise was recorded again to check whether the expert had revised it during the course of the study.

3.4. Development of future Scenarios

For clustering, the average expected probability of occurrence and the average impact for all 19 projections were plotted. Clustering along these two dimensions is a useful and common method for deriving appropriate measures and strategies [29]. To identify structure and similarities in the data, the hierarchical complete linkage method with the proximity measure of Euclidean distance was applied. Ordinal categories can be evaluated using this method and it is suitable when a high homogeneity of the clusters is a key requirement [88]. The clusters formed and the previously categorized comments of the experts were used to identify patterns in the qualitative data and to formulate plausible scenarios and conclusions for 2030 [29]. Scenarios comprise a qualitative, verbal representation of a future situation including the environment and risks [90] and should be concrete and comprehensible.

After the scenarios had been formulated, they were validated by two independent experts with regard to certain quality criteria. These were consistency, plausibility and relevance [1, 10, 98] and can be explained as follows: A consistent scenario does not have any internal contradictions and is therefore comprehensible. Plausibility refers to scenarios that are generally credible and capable of happening. The relevance of a scenario refers to its utility to contribute to specific insights regarding the research question.

To present the results clearly, the scenarios were named individually [80]. In addition to the expert comments, the qualitative description of the scenarios is also based on supporting evidence from the literature. If this is the case, it is explicitly indicated by the source citation.

4. RESULTS OF THE DELPHI STUDY

4.1. Quantitative Analysis

The descriptive statistics of the analysis are shown in Table 2. The inter quartile ratio (IQR) is a commonly used method for measuring consensus in Delphi studies [27]. An IQR ≤ 1 is considered an appropriate consensus indicator for 4- or 5-unit scales [71]. The results of the IQR show that in the first round 15 of the 19 projections (79%) reached consensus among the experts regarding their probability assessment. After the second round, 17 of the 19 projections reached consensus (89%). Projection 8 and projection 12 differ within the experts' opinions (IQR = 1.50). The change in the standard deviation between the first and second Delphi round illustrates the increasing convergence of the experts [80]. A total of 95 out of 513 possible changes in the probability ratings were made by the experts in the second round, of which 61 (64%) were revised upward and 34 (36%) were revised downward. On average, each of the 27 experts changed the rating for 3.5 projections in the second round compared to the responses in the first survey (*SD* = 2.40).

The most probable topics for 2030 are sustainability (projection 3), real-time tracking (projection 10) and automated coordination of trucks at the hubs (projection 11). The experts consider the relevance of digital players in the market (projection 14) and the use of the digital waybill (projection 13) to be more likely. Projection 16 (TaaS) is rated least probable.

The impact on the logistics environment of automated trucks is estimated to be strongest for sustainable operations (projection 3) and real-time tracking in the supply chain (projection 10). Looking at the various topics, the projections relating to progress in digitalization in logistics (projections 9 to 13), as well as developments in society, the environment and freight transport (projections 1 to 4), are the most expected and desired by the experts. Their impact on the logistics environment of automated trucks is also estimated to be the strongest in total. Projections of the topic area of business models and competition (projections 14 to 19), on the other hand, are the least desired.

4.2. Clustering

Based on the dimensions of probability and impact, the projections were clustered using the complete linkage method. Based on the recommended number of clusters $c \leq \sqrt{n}$ [4, 34], in total four clusters were identified differing in size. The clusters and their associated projections are visualized in Fig. 4. The first cluster contains projections 3, 10, and 11, whose occurrence is rated as most likely (*M* = 4.58). At the same time, the occurrence of the ten projections in cluster 2 is also rated as rather likely (*M* = 4.06). Cluster 3 contains the two projections about which the experts could not reach a consensus (projections 8 and 12). It contains the projections whose occurrence is disputed or uncertain, but still possible (*M* = 3.48). The last cluster is based on projection 16 with the TaaS business model. The occurrence of this projection is not yet foreseeable at the current level by the experts (*M* = 2.56) and would therefore be a surprising scenario if it occurred by 2030.

Table 2: Overview of quantitative results.

