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Technical and legal critical success factors: Feasibility of drones & AGV in the last-mile-delivery

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ABSTRACT

This paper aims to provide a current status of the legal situation necessary due to the regular changes of the law of the EU and Germany, by identify technical and legal critical success factors of the feasibility of drones and AGVs in last-mile-delivery. Furthermore, the paper provides importance rankings for legal and technical critical success factors from the point of view of logistics and supply chain experts. A conceptual model was developed capturing main legal and technical critical success factors from literature finding and then providing basis to a survey-based study that have been captured online. Results from the survey were evaluated and compared against each other using the Analytical Hierarchy Process. The results are based on business-to-business relationships between logistics service and mobility providers, as well as technical developers. The results of this research can help managers of large providers, transport companies in general and governments as well as political decision-makers in the innovation field to understand the legal situation of the EU and Germany as well as the technical problems that have to be overcome to profit from future technology in the last-mile-delivery.

1. Introduction

In line of new alternatives to optimize last mile delivery, there are several transport concepts about how drones and Autonomous Ground Vehicles (AGVs) can be used or combined to ensure innovative, but also faster last-mile-delivery. The problem regarding introduction of drones and AGV is primarily that tangible long-term tests are missing. Without the legal approval of individual countries, potential customers cannot experience the technology and there is no way for service providers to implement technologies that promote a human-machine trade-off. Last-mile-delivery represents the last part of the supply chain, which is considered the most inefficient due to its peculiarities and contributes a significant amount to total delivery costs (Nagpal, Bishnoi, Dhami, & Vijayvargia, 2021; Perrinaud & Saraceni, 2022; Saraceni et al., 2022; Sindi & Woodman, 2020). The spatial distribution of small receiving points, demands for more frequent but smaller shipments, and increasingly difficult delivery times all contribute to this (Nagpal et al., 2021; Maestro, Rodríguez, Casado, Prieto, & Corchado, 2020; Slabinac, 2015;). This is also due to the partly remote delivery points and poor infrastructure in developing countries (Turská, Chinoracký, Kurotová, Jaculjaková, & Rybick, 2018; Bashuna, Griffin, & Iskandarova, 2017; Scott & Scott, 2017), whereby the increasing urbanization of cities is also a challenge for logistics service providers (LSPs) (Boysen, Fedtke, & Schwerdfeger, 2021; Chen, Jin, & Huo, 2020; Kellner, 2020). Additionally, the e-commerce industry faces high labor turnover and recently is experiencing an acute shortage of drivers. In 2020, there was a shortage of 150.000 drivers, making the urgency for new alternatives essential, as last-mile personnel costs account for around 50% of the share of variable costs for LSPs (Humphreys, Dumitrescu, Biju, & Lam, 2020; Ji-Hyland & Allen, 2020; Ptock, 2018). These challenges for the LSPs may be solved in finding alternatives to human drivers. In addition, logistics providers are more and more under pressure due to increased demand for package deliveries. Since 2014, the volume of the e-commerce industry has been steadily increasing (Martinez Vidal, 2021; Paker, 2021), rising to 3.43 trillion US dollar worldwide in business to consumer (B2C) in 2020 (Paker, 2021).

Literature has so far failed to describe the legal situation of airspace and autonomous road traffic on a country-specific basis. This is also due to the fact that the laws per country are slightly changed on a regular basis. The EU draft legislation only provides the framework for the classification of drones, but does not legally regulate the airspace of the respective country.

This study aims to identify which technical and legal critical success factors (CSFs) prevent the introduction of AGV and transport drones,

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having Germany as a law-case. To elaborate on this, following research question was formulated: ***"To what extend do technical and legal critical success factors influence the feasibility of the usage of drones and AGV for last-mile-delivery?"*** *and* the following sub-questions: *Which institutions and laws hinder the introduction of autonomous driving and flying in the form of AGVs and drones? What are the most important operational, security and customer challenges from a technical perspective? Which of these challenges and CSFs are perceived as most restrictive from experts from the logistics and supply chain sector, technical developers and traffic right experts?*

By answering the research questions, the goal of this work is to provide concrete suggestions for technical solutions and to identify changes or gaps in the law that would no longer hinder these technologies. In addition, general recommendations can be formulated regarding process management to LSPs or any mobility providers. It is important to make clear that the unit of analysis in this study only encompass Technical and Legal CSF directly associated to the "technological device". Evidence to frame "security of the parcel" and "physical space at delivery place" would lay out of this research scope, as we would need to broader the research field with variables regarding security of parcel in locational context, localized issue at certain areas and/or countries, cultural matters, etc. We concerned that bringing up such approach could disrupt the unit of analysis as we have not found sufficient support to rationale. Thus, contextual CSF influencing the adoption of drones and AGVs are not included in the research scope. This remainder of this research is structured as follows. In the literature review section, the concepts of drones and AGVs are introduced, elaborating on technical and legal CSFs associated with their use, derived from their characteristics and existing regulations of use. In the following section, the chosen methodology is described. We conducted semi-structured interviews to with experts on the topics, with the aim of validating and enriching our literature findings, before disseminating a Qualtrics analysis in order to compare the CSFs found. Subsequently, we present the results of our Analytical Hierarchy Process (AHP) assessment calculations, and elaborate on a discussion on interesting points resulting from this comparison as well as their feasibility in Germany. Lastly, in the conclusion of this paper, we present the deriving theoretical implications of this research, as well as practical recommendations for LSPs, we dispense the limitations that we encountered, and highlight relevant future research directions.

2. Literature review - automation in the last mile: drones and AGVs

In this section, both drones and AGV are first classified technically and any differences are highlighted. Based on this, the advantages of using drones and AGVs in last-mile delivery are presented, before the technical and legal CSFs are elaborated.

The enormous increase in volume in the e-commerce industry presents the last-mile with ever-increasing challenges. *E*-commerce sales worldwide in 2020 were up 25.04% compared to 2019, totaling $2.91 trillion (Kelvin, 2021). The aforementioned driver shortage in the logistics market and low utilization rates of trucks increase the pressure on performance and costs, requiring action and leading to the need to bypass traditional processes in delivery (Mangiaracina, Perego, Seghezzi, & Tumino, 2019; Staats, Lohaus, Christmann, & Woitschek, 2017). A McKinsey study posits that the transportation and warehousing industry holds the third highest potential for automation technology. In warehouses and distribution centers, for example, multishuttle systems, conveyor connection, or picking robots are used, which automate the flow of goods (Dekhne, Hastings, Murnane, & Neuhaus, 2019). But also automated data processing like smart storage, analytic tools based on Big Data help to use resources more efficiently (Saraceni et al., 2022; Yerpude & Singhal, 2018).

The last-mile, which is the focus of this research, can also make use of various innovations and automation technologies. Madlberger (2020) found that these techniques can be divided into three different areas. First, technologies that ensure the collection of real-time information, such as sensor technologies that automatically collect data (Liu, Jayakumar, Stein, & Ersal, 2018), second, technologies that ensure real-time transfer of information, i.e. connectivity between systems such as Internet of Things (IoT) and telematics, and third, technologies that allow autonomous physical movement using actuators. These devices can also provide transportation in the last-mile of logistics (Madlberger, 2020; Saraceni et al., 2022), which is why these technologies will be the focus of this study.