		P Round 1 (*N* = 30)				P Round 2 (*N* = 27)						
Nr.	**Projection**	**IQR**	**Mdn**	**M**	**SD**	**IQR**	**Mdn**	**M**	**SD**	**SD change**	**I[a]**	**D[b]**
	SEF											
1	Lack of staff	1.00	4.0	4.20	0.65	0.00	4.0	4.22	0.42	-36.35%	3.81	3.52
2	Driving time regulation	*1.75*	4.0	3.43	1.26	1.00	4.0	3.56	0.92	-27.08%	3.63	4.11
3	Sustainability	1.00	5.0	4.57	0.72	0.00	5.0	4.81	0.39	-45.72%	4.33	3.59
4	Combined transport	0.00	4.0	3.87	0.92	0.00	4.0	3.89	0.83	-9.75%	3.33	3.59
	IAD											
5	Hub-to-hub transport	0.75	4.0	3.97	0.95	0.00	4.0	3.74	0.97	1.87%	4.11	4.19
6	Condition of infrastructure	1.00	4.0	3.57	1.05	0.00	4.0	3.81	0.82	-22.42%	3.52	2.93
7	Alternative drives	1.00	4.0	4.23	0.80	1.00	4.0	4.22	0.74	-8.27%	3.67	3.74
8	Charging infrastructure	*2.00*	4.0	3.47	1.23	*1.50*	4.0	3.56	1.13	-7.96%	3.70	3.89
	DIL											
9	Digitalized logistic chain	1.00	4.0	4.23	0.84	1.00	4.0	4.04	0.88	4.41%	4.15	4.78
10	Real-time tracking	1.00	4.5	4.37	0.75	1.00	5.0	4.56	0.68	-8.92%	4.19	4.74
11	Terminal coordination	1.00	5.0	4.30	0.97	1.00	5.0	4.37	0.87	-10.73%	4.11	4.70
12	Loading and unloading	*2.00*	3.0	3.23	1.23	*1.50*	3.0	3.11	0.87	-28.85%	3.67	4.37
13	eCMR	1.00	4.0	4.20	0.87	1.00	4.0	4.26	0.70	-19.84%	3.74	4.70

	BMC											
14	Digital players	1.00	4.5	4.20	1.01	1.00	5.0	4.30	1.05	3.39%	3.74	2.81
15	Consolidation	1.00	4.0	3.53	0.99	1.00	4.0	3.59	0.87	-12.04%	3.70	3.15
16	TaaS	*2.00*	3.0	2.87	1.31	1.00	3.0	2.56	1.03	-21.33%	3.00	2.89
17	SaaS	1.00	4.0	4.17	0.93	1.00	4.0	4.22	0.87	-6.32%	3.93	4.15
18	Digital freight forwarder	1.00	4.0	4.03	0.95	0.00	4.0	3.93	0.90	-5.11%	3.67	3.78
19	Sharing concepts	1.00	4.0	3.50	1.02	1.00	4.0	3.56	0.92	-10.58%	3.52	3.85

Note. IQR = Interquartile range. Mdn = Median. M = Mean. SD = Standard deviation. P = Probability of occurrence. I = Impact. D = Desirability. SEF = Society, environment, and freight transport. IAD = Infrastructure & alternative drives. DIL = Digitalisation in logistics. BMC = Business models & competition. IQR values in italics indicate that no consensus was reached.

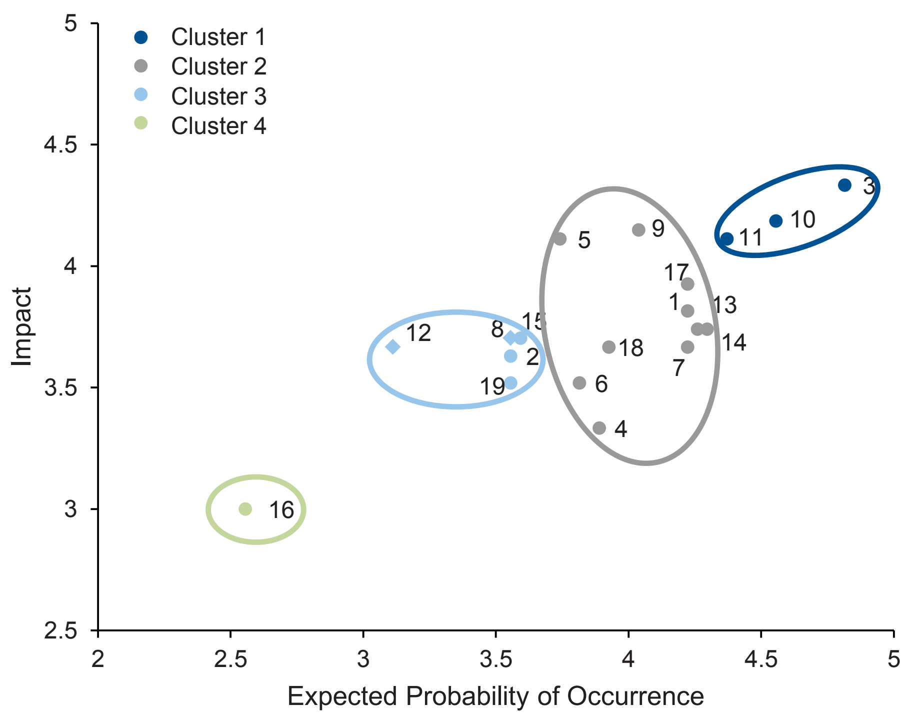
4.3. Qualitative Analysis

In this Delphi study, the experts were asked to give reasons for their probability assessments. In total, the experts gave 530 out of 570 possible comments. The largest number of comments for a high probability was given for projection 1 (staff shortage) with 28 comments and for projection 9 (digitalized supply chain) and 10 (real-time tracking) with 26 arguments each. This emphasizes the potential for discussion and the relevance of these projections. The largest number of comments for low probability was given for projection 12 (loading and unloading) and projection 17 (TaaS) with 17 and 16 comments each. Projection 12 is also one of the two projections for which no consensus was reached, and thus is controversial. The 530 comments obtained in this study were used to formulate the four scenarios and conclusions that will be presented in the following section.

5. DISCUSSION

Guided by the research question of what the direct logistics environment of automated trucks could look like in 2030, scenarios based on the results of the Delphi study are described narratively below. Please

Figure 4: Scatter plot and clusters of future projections



Note. Numbers correspond to the respective projection; dot = consensus reached; square = no consensus reached.
Cluster 1: Sustainable logistics with widespread digital, automated tracking and coordination; Cluster 2: Progress in electrification and digitalization more significant than in automation and infrastructure; key players in logistics challenged; Cluster 3: Unexploited potentials in electric charging, efficient use of trucks and automated (un)loading; Cluster 4: No new business models on automated trucks yet.

note that the scenarios differ in size due to the selected clustering method. For a better overview, each scenario is named accordingly, briefly summarized, followed by a detailed description. The resulting probabilities of occurrence of the original projections are justified by the comments of the experts interviewed and thus underpin differently expected developments by 2030. If not explicitly indicated by a source, the argumentation is based on the comments of the experts of this study.

5.1. Cluster 1: Sustainable logistics with widespread digital, automated tracking and coordination

Cluster 1 includes the three projections (3, 10, 11) rated most probable for 2030. Consensus was reached for all of the included projections. Moreover, the range of average impact of the projections ($M = 4.11 – 4.33$) suggests that the events will have a particularly relevant and consequential impact on the logistics environment of automated trucks. It describes increasingly sustainable and digitalized logistics and can be summarized as follows: By 2030, sustainability has become an increasing differentiator for logistics service providers and companies that do not think sustainable are disappearing from the markets. In this scenario, there is substantial progress in terms of digitalization, like the widespread real-time tracking of trucks and goods as well as automated and digital coordination of trucks on hub premises. However, by 2030 this progress is not yet seamless and partly limited to large logistic centers and players with a high degree of standardization. Below, these conclusions are described and justified in more detail.

For this scenario, the experts agree that both social and environmental sustainability will continue to gain in importance until 2030 (projection 3) as it is already an enormous driver in logistics today. Concerning environmental sustainability, by 2030 the political pressure on logistics companies will be increased due to emission standards, stricter regulations and CO_2 taxation. Social acceptance and the demand for sustainable transport services as well as competitive pressure are further reasons for the development towards sustainability and climate neutrality. The transport industry will therefore meet its responsibilities in the area of sustainable use of resources by 2030. Facing the impeding shortage of skilled workers, logistics companies will be taking actions in respect of social sustainability. As a consequence of the trend toward greater sustainability, costs are likely to rise for companies by 2030. However, companies that do not adopt a sustainable approach will be disappearing from the market. The associated projection 3 is therefore rated as the most consequential for the environment of automated trucks. These results are in line with the conclusions of Ruess and Litauer [76], who forecast cost and competitive disadvantages as a result of insufficient anchoring of sustainability in the strategic corporate orientation.

Next to the growing importance of sustainability, in this scenario the experts expect substantial progress in digitalization and automation until 2030. However, there will be differences between the various actors along the supply chain regarding the level of development. More precisely, widespread real-time data tracking (projection 10) is expected to occur by 2030, with the reasoning of current innovation thrusts and current trends in tracking and tracing and the Internet of Things. These innovations listed by the experts are also widely cited in the literature [93, 99, 102, 103]. More specifically, the experts of this Delphi study state that solutions via transponders, GPS, and RFID, the higher availability of environmental data as well as the decreasing hardware and communication costs by 2030 will be enablers of this widespread tracking of trucks and goods. This development is seen as an inevitable and logical next step and has also been classified as probable in the Delphi study by Gracht and Darkow [29]. Nevertheless, the experts of this study do not foresee automated recording and seamless tracking for all means of transport and goods by 2030. Because there are many actors involved in the supply chain, some will still be operating non-digitalized in 2030 and further, permanent tracking is not considered to be useful or necessary for all kinds of goods. In this scenario the situation is similar for the digitalized and automated coordination of trucks on site. The experts expect solutions for this kind of coordination to function efficiently by 2030 (projection 11), because current progress already shows the development into this direction as automated real-time route planning is already possible albeit with restrictions. However, the experts assume that more extensive digitalization will first take place in larger logistics centers with a high degree of standardization and comparatively simple processes. Implementation will be slower for small depots because the automated coordination of trucks requires specific infrastructure. Although digital coordination is necessary for automated trucks, it can be assumed that in 2030 such vehicles will not yet be widespread, because not every hub will be able to offer these digital services.