Drones can either be scheduled, dispatched, and loaded from airhubs before launching (Li, 2019; Ndiaye, Salhi, & Madani, 2020; Zhao et al., 2018), or launched from classic conventional delivery trucks (Pugliese & Guerriero, 2017; Wang et al., 2019; Zhao et al., 2018). In both cases, there is the advantage of a decentralized application, allowing the drone to be launched and reloaded multiple times. This also provides the potential for penetration within densely populated cities, as the mobile hub, or delivery vehicle can continue to move to other areas (Borghetti et al., 2022; Wang et al., 2019; Pugliese & Guerriero, 2017). However, it is also possible to have drones launch and recharge centrally, without a mobile distribution center.

AGVs are autonomously operated delivery vehicles that do not require a driver (Amer, Zamzuri, Hudha, & Kadir, 2017; Liu et al., 2018; Turská et al., 2018). These vehicles can also be considered as mobile parcel stations, as AGV contain parcel-lockers where customers can pick up their parcels. The advantage compared to a conventional parcel station is that there is flexibility of location, so the customer does not have to become mobile if the route leads to them (Olejarz, 2020; Turská et al., 2018; Ulmer & Streng, 2019).

As more and more people tend to shop online instead of driving to conventional stores it needs to be explored what the reasons for this move are, beside the known technical challenges and associated CSFs (Jacob & Monachan, 2021; Pugliese, Guerriero, & Macrina, 2020; Qalati et al., 2021), which will be highlighted in the following.

2.1. Drones: solutions and critical success factors

Existing literature shows already successful tests of robots and drones in last-mile delivery, such as the launch of Amazon Prime Air drone in 2018, or DHL's parcel copter in 2017 (Jung & Kim, 2017). However, very few highlight the legal and technical CSFs. In Germany, it has not been possible yet to tangible tests with end consumers of these technologies, as the legal situation prohibits these real-life tests since the in 2017 published Drone Ordinance (Landrock, 2018). Successful testing of drones has demonstrated several benefits for the supply chain industry.

The first major benefit is the cost advantage, as drones lead to a reduction in last-mile delivery costs by replacing labor costs, which account for up to 50% of operation costs (Ptock, 2018). In addition, drones are faster (Roca-Riu & Menendez, 2019), and by using the airspace, blockages such as congestion cannot occur (Borghetti et al., 2022; Graf & Anner, 2021).

Furthermore, a reduction in misunderstandings and errors occurs with drones, as drones cannot forget anything, be overtired, or mix up packages (Chitta & Jain, 2017). A next advantage is the geographical or infrastructural advantage that drones can provide. Remote locations can be reached and weak points in transport routes, or networks can be bypassed (Chitta & Jain, 2017). In addition, a carbon dioxide (CO_2) reduction can be highlighted from this aspect in particular, since no long distances with loaded cars have to be driven to remote locations, not least because drones are fully electrically powered (Roca-Riu & Menendez, 2019). It means that drones show a way to relieve road traffic and to use it in a sustainable way, as the usage of airspace has been a long untapped potential in the last mile of the supply chain (Borghetti et al., 2022; Kellermann, Biehle, & Fischer, 2020).

Technical Solutions - After the technological perspective has been explained in the context of the infrastructure of a drone-based delivery system, the technologies required for this are now described in context of system functions.

With the help of a global positioning system (GPS) positioning system, precise satellite technology and geofencing, which is a combination of GPS network and LRFID (Local Radio Frequency Identifier), the drone positions itself (Hussein et al., 2020). Alternatively, an external pilot helps in dangerous environments (Gettinger & Michel, 2015).

The last point to mention about the technology of drones is the energy source. Drones have four common energy sources: traditional airplane fuel, battery cells, fuel cells, and solar cells. Despite the negative effect on CO_2 pollution and environment, traditional airplane fuel is still one of the most used energy sources for air operations (Buchal, 2020).

Battery cells, which are primarily used for smaller drones with short distance flight (Vergouw, Nagel, Bondt, & Custers, 2016). Fuel cells are more efficient and environmentally friendly than using conventional battery cells (Fuchs, 2018), but this application in drones has been rare (Vergouw et al., 2016), which could also be due to the fact that fuel cells are more expensive than conventional batteries. If the solar drone is realized, it brings quite a few advantages, such as the infinite flight duration, which is made possible by remote energy transmission using solar cell technology (Keidel, 2010).

Technical critical success factors - With regard to the previous explained technical solutions of drones as critical reflection, technical CSFs of the usage of drones will be elaborated now.

The first technical CSF elaborated in the literature is the battery life of drones, which must last long enough to ensure the transportation of products (Anbaroğlu, 2017). In addition, the small payload only provides a small battery, which usually also provides only a short flight duration (Agatz, Bouman, & Schmidt, 2018).

The technical CSF that interacts with this is also the payload as such, as most drones are only capable of carrying shipments between 2.5 and 4 kg (Laksham, 2019). Agatz et al. (2018) also defined battery life as one of the most important constraints in their linear program model on drone flight duration. The already described mobile recharging stations for example in collaboration with trucks from Ndiaye et al. (2020) obviate this problem, but with using a central recharging station the recharging process becomes a technical CSF (Gabani et al., 2021).

Yaacoub and Salman (2020) studied the System Security of aerial drones and classified hackers as a presumed threat to System Security because hackers can gain complete control of an aerial drone if they penetrate the system. The described positioning techniques of drones work with help of a GPS system (Hussein et al., 2020). In case the system loses, the connection to the satellite secure operations cannot be ensured (Gowda, Manweiler, Dhekne, Choudhury, & Weisz, 2016). Another technological and important constraint is the detection of other objects in the airspace.

As it is envisioned that at some point in the future, multiple drones will make deliveries from various LSPs, this fact becomes significantly more important. Described sense & avoid techniques are used for this purpose to detect and fly around obstacles such as birds, but also other flying objects such as drones (Dalamagkidis, Valavanis, & Piegl, 2008). These techniques work by using sensors with radar technology (Anbaroğlu, 2017). Air Traffic control is used for evaluating weather conditions, which affect the flight path of drones in case of particularly strong winds or rain (Hallermann & Morgenthal, 2013).

A final more important technical CSF that emerges from the literature is the communication between the pilot and the drone; if this is interrupted, it is a risk that the drone will crash (Chitta & Jain, 2017). Of course, this is only true until drones are allowed to fly entirely autonomously, since from this moment on no pilot will be needed. About the energy source and type of batteries the first CSF is, that airplane fuel is seen critical in Germany, as it has been the subject of critical discussion in Germany for some years now, and the introduction of an additional kerosene tax has already been considered due to the high CO_2 emissions (Weihe & Knoll, 2015).

Pitzl (2010) highlights that this reason encouraged the search for alternative energy sources due to the rising cost of fuel. Furthermore, the battery cells increase cost and weight of the transport drones (Boukoberine, Zhou, & Benbouzid, 2019) what also influences the flight duration, as more transported weight needs more energy. In addition to that fuel- and solar cells are very expensive and therefore rarely used, as the high cost compared to other energy sources limits the technical feasibility enormously (Afshar & Frank, 2020; Keidel, 2010). Vergouw et al. (2016) mentions that low efficiency is a reason why fuel & solar cells are used less often than other battery types.

Based on the theoretical background provided, all findings that will be integrated in the conceptual model for technical CSFs of drones are presented on Table 3, Code: A (Appendix).

Legal critical success factors - In the following legal CSFs from the legal situation in Germany regarding transport drones will be described. Only the most important points of the regulation are discussed here, since it only concerns drones that are used commercially.