5.2. Cluster 2: Progress in electrification and digitalization more significant than in automation and infrastructure; key players in logistics challenged

Cluster 2 consists of ten projections (1, 4 – 7, 9, 13, 14, 17, 18) that are rated as rather likely with an expected probability of occurrence between $M = 3.74$ and $M = 4.30$. The projections are therefore very valuable from a strategic perspective. Furthermore, the impacts of the projections are assessed as relevant ($M \geq 3.33$). Consensus was reached for all of the included projections. In this scenario, small fleets of automated trucks are initially used in hub-to-hub transport by 2030. Partly due to the infrastructural situation being largely unchanged from today the proportion of automated trucks by 2030 is still low. As a result, there is still a high demand for drivers and a shortage of qualified personnel. Next to automation, the electrification of trucks has proceeded as well and about 30% of the trucks drive on electric drives. Small changes in infrastructure have concentrated on providing the required charging infrastructure. With the perceived increase of sustainability due to electrification, the transportation of goods still focuses on the road in 2030. Another area with a lot of progress in this scenario is digitalization: Freight and customs documents are digitalized and largely established in Europe and large parts of the supply chain are digitally connected by 2030. The market for telematics systems however continues to be fragmented and leaves a need for standardization. Due to the progress in digitalization, digital players like Amazon have become growing competitors in logistics and digital freight forwards continue to gain importance. The detailed reasoning for these conclusions are presented below.

The likelihood for the necessary technology for automated trucks being available by 2030 has increased significantly in recent years, as stated by the experts. In addition, legislation in Germany has recently paved the way for autonomous vehicles. However, as the experience with the use of automated trucks will still be limited in 2030, automated driving will initially be limited to specific application areas in this scenario. According to the experts, highways and thus long-distance traffic between logistics centers are best suited for the use of automated trucks for numerous reasons: influences on the system, complexity of the traffic area and, thus, safety concerns are lower than in cities and municipalities. Therefore, deployment on federal highways and freeways is the easiest and quickest to implement [42] and has the highest benefits for logistics companies carrying the largest transport volumes. Accordingly, the majority of experts considers it to be more likely that automated trucks will be mainly used between logistics centers connected by major roads in 2030 (projection 5). In addition to that, some experts also see great potential for automation in company and terminal premises as well as clearly defined short distances between logistics centers. However, the market penetration of automated trucks will initially be slow and many things will still occur in a conventional manner in 2030 according to the experts and literature [53]. One reason for the low proportion of automated trucks by 2030 is that according to the experts the infrastructure will remain largely unchanged from its current state until 2030 (projection 6) due to the investment and repair backlog as well as long approval and construction times. It remains to be determined which components and systems will be required for the infrastructure of automated transport. Adaptations may be necessary at complex locations such as intersections or highway entrances. Further requirements for the traffic infrastructure may arise, for example, control towers on highways, troubleshooting centers or dynamic obstacle warnings. Consequently, these aspects will not be completely implemented by 2030. As the government will pay all the associated costs logistics companies themselves would have to drive forward and pay for upgrades to the infrastructure for faster changes [82].

Although automation will reduce the shortage of drivers, there will still be a high demand and shortage of qualified truck drivers in 2030 due to the relatively low proportion of automated transport. As a result of demographic change, the steady decline in the availability of labor will continue for rather unattractive jobs such as truck drivers but also for logistics experts and IT specialists (projection 1). In addition, the use of automated trucks will change logistics in terms of personnel and the distribution of tasks. In the experts' opinion, the tasks previously performed by the driver such as departure checks or documentation might be replaced by digital solutions where the trucks are driverless. The digitalization of vehicles must therefore be accompanied by the digitalization of the entire logistics process [7, 37]. As a result, new tasks and new required competencies related to the emerging digitalized and automated processes are expected in logistics by 2030. Therefore, the experts expect an increased shortage of skilled workers in this scenario, which is in line with literature [37, 81].

In this scenario, the electrification of trucks will also be further advanced by 2030. The majority of experts considers the use of electric drive systems in long-haul transport (projection 7) to be rather likely or likely. OEMs indicate that electric trucks for long-distance transport will be produced and sold in the next few years. According to the experts, around 30 to 50% of all trucks on the road by 2030 could have electric drives, as a result of political pressure on climate targets, the development of battery technology and price degression. However, experts' opinions are divided regarding the use of battery and fuel cell technology in long-distance transport as these represent two different drive systems with different future application profiles. Fuel cell electric vehicles tend to be used for long-distance transport because they differ only slightly from conventional trucks in terms of operating procedures. However, the development of this currently energy-intensive technology depends on the production of the underlying material. It is therefore doubtful that this type of drive will be widely introduced by 2030. Battery electric vehicles will tend to be used for short distances, unless there is a rapid breakthrough in research on lightweight energy storage. Overall, the number of electrified trucks will grow slowly and the impact will initially be small. The discussion about the drive technology of the future among the experts underscores the uncertainty that is also apparent from discussions in the literature [58, 59].

In view of the electrification of trucks, the focus of the above mentioned few changes in infrastructure will be on providing truck charging and hydrogen refueling stations rather than on modernizing the infrastructure for automation or CT, according to the experts.

Facing the increasing importance of sustainability (cluster 1), electrified trucks are seen as a way to achieve the climate goals, which will play a significant role in slowing down the expansion of CT in this scenario. Although CT is currently driven by political considerations in view of climate targets and growing transport volumes, the experts think that CT will continue to grow only slowly until 2030 and freight transport will still be concentrated on the roads (projection 4). According to the expert panel, freight transport by road continues to offer the greatest reliability, speed and flexibility in both urban and rural areas, and will be even more attractive as a result of automation. The fact that only a certain proportion of road freight transport is suitable for an economic transfer to rail supports this prediction and is in line with the literature [26, 103]. However, the experts are aware of the possibility that there will be a shift towards rail if the climate-friendly use of vehicles cannot be realized.

As already mentioned above, the automation and digitalization of vehicles must be accompanied by the digitalization of the entire logistics process. Therefore, this scenario considers a significant progress in digitalization: The experts expect freight and customs documents to be largely digitalized in Europe by 2030 (projection 13). As a reason, they cite that current pilot concepts and initiatives by logistics providers point to this development and the desire to profit from the expected efficiency potential [33]. Logistics service providers are increasingly researching BC technology so that the freight and customs documents can be realized with smart contracts [26]. In this context, the legal framework plays an important role. The experts consider Germany's accession to the eCMR Additional Protocol a critical step for a Europe-wide roll-out of the digital consignment note. The next step is the recognition of the legal security of digital documents by the legislator. Even though the experts assume that the digitalization of freight and customs documents will be widespread in Europe by 2030, they also acknowledge that this will not be the case for each end every area, region or country, as already pointed out in cluster 1. Limiting factors will be deficient international coordination and a lack of standardization. Missing standardization is also a reason for the experts rating the digital networking of the various actors along the supply chain as just rather probable (projection 9). The experts acknowledge the increasing trend towards networked systems that is also reported in the literature [37, 45, 93] and makes cross-modal and cross-company connectivity between all players in the supply chain probable for 2030. The experts predict that optimal logistics control using telematics systems and corresponding platforms will be a central element of future logistics processes. In addition, data availability, ideally across the entire logistics chain, is a decisive factor in increasing efficiency. However, they name standardized interfaces in transport management and telematics systems as the prerequisites for it. Although the supply chain is already partially digitalized and telematics systems are established on the market, a connection between all actors and a changeover of all manual to digital standards is still seen as unlikely by 2030 by some experts. With more than 50 telematics system providers in Europe alone, the market is very fragmented and thus transporters may be required to use different platforms in parallel. OEMs also offer telematics systems, platforms and interfaces in addition to their main product the truck (e.g. RIO for MAN Truck & Bus; FleetBoard for Daimler Trucks). From the experts' point of view, this development will continue and OEMs will increasingly become integrated system providers by 2030 (projection 17). Therefore, the problem of insufficient interface integration in transport management systems will remain as long as OEMs offer their own platforms and telematics, which do not allow sufficient networking. However, it is questionable whether OEMs will be able to maintain these offerings in the highly fragmented telematics market or whether third-party solutions will dominate the market in 2030.

In view of the progress in digitalization in this scenario, the experts are of the opinion that digital freight forwarders will continue to grow in importance and take over the intermediation of transport services (projection 18). The experts see open platforms as an increasing necessity for SMEs to remain competitive in 2030. In recent years, there has been a trend toward 4PL and 5PL, a business model without assets but with expert knowledge and digital tools, which will continue in the experts' opinion. This is also in line with literature [70, 81, 93]. As a complement to the specialization in transportation services the business model of the specialized supply chain architect is developing and will play an important role by 2030 according to the experts. Nevertheless, they share the opinion that digital freight forwarders will not dominate the market when compared to the large logistics companies in 2030. However, global corporations will become growing competitors in logistics by 2030 (projection 14). The experts see a great advantage of Tech Groups in the optimal control of logistics processes as well as through the use of collected logistics and customer data. This advantage is also emphasized in the literature [81, 84, 85]. The experts cite the recent investments by Amazon in Rivian (electric cars) and by Google in Waymo (automation technology) further illustrating their intention to offer autonomous logistics and transport capacities in the future. Nevertheless, some experts consider an in-depth participation in logistics to be unlikely and are of the opinion that they will only offer services in the area of general cargo and courier, express, and parcel services (CEP), which only form a small part of freight traffic.