The introduction of the EU Drone Regulation on 31.12.2020 regulates the legal situation for the European area, but also for the European Free Trade Association states: Norway, Iceland, Liechtenstein and Switzerland. Each member state must designate one or more bodies as the competent authority for regulating drone flights (Stritzinger, 2021). In Germany, this is the Deutsche Flugsicherung (DFS), the authority for German air traffic control (Keicher, Rauber, Schwarz, & Brunner, 2021).

According to the European Union Aviation Safety Agency (EASA), which drafted the laws for the EU drone regulation, the following tasks presented on Table 3, Code: B (Appendix) apply to the respective authority.

The category under which pilot-operated, but also semi-autonomous and autonomous delivery drones are to be classified according to the EU Drone Regulation, are called “certified” by the EU in the legal text. Unmanned aerial vehicle operations in the “certified” category include at least one of the following facts that are presented on Table 3, Code: C (Appendix).

Member states must establish accurate registration systems, which have to include the following components, which are shown in Table 3, Code: D (Appendix).

All points on Table 3, Code: E (Appendix) can have an impact on the commercial use of transport drones and influence any route guidance, control by pilots, or otherwise. These findings result from the German law.

2.2. AGV: solutions and critical success factors

AGVs are vehicles that can drive with ground contact and without human assistance (Luettel, Himmelsbach, & Wuensche, 2012; Perrinaud & Saraceni, 2022), thus they can be classified as driverless transport systems (DTS).

AGV have been used in the past for ground operations by the military and others. However, this research is about AGV with parcel-lockers, which play a role in last-mile delivery of the supply chain, and are autonomously used for consumers to pick up their parcels from a mobile parcel-locker (Kassai, Azmat, & Kummer, 2020). LSPs have rarely used autonomous vehicles until now, but the development. Also the acceptance is increasing steadily.

The previously described driver shortage in the logistics market (Ptock, 2018) can be circumvented by using AGVs, as it does not require a driver (Luettel et al., 2012; Ptock, 2018). It also eliminates the associated labor costs for personnel. However, Joerss et al., highlights that a study by McKinsey in 2016 found that the cost share can only be guaranteed if the driver’s salary is between €10 and €12 per hour. This is because the purchase of the AGV and the energy consumption due to autonomy offset the personnel costs that are eliminated (Joerss, Schröder, Neuhaus, Klink, & Mann, 2016). However, there is also the advantage in semi-autonomous driving that a driver on board, even if not actively driving the vehicle, can perform other tasks such as customer service, or sorting packages (Ritz, 2018). With the elimination of driving, driver training also becomes redundant, which in turn can save further costs. The lack of a driver also renders legal requirements for driving and rest times ineffective, meaning longer delivery windows and thus more service for customers (Disruption, 2016).

Furthermore, autonomous driving systems prevent human errors that could, for example, lead to accidents and thus to delivery delays, but also human damage (Piao et al., 2016). This, in turn, also leads to lower insurance costs for AGVs than for conventional delivery trucks (Geistfeld, 2017). Operational delays due to parking and searching for parking spaces in densely populated areas are also eliminated, as the delivery interaction is controlled by the customer picking up the package independently (Disruption, 2016). Another positive aspect is the impact on payload, as more can be loaded without a driver (Joerss et al., 2016), but this primarily applies to heavy goods, as classic delivery trucks tend to carry bulky packages and comparatively little weight (Haase & Hoppe, 2008). Piao et al. (2016) also note that AGVs bring reduced fuel costs and CO_2 emissions, similar to the transport drones previously described. Thus, the use of AGVs also has a positive impact on sustainability and can therefore improve Corporate Social Responsibility reports of LSPs (Johnson, 2014).

Technical Solutions - In order for an AGV to orient itself and operate autonomously, various sensors and systems are used for navigation. Sensors include light detection and ranging (LIDAR), GPS, radar, vision, and ultrasonic (Babak, Hussain, Karakas, & Cetin, 2017). LIDAR is a technique that uses sensors to measure a distance between the AGV and external objects.

GPS (global positioning system) is based on satellites that continuously broadcast the current position of the object with radio signals. Radar can measure the relative distance, velocity, and orientation of the object (Babak et al., 2017). Vision sensors are image-processing systems that are programmed and optimized using artificial intelligence. Ultrasonic sensors work comparable to the lidar technique.

The last point to mention about the technologies of AGV are the sources of energy. Roughly, the energy sources can be divided into fuels (gasoline, diesel, gas) for internal combustion engines and electricity for electric motors. The type of local (e.g. battery, or tank) and stationary (e.g. charging station, or gas station) energy storage also depends on this energy source (Haberfellner, 2014). Iris and Lam (2019) found that AGVs predominantly use diesel or electricity as an energy source. In both cases, the vehicle relies on charging or refueling stations (Haberfellner, 2014). The report from Wietschel, Kühnbach and Rüdiger (2019) indicated the studied CO_2 emissions in grams per kilometer (km). Here, electric vehicles scored 134 g per km, well ahead of diesel (159 g per km) and gasoline (183 g per km). For 2025, a further reduction of up to 101 g per km is predicted (Wietschel, Kühnbach, & Rüdiger, 2019).

Technical Critical success factors - The described detection techniques are essential to ensure safe navigation and also detect and avoid obstacles (Babak et al., 2017). If the systems are equipped with lower light intensity due to insufficient energy, for example, this safety is not given, as the autonomous driving system could fail in this case (Iris & Lam, 2019). Respondents in the Piao et al. (2016), what underlines the importance of technical CSFs regarding safety, perceived safety issues such as system failures as the biggest concern regarding AGV technology.

Electricity propulsion also limits the travel time of AGV compared to conventional delivery trucks (Pakusch, Stevens, Boden, & Bossauer, 2018). To ensure onward travel and recharging it needs a suitable infrastructure of charging stations, which can be a hurdle for LSPs in terms of onward travel (Pagani, Colling, & Furmans, 2018). The fact that this charging also works autonomously is currently still viewed critically (Bechtsis, Tsolakis, Vlachos, & Iakovou, 2017).

In addition, employees are needed to intervene in the event of breakdowns and make the vehicle drive again. Getting these employees to the vehicle that has broken down requires further effort for service providers (Pagani et al., 2018). This required maintenance for AGV is different for drone-delivery where maintenance costs are low as there is no need to maintain a drone-network like a road-network, which needs regular maintenance (Raj & Sah, 2019). System Security is another important technological aspect, as the vehicle technology must be protected from hackers to ensure safe autonomous vehicle driving (Sarder & Haschak, 2019), because the hackers could not only take control of the vehicle, but also steal data and manipulate the equipment (Sarder & Haschak, 2019).

Furthermore, a customer needs a smartphone and a code to pick up his parcel from the parcel-locker what implies customer readiness. If the opening of the door does not work due to a sensor malfunction, for example, the customer cannot pick up his parcel (Hepp, 2018). Consumers without a code or smartphone to open the locker could also not use this service. Also concerning the energy source there are some CSFs: Ajanovic and Haas (2019) compared the CO_2 emissions from the production of conventional and battery-powered electric vehicles and found that the emissions from the production of batteries for electric vehicles are higher than for conventional vehicles.

Type and size of battery used for production of electric vehicles have high impact on the material used and manufacturing emissions (Hao, Mu, Jiang, Liu, & Zhao, 2017), which has an additional negative impact on the sustainability of battery use. All findings from the literature review about the technical CSFs of AGV that will be integrated in the conceptual model can be found in Table 4, Code: F (Appendix).