5.3. Cluster 3: Unexploited potentials in electric charging, efficient use of trucks and automated (un)loading

The scenario derived from cluster 3 includes five projections (2, 8, 12, 15, 19) of which two (8, 12) did not reach consensus among the experts. The expected probability of the projections in this cluster is rated as neutral to somewhat likely ($M = 3.11 – 3.59$) and is, thus, more ambiguous. In addition, this cluster is characterized by its intermediate to rather higher estimates of impact (≥ 3.52) and rather higher desirability (≥ 3.85). This suggests that these projections tend to be viewed by the experts as an opportunity rather than a threat. In summary, this scenario describes the following situation: In spite of the fact that sustainability plays an important role in 2030 (cluster 1), the charging network for electric trucks is not yet widespread. Charging stations are initially found on routes between large logistics centers or privately in depots. Also, the concept of sharing (trucks and storage space) among large logistics operators for higher sustainability still remains unrealistic until 2030. Unexploited potentials like these also show in other areas in this scenario: The adaption of driving times to the requirements of automated driving and regulation of passive driving is in progress, but not yet finalized by 2030. The same goes for automated (un) loading of trucks and the automated identification of goods which is not yet widespread in 2030. In general, the proportion of automated and sustainable trucks in 2030 is low, mainly owned by large companies due to the necessary large investments. These conclusions were drawn as follows.

This scenario is characterized by unexploited potentials in the logistics environment of automated trucks in 2030. Starting with the charging infrastructure to enable electrified transport between logistics centers, almost half of the experts surveyed considers it to be only rather likely that it will be adequately developed by 2030 (projection 8). The experts argue that the energy and space requirements are far too high for an adequate infrastructure to be realized by 2030. Due to the charging times, more parking areas will have to be created. Necessary investments and slow construction developments are delaying extensive infrastructural expansion. At the same time, some experts argue that battery capacities are improving thanks to the massive upswing in technology. As already mentioned in cluster 2, the experts assume that a charging infrastructure network will either be politically driven or built up through current initiatives by the OEMs to achieve climate targets. Some of the experts are of the opinion that this will enable an adequate charging infrastructure by 2030 especially in hub-2-hub transport, as charging infrastructure in private depots can serve as a backbone. The skepticism in this projection coincides with current doubts in the literature [25]. Since this projection is controversial among experts and not subject to consensus, it should be interpreted with caution.

The unexploited potentials continue in terms of sustainability. Even though sustainability, cost and competitive pressures will call for an optimization of logistics processes, the experts consider a strengthening of the trend toward shared use of transport and storage space (projection 19) to be rather unrealistic by 2030. According to the experts the development of sharing is slowed down by fragmented systems and a lack of standardization. Further, OEMs are more likely to work towards providing truck capacity flexibly to their customers through models like pay per use or short-term leasing (cluster 4). Large logistics companies will optimize empty runs and storage areas within their own volumes.

In terms of automation the experts consider the differentiation between active manual and passive automated driving time (projection 2) to be a prerequisite for selling automated driving as this will first reduce the costs of logistics services enormously. The legislator is therefore expected to react to the corresponding pressure from the logistics industry. The majority of experts consider an adjustment of the driving time regulations to be more likely and to have a greater impact. However, the revision of the current regulations will be difficult as working time legislation will play an important role. In the view of several experts, benefits for the freight forwarder based on the driving time regulations cannot be expected by 2030, not least because Europe-wide changes will not be easy and changes will depend on the reliability of automation.

Further, the assessment of the role of automation in the (un-)loading of trucks and the identification and allocation of goods by 2030 (projection 12) differs among the experts. No consensus was reached for the corresponding projection. Some experts expect growing networking due to the already increasing autonomous intralogistics with loading robots, drones and driverless transport systems. The rapid development of recording systems for goods (e.g. trackers, barcodes, QR codes) also favors this trend. However, a complete automation of loading and unloading will be difficult to implement depending on the seasonality of the industry, the heterogeneity of the goods and load carriers, and the complex load securing. Many experts are of the opinion that by 2030 initial implementations will only exist for large logistics centers that can afford the technology and have standardized goods and packaging and a high turnover rate. Unloading robots, especially for non-standardized goods and special loads, are not yet ready for use. Consequently, by 2030 automated trucks will be able to approach the loading zone in an automated manner, but personnel will still be needed for most of the subsequent process steps, such as opening the container, the swap body or releasing the load restraint.

A possible reason for the unexploited potentials in this scenario might be that sustainability, automation and digitalization involve investments that small fleet operators are unable to meet. Therefore, the experts expect that logistics service providers will be confronted with changes in view of the continuing consolidation process in their industry (projection 15). However, the experts cite that consolidation will not have occurred on a large scale by as early as 2030. Especially in rural areas, a heterogeneous environment of small logistics service providers with small, manual truck fleets (less than 10 trucks) is to be expected. Once automated transportation becomes common practice, the market will focus on large key players, but this is not yet to be expected by 2030.

5.4. Cluster 4: No new business models on automated trucks yet

Cluster 4 consists of only one projection (projection 16) and deals with new business models for OEMs in regard to automated trucks. The expert panel agrees that a widespread offering of transportation services by OEMs by 2030 should be classified as mid-range or rather unlikely ($M = 2.56$). This scenario describes a small amount of pilot projects but no established new business models in 2030. The reasoning is as follows.

A far-reaching offering of transport services by OEMs by 2030 can be classified as rather unlikely according to the experts (projection 16). Therefore, in this scenario there will only be an early phase of the initiation of the OEM business model transport as a service by 2030. As already described in the previous scenarios, only a few automated vehicles are expected to be in service by 2030 (cluster 2) and the driver might still be needed to some extent. This is partly due to the fact that automated trucks will initially be a high investment that only a limited number of companies will be able to take (cluster 3) and not every hub will be able to provide the required infrastructure for the digital and automated coordination of trucks (cluster 1). In addition to that, the expected growing shortage of skilled personnel (cluster 2) might complicate the integration of automated trucks into the existing hub processes. These challenges, as well as the lack of logistics expertise of OEMs, slow processes in strategic development and unattractive low margins in the logistics sector could hinder the development of this new OEM business model in the view of the experts. In addition, OEMs would have to compete with their customers. From the experts' point of view, most OEMs will therefore stick to their core competencies. Nevertheless, the experts assume that automated trucks will enable new business models in the field of mobility. OEMs attach great importance to offering mobility services [43, 79]. Automated trucks provide the basis for offering cargo space capacity or business models such as pay per use or pay per mile, as already expected by Schiller et al. [79]. TaaS is seen as the model of the future and OEMs will eventually own their own fleets in the future. However, the extent to which it will occur cannot yet be estimated by the experts due to the costs of automated trucks and the high transport volume.

6. LIMITATIONS

There are some limitations to the results of the presented study which are discussed in the following. The composition of the expert panel is to be mentioned in this context. With 27 participants we reached the recommended panel size [64] and integrated different points of views on the research question. However, 59 % of the respondents were from the field of academic research and the automotive industry. This distribution may have led to a bias in the results. Furthermore, it must be noted that some of the stakeholder groups are rather small. For example, the group of digital services with two representatives might be underrepresented. However, it is to emphasize that all identified relevant areas of expertise were covered by the expert panel multiple times, so that appropriate heterogeneity could be ensured. In addition, 89% of the respondents in the present study did not revise their self-rating of expertise in the second round, but rated it the same after seeing the feedback from the first round in the second questionnaire. This speaks for the stability of the experts' assessed expertise.

Furthermore, the second questionnaire provided a limited number of the categorized and most frequent arguments for and against the occurrence of a projection, as it is common practice in Delphi studies (e.g. [20]). This selection of comments can have an influence on the experts which is a known limitation of the Delphi method [91] and has to be taken into account when interpreting the results.

In addition, it has to be stated, that some of the formulated projections are of a slightly bigger scope than others and partially combine multiple statements (e.g. projection 3, 11, or 15). The formulation of the projections can have an influence on the outcome of the Delphi study, which is a general limitation of Delphi studies [91]. To counteract this limitation, the projections' formulation was evaluated regarding consistency, ambiguity and content validity by three experts in the projection phase, as described above. If a projection included several aspects, the expert panel was able to address these aspects separately in the comments. This information was used for the creation of the scenarios. Further, it must be noted that scenarios do not provide forecasts but are subject to uncertainties. This is partly due to the fact that the future projections cannot be viewed in isolation, but are interlinked in many ways [89].

7. IMPLICATIONS AND OUTLOOK

As automated trucks are expected to provide benefits on an economic, environmental, and social level in the commercial vehicle industry, OEMs are increasingly dedicated to developing the necessary technologies [20]. At the same time, the logistics industry is changing, driven by recent technological, social, and political developments [99]. In light of these developments, it is of great importance not only to shape the technical progress of automation, but also to consider the future framework conditions automated trucks will operate in. In this paper, a Delphi-based scenario study was conducted to investigate the future logistics environment of automated trucks in Germany in 2030. 19 projections for the year 2030 were developed and evaluated by 27 selected experts in a two-round Delphi study. The experts included perspectives from the automotive industry, logistics representatives, consultants, academic and political representatives. The methodological rigor of the Delphi study was ensured in all steps and consensus could be found for 17 of the 19 projections. Based on complete-linkage clustering, four narrative scenarios were developed for the year 2030.

By compiling the information on the current trends in the logistics field and presenting the current state-of-the-art, this paper provides a useful overview based on literature and expert knowledge. Further, with the detailed description of the execution of the Delphi study and the presentation of the found limitations, this research can contribute to the guidance for and the improvement of future Delphi studies. Moreover, with the four developed scenarios, we provide the research community with collected, organized and elaborated expert knowledge from a 360° point of view and valuable insights on how the current trends in logistics will most likely emerge until 2030. These results on the future logistics environment in general provide a sound basis for strategic decisions in the automotive and logistics sectors and can serve as a basis to further investigations.