Legal Critical success factors - Since AGVs technically belong to conventional delivery vehicles and the technology with parcel-lockers is already used in Germany (Vastag & Schellert, 2020), only the topic of autonomous driving will be discussed below, as this is to be seen as a CSF to the introduction of AGVs in Germany. The Road Traffic Act creates the legal basis of the laws in Germany regarding road traffic. The latest amendment to the law by Article 3 dates from November 26, 2020 and is defined in more detail below with regard to autonomous driving.

Table 4, Code: G (Appendix) shows all autonomous driving functions that are defined as follows for the purposes of the Road Traffic Act (2020) in Germany. Code: H presents all points that are relevant to the possible use of AGV and defined from the Road Traffic Act in Germany. The motor vehicle with autonomous driving function must ensure these points.

Principally, all the points listed refer to level 4 of autonomous driving (driver on board). The Road Traffic Regulation Authority will re-evaluate the legislative changes enacted in 2020 at the end of 2023 (Road Traffic Regulation, 2020). In the current situation until 2022 the general legal situation in Germany completely prohibits fully autonomous transport (level 5) (Schmoch, Beckert, Reiß, Neuhäusler, & Rothengatter, 2020; Zeh, 2019). These regulations, also the solution and technical CSFs approached in this research provides the basis to the theoretical framework of this research and can be summarized in a research structure.

2.3. Summary of findings

After the identified solutions and CSFs presented in the previous sections, this part makes an overview of the most important CSFs legally but also of technical nature. In respect of safety matter, we had considered "security of the parcel" and "physical space at delivery place" as CSF during the research design process. However, evidence from revised literature were not sufficient to frame "security of the parcel" and "physical space at delivery place". Thus, it would lay out of this research scope. For this reason, we take the approach of directly CSF impact on the "technological device" adoption, and not including indirect Technical and Legal CSF, to prevent broadening the focus. In this sense, we can argue that the Technical and Legal CSF directly associated to the technological device is our unit of analysis, but not security in surrounds of delivery area, nor the requirement of physical space at delivery place. Table 1 provides an overview of all findings and authors

Table 1
Theoretical framework of technical and legal critical success factors of drones & AGV.

	LEGAL BARRIERS		TECHNICAL BARRIERS	
DRONES	LD1 **No-fly zone**	maximum height set at 120 m above the ground (DFS, 2021) **(E1)**	**TD1 Operational capability**	Battery Life reduces flight duration (Anbaroğlu, 2017) **(A1)**
		flying out of sight of pilot is prohibited (DFS, 2021) **(E2)**		Small Payload reduces flight duration and weight of packages (Agatz et al., 2018) **(A2)**
		No flying at bad weather conditions (EASA, 2020) **(E3)**		Other objects in the airspace (risk of collision) (Dalamagkidis et al., 2008) **(A3)**
		No directly flying over residential properties, nature reserves (DFS, 2021) **(E4)**	**TD2 Operational security**	GPS techniques (satellite needs connection) (Roeckerath, Frank, & Hattebuhr, 2015) **(A4)**
		No flying in a radius of 1,5 km directly flying over airfields (DFS, 2021) **(E4)**		Sensor techniques (weather conditions affect security) (Hallermann & Morgenthal, 2013) **(A5)**
		at least 100 m safety distance from hospitals & highways (DFS, 2021) **(E5)**		Air flight control (communication between pilot and drone has to be ensured) (Chitta & Jain, 2017) **(A6)**
	LD2 Pilot quality	flyer license for drone pilots is needed (EASA, 2020) **(E7)**	**TD3 System security**	Hacker might control the flight control system (Yaacoub & Salman, 2020) **(A7)**
		issurance for drone pilots is needed (EASA, 2020) **(D3, E6)**		Airplaine fuel is seen critical in Germany (Weihe & Knoll, 2015) **(A8)**
			TD4 Energy source	Battecy cells increase costs and weight of drones (Boukoberine et al., 2019) **(A9)**
	LD3 Documentation of operations	documentation of flights (EASA, 2020) **(B3,B4)**		Fuel & solar cells are very expensive and therefore rarely used (Afshar & Frank, 2020; Keidel, 2010) **(A10)**
			TD5 Recharging	Without mobile recharging stations like a truck recharging becomes a technical barrier (Gabani et al., 2021) **(A11)**
AGV	**LA1 System quality**	ensure secure radio & GPS connections (road traffic act Germany, 2020) **(G1,G2,H3)**	**TA1 Operational capability**	GPS techniques (satellite needs connection) (Babak et al., 2017) **(F1)**
		technical equipment of the AGV needs certification (road traffic act Germany, 2020) **(G1,G2)**		Electricity propulsion limits the travel time (Pakusch et al., 2018) **(F2)**
	LA2 Driving ban	at any time technical supervisor (human) is needed (road traffic act Germany, 2020) **(H2)**	**TA2 Operational security**	light intensity due to insufficient energy (Iris & Lam, 2019) **(F3)**
		level 5 of autonomous driving is not allowed (road traffic act Germany, 2020) **(H2,H6)**	**TA3 System security**	System Security to protect from hackers (Sarder & Haschak, 2019) **(F8)**
			TA4 Energy source	battery production increases Co^2 emission (Ajanovic & Haas, 2019) **(F10)**
				autonomous recharging process is seen critical (Bechtsis et al., 2017) **(F4)**
	LA3 Documentation of operations	all operational data has to be secured (road traffic act Germany, 2020) **(H5)**	**TA5 Recharging**	Missing infrastructure of recharging stations (Pagani et al., 2018) **(F6)**
				AGV needs regularly recharging independent from energy source (Haberfellner, 2014) **(F5)**
			TA6 Maintenance	breakdowns need to be managed by employees or technical experts (Pagani et al., 2018) **(F7)**
			TA7 Customer Readiness	customer needs a smartphone to unlock the parcel-locker (Hepp, 2018) **(F10)**

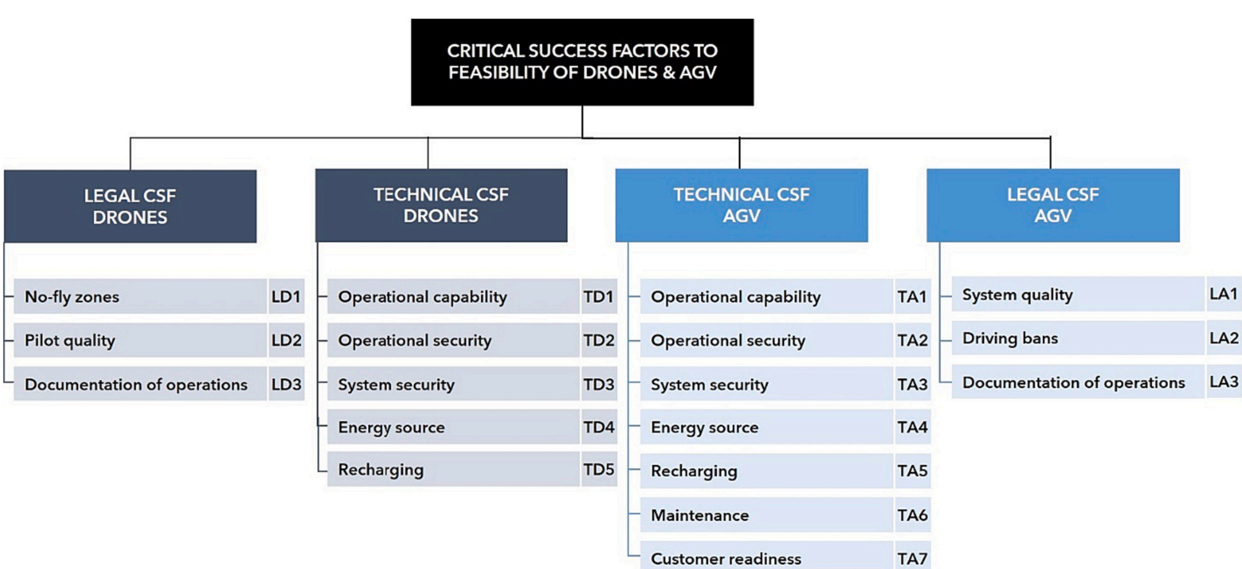

Fig. 1. Conceptual model: LD stands for legal CSFs for drones, TD for technical CSFs for drones, while TA stands for technical CSFs for AGV and LA for legal CSFs for AGV.

as well as the codes from tables, which were showed earlier in the literature review. In this way, the origin of the respective CSF can be traced and the reader can also find it in the respective section. Those codes are input for the categories of the conceptual model on Fig. 1 and final rankings of the Analytical Hierarchy Process (AHP) in the following.

The conceptual model is showed on Fig. 1 and will be tested later using the AHP from Thomas Saaty (1980). In combination, Fig. 1 and Table 1 are the base to assign each CSF and respective sub-factors from the category.

The literature review shed light on varying aspects related to drones and AGVs respectively, which we then classified into technical and legal CSFs for each technology. It was interesting to note that the legal CSFs for drones and AGVs are similar to a great extent, but more importantly, that AGVs are currently associated with more technical CSFs than drones. It can be evidenced that some CSFs are currently in direct conflict with the benefits associated with drone and AGV technology. One major advantage of both technologies is that the driver required can be eliminated based on design. However, existing regulation negate this option in real-life applications, and consequently the potential of drones and AGVs to stand as a solution that can address driver shortage and minimise labour costs. Similarly, a prohibition of flying over residential areas fly-zones could restrict the potential of drones to access densely populated city areas. Contingent on permitted fly-zones, congestion in airspace could also emerge as a problem. Given the aforementioned, we have decided to validate those findings with supply chain and legal experts, using semi-structured interviews to acquire relevant insights.

3. Methodology

First, the technical and legal CSFs of AGV and drones found in the literature were reviewed. The next methodological steps are shown on Fig. 2. The result from the literature review were extended using semi-structured interviews together with experts from the supply chain and logistics industry and lawyers for traffic law to ensure that no essential CSFs to the feasibility of these technologies were left out.

To test the conceptual model with the help of experts from this field, data was collected by developing and sending out AHP decision matrices for an assessment. These matrices and related decision criteria were created and analyzed with the survey tool "Qualtrics". For these comparisons, respondents were asked to weight the relationships comparing the CSFs to the adoption of drones and the same procedure to compare the CSFs to the adoption of AGV. Both procedures were analyzed using the analytic hierarchy process (Saaty, 2008) in the following. This process is suitable for ranking sequence of different criteria related to a complex problem by using a pairwise comparison matrix (Sari, Kandemir, Ceylan, & Gül, 2020). After the weights were approved, the consistency of the pairwise comparisons were checked. If the weights were consistent, the final rankings of all investigated CSFs and results, discussion and conclusions followed.

In this study, all weights were consistent, so no optimization techniques had to be applied.

3.1. Expert interviews

In total two semi-structured expert interviews were conducted with organizations based in Germany. All interviews were completed by telephone, or by videoconference via the platform "Zoom", as the COVID-19 restrictions did not allow face-to-face interviews. Together with the interviewees, the results of the literature review were discussed, and any additional information was elicited, as well as previously described CSFs were reviewed before being incorporated into the

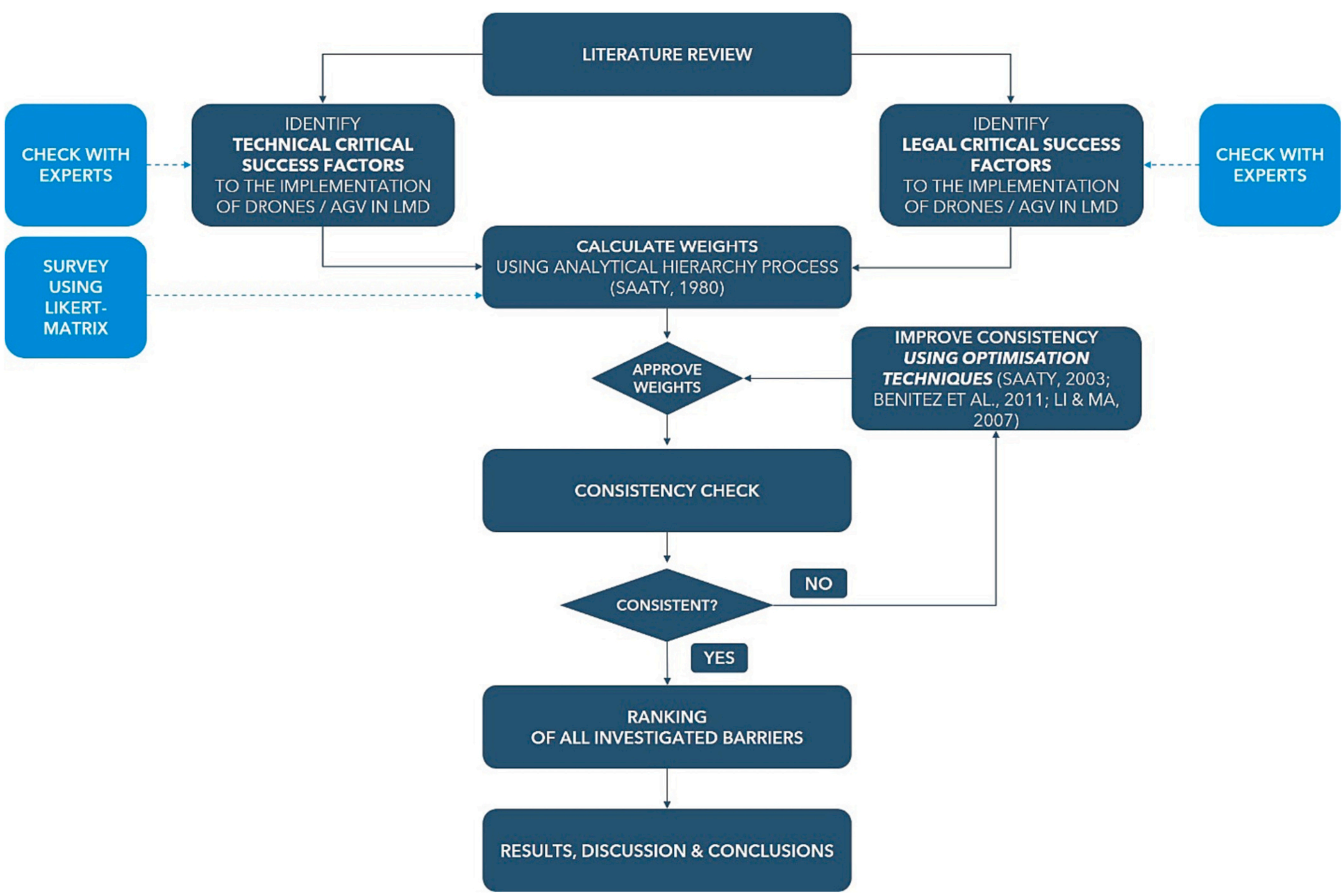

Fig. 2. Flowchart methodology.

conceptual model and the AHP matrices.