In detail, the results of this Delphi study show many unexploited potentials in the environment of automated trucks in 2030. Especially in the field of digitalization there are a lot of optimization opportunities: For example, the beneficial digital connection between all actors along the supply chain will not be finalized by 2030 (cluster 1) and the required infrastructure for the digital coordination of (automated) trucks will not yet be available to all depots (cluster 1). The lack of standardization is mentioned as a central limiting factor throughout the scenarios. Because of missing standardization integration of the many telematics systems on the market will not be possible by 2030 (cluster 2) which hinders connectivity along the supply chain. Missing standardization also plays a role for the international implementation of digital freight documents which limits the benefits of this progress to certain regions and areas in Europe. Standardization of processes and load packaging also plays a role for the implementation of automated loading and unloading of trucks (cluster 3) which promises great benefits but can not be expected by 2030. In summary, standardization is presented as one of the key elements for progress in the logistics environment of automated trucks. Therefore, the pursuit of standardization should be prioritized and focused on in the further development of the specific areas.

In spite the fact that environmental sustainability will be a very important factor (cluster 1), the results of this Delphi study show that there will still be room for improvement by 2030. The concept of sharing load and storage space is not expected to grow (cluster 3) despite its contribution to increased sustainability. This aspect should be reconsidered for strategic decisions. Further, the electrification of trucks holds great benefits in terms of environmental sustainability but will still be limited in 2030 (cluster 2). The results indicate that infrastructural changes for better charging options could enable more electrified transport of goods. It is therefore recommended to further drive this development.

Moreover, the scenarios indicate that further infrastructural changes like additional lanes for automated trucks or communication between infrastructure and vehicle could speed up the market penetration of automated trucks (cluster 2) and increase the initially low proportion of automated trucks in use by 2030. Therefore, the role of infrastructural changes should be further researched and considered instead of leaving the enablement of automated driving exclusively to vehicle functions. This also applies to the infrastructure of logistic centers. It has to be addressed whether there will be defined prerequisites for the use of automated trucks that have to be met by the hub infrastructure or whether other solutions can be created to enable automated transport in 2030. These other solutions could lie in human assistance for the automated truck which could in turn have an influence on the design of the future cab.

Because of the initial low proportion of automated trucks in 2030 many transports will still be in a conventional manner (cluster 2). That means that there will be mixed transport with automated as well as manually driven trucks between logistic centers, which has to be kept in mind for designing the in-hub processes. Further, automated trucks will change logistics processes and introduce new tasks and qualification requirements. At the same time, there will still be tasks that have to be carried out manually by 2030 such as (un)loading the truck or (dis)connecting the trailer (cluster 3). Facing the expected shortage of skilled workers (cluster 2) and the striving for social sustainability in 2030 (cluster 1), hub operators should also focus on ensuring that the future jobs and working conditions in the context of automated trucks are attractive and ergonomically well designed for the limited number of workers in 2030. In this context, the results of this Delphi study can be used to identify the future task distribution in hub-to-hub transport in 2030. Currently, truck drivers in hub-to-hub transport take on tasks that go beyond driving the truck. Examples include the registration at the hub, the handling of freight documents, or loading and unloading the truck [19, 35, 56]. Providing a well-founded picture of the future logistics environment and especially the future state of digitalization, the results can be used to identify which of the tasks still have to be carried out by humans and which tasks will be covered by digital solutions in 2030. These changed tasks in and around the automated truck can have an impact on future jobs, future processes and even on the design of the truck cabin, which further illustrates the relevance of the study results.

In the process of this study we identified further relevant areas of interest that could be investigated in future research: The previous examples show that investigating the direct logistics environment of automated trucks is important for their integration into the future processes. As stated above, 2030 was defined as the year of focus for this study because the first automated trucks are expected to operate in hub-to-hub transport by then [62]. For truck generations in the more distant future, it would also be beneficial to investigate the logistics environment of 2035 or 2040 in future research. Moreover, in this study no consensus was reached among the expert panel on the development of the charging infrastructure (projection 8) and the development of the automated (un)loading of trucks (projection 12) until 2030. Therefore, especially these trend areas may represent topics in need of a deeper analysis in future research. In the course of prioritizing relevant influencing variables in the projection phase, certain logistic trends were not integrated in this study in order to keep the focus on the direct logistics environment of automated trucks. Subsequent research could therefore investigate the consequences that factors such as cybercrime, extreme weather events, or trade conflicts will have on the logistics environment and whether this will make the role of an in-vehicle person more relevant. In addition, the trend of ITS should be further addressed in future studies on the logistics environment of automated trucks. Moreover, the presented scenarios focus on the context of heavy commercial vehicles in German domestic transport. As transportation of goods often crosses boarders, the results of this study could serve as a basis to expand the focus to the European level or to explore other markets in future research.

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