Taking into account the research limitations, we intended to narrow down the reasoning into a Ceteris paribus approach. Thus, the cutting-edge of this research lies in understanding the practitioners' perspective. Even though public authorities play a key role in the implementation phase of these new options for package delivery, we focused to understand the perspective from practitioner's point of view. At a future research, the perspective of public sector and authorities should be investigated.

3.2. Sample and data characteristics

The AHP assessment matrices were disseminated using non-probability-convenience sampling (which means that the author independently selects the respondents to ensure that the respective profile fits the requirements of the research questions) to organizations based or with operate divisions in Germany (Bagla & Khan, 2017).

Two AHP assessment matrices, one for drones and one separate for AGV were sent to relevant employees and experts in logistics and supply chain field, related to transportation in the first instance. In the second instance, companies related to the development of technology of drones and AGV were contacted. To expand this sample, all contacted companies were encouraged to share the survey with their business partners from the logistics and supply chain sector, which increased the number of participants comparable to the principle of snowball sampling from Goodman (1961). Furthermore, various experts were contacted via the portal "LinkedIn" to increase the survey's reach.

3.3. Data collection

After the qualitative expansion of AGV and drone CSFs was completed in the form of semi-structured interviews, the sample group described in *Sample and Data characteristics* was contacted and asked to participate in the AHP assessment. In total, data was collected from 05/25/2021 to 06/18/2021 and 211 companies and employees were contacted, resulting in 39 completed surveys for drones and 38 surveys for AGV.

3.3.1. Survey design

Along with the survey links, respondents who consented to participate were also sent an instruction sheet for the AHP assessment, and were asked about knowledge of transportation drones and AGV to ensure that the respondent is familiar with the subject of the AHP assessment.

Respondents are asked for some details about themselves and the company. Information about their job experience should be provided in order to be able to assess experience in operations, as well as information about the annual turnover of the company, as it is assumed that companies would only consider innovation in the form of drones or AGVs for their operations once they have reached a certain annual turnover. Various CSFs of a technical and legal nature are each divided into paired comparisons. With the help of a Likert matrix containing 18 decision points (Appendix A), the weighting of two criteria each can be made.

3.3.2. Interview guide

Figure 5 (Appendix) shows three examples from the survey for the pairwise comparison of the Likert matrix, which is the input for Saaty's (1980) AHP method. The principle of pairwise comparison is done with the fundamental scale of absolute numbers from Thomas Saaty (1980) shown in Fig. 6 (Appendix). To first give the participant a sense of the different main criteria, the sub-criteria of these are compared first. This, because criteria elements can be extensively deconstructed into sub-criteria and beyond, depending on the complexity of the problem. A particular factor might not be universally applicable, but rather exhibit varying degrees of importance. Consequently, the given criteria is then subdivided into sub-criteria that signify different levels of intensity for that particular criterion. Thus, each criterion is compared in turn, resulting in a total of 55 pairwise comparisons for transportation drones and 46 pairwise comparisons for AGV.

The criteria and sub-criteria of legal and technical CSF, both for drone and AGVs, were included in the weighting procedure based on the findings and authors which were presented in the literature review and coded on Table 1. In this way, the origin of the respective CSF can be traced based in the aforementioned literature revision procedure. The codes (Fig. 1) are inputs for the categories of the conceptual model and final rankings of the AHP.

This decision between sub-criteria is incorporated into the weighting of the main category "operational capability", which is later compared in pairs with other main criteria such as system safety or the energy source of drones. That was also done for AGV but in the second survey to ensure that CSFs of drones are not compared to AGV and vice versa.

3.3.3. Data cleaning

Before the results are recorded and included in the AHP calculation, the data sets must be cleaned (Arani, Abdolmaleki, Maleki, Momenitabar, & Liu, 2021; Goldsmith et al., 2021). Thus, all records where the respondent indicated no knowledge of transport drones, and or AGV were removed. Furthermore, all datasets from the AHP assessment that were not completed in full to the end were removed. Records in which respondents forgot to state their position, or company, for example, were retained. In total, 26 records had to be deleted because they could not be used.

4. Results and discussion

In the following chapter, the results of the assessment develop in this research are presented. First, the distribution of the respondents is shown, each for the decision matrices for drones, as well as AGV before the results are presented in each case. Subsequently, the weighting of the criteria is shown and analyzed with reference to the respondents to highlight any special patterns.

4.1. Results and analysis: findings from literature and interviews

In one of the expert interviews conducted for this study, MSc. Maximilian Schellert (expert for logistics and supply chain management - Fraunhofer Institute) said, "that the technology is presumably further along than the legal situation in Germany". This statement is underlined by the current legal situation in Germany, which makes operations for drones and AGVs completely impossible. For example, fully autonomous driving of level 5 is prohibited in Germany (Table 4, Appendix), which means that any savings for personnel costs could not be realized, although these account for an enormously high proportion of the costs of last-mile delivery (Allen et al., 2018; Humphreys et al., 2020).

With the help of the interviews, the findings from the literature review were validated and enhanced in some places. The results and findings of both expert interviews are presented in Table 5 (Appendix).

Some new insights (shown in italics) emerged from the interviews conducted, which enhance the literature review. The first finding is the loudness of drones, which negatively affects social acceptance, but also that the long-term tests in Germany which are the basis for possible changes in the law. During these long-term tests, potential customers might perceive the loudness of drones as a CSF. Loudness is therefore seen as a technical element and thus a technical CSF.

However, technical solutions could help to make the drones quieter, which in turn could positively influence social acceptance and thus feasibility. The second finding resulted from Interview B. It was found out that every company needs a special insurance according to the German goods transportation act. Nevertheless, this insurance is needed in any case, even without the use of drones or AGVs, which is why this finding is not additionally included in the conceptual model, as it does not influence the feasibility of drones or AGVs. Fig. 7 (see Appendix) shows the new conceptual model with the extension of the CSF regarding the loudness of drones, which is shown in pink.

Due to time constraints, this newly revealed CSF could not be included in the AHP assessment, as data collection had already started and thus not all participants included the loudness of drones in the weighting of the criteria. However, it is an important highlight for decision-makers and solution providers to consider in the implementation of this new technology.

Torija, Li, and Self (2020) assessed single transport drones delivery loudness and have found out, that customers perceived the loudness of drones especially in urban areas as enormously disturbing. To increase customer acceptance of this delivery solution, the technology to regulate the loudness of drones would accordingly be helpful for LSPs. From this fact results that UAV loudness can generally be considered a CSF for transportation drone implementation.

4.2. Results and analysis: analytical hierarchy process assessment

In this section, the results of the AHP (Saaty, 1980) are shown. Experts from the logistics and supply chain industry, as well as technical developers and traffic law experts were asked which CSFs are most likely to be perceived as restrictive in order to highlight the prioritization of these CSFs.

4.2.1. Respondents and calculation

The AHP assessment calculations performed follow the scheme given by process owner Thomas Saaty (1980). Using the geometric mean, all pairwise comparisons were first calculated before direct and inverse comparisons were tested using consistency checks. The literature describes that the consistency ratio of pairwise comparisons is reliable if C.R. < 0.10 (Kumar & Gupta, 2020; Saaty, 1980). If C.R. > 0.10, the pairwise comparisons should be re-evaluated due to inconsistencies (Arumi, Setiawan, & Primadewi, 2020; Kumar & Gupta, 2020; Qarnain, Sattanatha, & Sankaranarayanan, 2020). Full details of calculations and formulas applied can be found in Appendix B.

4.3. Results AGV

Figure 3 shows the pairwise comparison of all main CSFs from the conceptual model for AGV, which are included in the weighting of the CSFs.

The tables of all sub-factor comparisons for AGV, which are included in the AHP decision matrix, can be found in Appendix C.

Finally, regarding the results of the calculations for AGV, table 6 (see Appendix C) shows the consistency checks of the AHP assessment. All decision matrices contain consistent pairwise comparisons as the consistency ratio is <0.10 (Arumi et al., 2020; Kumar & Gupta, 2020; Qarnain et al., 2020; Saaty, 1980).

Table 7 (see Appendix C) shows the relative importance, local and global weights, as well as the final ranking for the AHP results for AGV.

4.3.1. Data analysis AHP assessment and discussion on AGV

With reference to the demographics of the respondents, the results of the AHP assessments are now analyzed for AGV.

One of the striking features of the data analysis was that forwarding dispatchers placed particular emphasis on Operational Performance and, contrary to the overall results, less emphasis on Operational Safety. Thus, dispatchers perceived both criteria to be of roughly equal importance, while the overall results reflected a rating of (4) for Operational Safety and (1/4) for Operational Performance. Further, general managers of forwarding companies perceived driving bans to be more restrictive compared to operational performance (1/6) with an average of (6), while dispatchers rated at a comparison of (3) for driving bans and (1/3) for operational performance. General managers also gave higher importance to operational safety (6) compared to operational performance (1/6). The reason for the increased assessed importance of operational performance of AGV by forwarding dispatchers could be, for example, that operational performance influences the daily work of dispatchers rather than operational safety (Mertin, 2021; Meyer & Hansen, 2019). The fact that general managers of LSPs are more likely than dispatchers to perceive driving bans as important as operational performance, and operational safety in turn more likely than operational performance is presumably due to the fact that general managers are more likely to see the big picture of technology adoption. In addition, general managers are more likely than dispatchers to make strategically significant long-term decisions (Crossan, Fry, & Killing, 2004; De Giovanni, 2009; Storey, 2002).

4.4. Results drones

Figure 4 shows the pairwise comparison of all main CSFs from the conceptual model for drones. The tables of all sub-factor comparisons for drones that are included in the AHP decision matrix can be found in Appendix D.

As with the AGV calculations, a consistency check was performed for

CRITERIA COMPARISON	Operational Capability	Operations Security	Re-charging	Main-tenance	System Security	Energy Source	Customer Readiness	driving bans	System Quality	Documentation of operations
Operational Capability	1	$\frac{1}{4}$	1	4	1	2	2	$\frac{1}{4}$	$\frac{1}{2}$	6
Operations Security	4	1	2	7	4	5	4	4	3	7
Recharging	1	$\frac{1}{2}$	1	4	$\frac{1}{3}$	5	5	$\frac{1}{2}$	$\frac{1}{2}$	3
Maintenance	$\frac{1}{4}$	$\frac{1}{7}$	$\frac{1}{4}$	1	$\frac{1}{3}$	$\frac{1}{2}$	1	$\frac{1}{3}$	$\frac{1}{4}$	2
System Security	1	$\frac{1}{4}$	3	3	1	2	2	$\frac{1}{2}$	2	7
Energy Source	$\frac{1}{2}$	$\frac{1}{5}$	$\frac{1}{4}$	2	$\frac{1}{2}$	1	4	$\frac{1}{5}$	2	4
Customer Readiness	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{5}$	1	$\frac{1}{4}$	$\frac{1}{2}$	1	$\frac{1}{5}$	$\frac{1}{4}$	3
driving bans	4	$\frac{1}{4}$	2	3	2	5	5	1	3	8
System Quality	2	$\frac{1}{3}$	2	4	$\frac{1}{2}$	$\frac{1}{2}$	4	$\frac{1}{3}$	1	2
Documentation of operations	$\frac{1}{6}$	$\frac{1}{7}$	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{1}{7}$	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{1}{8}$	$\frac{1}{2}$	1

Fig. 3. Main criteria AHP (AGV).

CRITERIA COMPARISON	NO-FLY ZONES	PILOT QUALIT Y	DOCUMENTATIO N OF OPERATIONS	OPERARATION S CAPABILITY	OPERATIONS SECURITY	SYSTEM SECURIT Y	ENERG Y SOURC E	RE-CHARGIN G
NO-FLY ZONES (LD1)	1	3	5	3	$\frac{1}{4}$	$\frac{1}{4}$	3	3
PILOT QUALITY (LD2)	$\frac{1}{3}$	1	4	2	$\frac{1}{4}$	$\frac{1}{3}$	3	1
DOCUMENTATIO N OF OPERATIONS (LD3)	$\frac{1}{5}$	$\frac{1}{4}$	1	$\frac{1}{3}$	$\frac{1}{7}$	$\frac{1}{5}$	$\frac{1}{3}$	$\frac{1}{3}$
OPERARATIONS CAPABILITY (TD1)	$\frac{1}{3}$	$\frac{1}{2}$	3	1	$\frac{1}{3}$	$\frac{1}{3}$	4	2
OPERATIONS SECURITY (TD2)	4	4	7	3	1	3	4	4
SYSTEM SECURITY (TD3)	4	3	5	3	$\frac{1}{3}$	1	4	3
ENERGY SOURCE (TD4)	$\frac{1}{3}$	$\frac{1}{3}$	3	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	1	3
RECHARGING (TD5)	$\frac{1}{3}$	1	3	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{6}$	$\frac{1}{3}$	1

Fig. 4. Main Criteria AHP (Drones).

the drone decision matrices. These results prove the consistency of the pairwise comparisons after the consistency ratio is <0.10 in present cases (Arumi et al., 2020; Kumar & Gupta, 2020; Qarnain et al., 2020; Saaty, 2003; Saaty, 1980). Table 8 (see Appendix D) provides information about the results of these consistency checks.

The ranking below shows the weighting of the experts surveyed on the CSFs to drones. As in the case of AGV, relative importance, local and global weights, and the final ranking can be retrieved from Table 2.

4.4.1. *Data analysis AHP assessment and discussion on drones*

The results for drones show similar characteristics as for previous described results of AGV. Operational hurdles such as no-fly zones (visual contact with the pilot, overflight prohibitions and distance requirements) are rated by dispatchers with an average of (6) compared to other criteria. In the overall ranking, however, the no-fly zones only get a rating of (3). Moreover, while the overall ranking rates pilot quality over operational performance at a (2), forwarding dispatchers rated

Table 2
Final ranking drones.

Main criteria	Relative importance	SUB-criteria/descrition	Local weight	Global weight	Ranking
System Security **(TD3)**	0.21	System must be protected from hackers	0.21	0.209	1
Operations Security **(TD2)**	0.31	Other objects in the airspace (risk of collision)	0.57	0.016	2
Pilot Quality **(LD2)**	0.09	Flyer license for pilot is needed	0.75	0.233	3
Operations Capability **(TD1)**	0.09	Small payload reduces flight duration & weight of packages	0.67	0.206	4
Operations Security **(TD2)**	0.31	Sensor techniques (bad weather conditions)	0.21	0.005	5
Recharging **(TD5)**	0.05	Mobile recharging stations are needed	0.05	0.055	6
Operations Security **(TD2)**	0.31	Air flight control system (communication pilot & drone)	0.14	0.004	7
No-fly zones **(LD1)**	0.15	Pilot need eye contact with drones	0.26	0.054	8
No-fly zones **(LD1)**	0.15	No flying when bad weather conditions	0.24	0.049	9
Operations Security **(TD2)**	0.31	GPS techniques (satellites need connection)	0.10	0.003	10
Operations Capability **(TD2)**	0.09	Battery life reduces flight duration	0.33	0.103	11
Documentation of Operations **(LD3)**	0.03	Documentation of all flights is needed	0.03	0.027	12
Energy Source **(TD4)**	0.07	Airplane fuel is seen critical in Germany	0.40	0.060	13
Energy Source **(TD4)**	0.07	Battery cells increase costs and weight of drones	0.40	0.060	14
No-fly zones **(LD1)**	0.15	No flying over residential properties and nature reserves	0.17	0.036	15
Pilot Quality **(LD2)**	0.09	Insurance for drone pilot is needed	0.25	0.078	16
No-fly zones **(LD1)**	0.15	No flying in a radius of 1.5 km over airfields	0.15	0.030	17
No-fly zones **(LD1)**	0.15	At least 100 m safety distance from hospitals and highways	0.11	0.024	18
Energy source **(TD4)**	0.07	Fuel & solar cells are very expensive and therefore rarely used	0.20	0.030	19
No-fly zones **(LD1)**	0.15	Maximum height (120 m)	0.07	0.016	20

pilot quality at an average of a (4.5), thus as about twice as important. This is logical, as these prohibitions have an extreme impact on the daily dispatching work of the dispatchers. Both no-fly zones and mandatory eye contact with the pilot complicate operations from the respondents' point of view. The latter aspect also means that any savings in personnel costs cannot be claimed by LSPs.

4.5. Summary of results and discussion

The results of this study clearly show that the aspect of security is the most likely to be perceived as restrictive by the experts, thus Operations Security and System Security land on the 1st and 2nd place for the AHP ranking of AGV, respectively of drones (see Appendix, Table 9). The possibility that this technology is not 100% secure or, for example, that hackers have control of the vehicle or drone is obviously a deterrent for the group of experts surveyed. This is presumably also due to the fact that no long-term tests with drones and AGVs have been conducted in Germany (Cohort, 2016; Kouroutakis, 2020) and no representative statistics on safety are available. Thus, it could also not be proven that perceived safety risks may have no influence at all on operational or system safety.

Nevertheless, the study shows that perceived safety lags behind from an expert perspective on these technologies. If their safety cannot be guaranteed at least on par with conventional delivery methods, this will have an increasingly negative impact on legislation (Kim, Joung, Jeong, & Park, 2020; Kirillova, Shavaev, Wenqi, Huiting, & Suyu, 2020). Drone operations are also entirely impossible, with no-fly zones and laws alone leading to enormous restrictions (see Appendix, Table 3). This makes it very difficult for dispatchers to plan efficient routes if, for i.e., private property and highways are not allowed to be flown over. The penetration potential of drones also suffers enormously from these laws, as it is an important indicator of the potential of a means of transport (Fraedrich et al., 2017).

As in the case of AGVs, the personnel costs saved by technology are also null and void for drones due to the legal situation; in Germany, for example, one pilot per drone is mandatory (see Appendix, Table 3). This is clearly too unattractive for LSPs due to the personnel cost factor, as a drone can also only transport one package and a conventional delivery driver with an average delivery truck brings between 200 and 250 packages on his route to the customer (Straube, Grunow, Ihlenburg, & Sinn, 2021).

In general, the legal restrictions in Germany show the lack of openness to innovative technologies in road and air transport. In this case, it would also be an opportunity to reveal a potential source of revenue to the legislator. Similar to road haulage, the urban area for AGVs or the airspace for drones could be taxed with tolls. Thus, the legislature would also generate revenue with the introduction of these technologies, the truck toll brought Germany a total of 4.3 billion euros in revenue in the last 5 years (Puls, 2020).

Furthermore, the results of the AHP rankings show some peculiarities: The experts rank the mandatory 100-m safety distance to freeways 18th out of 20 CSFs, even though Germany has a very dense network of freeways and national roads (Strewe & Kamphausen, 1995), making route planning enormously difficult for dispatchers. The fact that security risks such as protection against hackers (1st place) or other objects in the airspace and possible collisions (2nd place) are at the top of the ranking is hardly surprising, since no LSP could use drones in operations in the long term without ensuring security. In the AHP assessment for AGVs, it is astonishing that the legislation requiring a driver is only ranked eighth out of 15. This fact turns an autonomous vehicle into a manned one, rendering all advantages such as savings in personnel costs or extended driving time due to the elimination of driving and rest periods null and void. Before the criteria were evaluated, these points suggested a higher ranking. The fact that the two aspects "regular recharging" and "limited driving time due to electric drive" end up in the last two places (14 and 15) can be explained as follows: Even conventional vehicles do not have an infinite driving time, as they have to refuel regularly.

5. Conclusion

This research archived the main goal by answering the research question "***To what extent do technical and legal critical success factors influence the feasibility of the usage of drones and AGV for last-mile-delivery?"***, taken a combined approach. An in-deep literature review and interviews were made to identify important element of the feasibility of the new technologies, followed by the model development and an AHP-assessment to evaluate technical and legal CSFs.

This study ranks legal and technical CSFs of drones and AGV according to their relative importance using an AHP (Saaty, 1980). For this purpose, 77 experts from logistics and supply chain companies were asked to rank uncovered CSFs according to the degree of restriction for the introduction of drones and AGV according to their relative importance. The evaluated rankings clearly show that aspects of System Security, but also Operational Security for drones and AGV are perceived as most important element to be considered to the implementation of the technology.

5.1. Theoretical implications

The results of this research show some theoretical implications for supply chain management with focus on last-mile-delivery, but also for general delivery logistics with focus on Germany. The literature so far provides some studies on CSFs of technologies and also those of the introduction of drones and AGV. However, these studies tend to be generalist in nature and focus on a variety of different CSFs (Abiodun, 2021; Bergsma, 2021; Kellermann & Fischer, 2020; Sah, Gupta, & Bani-Hani, 2020; Kristoffersson & Pernestål Brenden, 2018), while this study goes deeper into two specific types of CSFs with technical and legal CSFs. Not only does this study point out which laws are perceived as CSFs to the adoption and use of drone and AGV technology, but it also provides a ranking of which laws are most likely to be perceived as restrictive in relation to the technologies according to expert groups. In addition, the framework for the research and the approach in methodology is transferable for any other country. Correlations between the progress of technology and the legal situation were also examined, as illustrated by the prioritization and rankings established using the AHP (Saaty, 1980). As described, security concerns of the systems and operational issues are clearly at the top of the AHP ranking here.

5.2. Practical implications

First, this study provides an overview of the legal situation in Germany at the time of the study period. Every reader gets a deep insight into the road traffic law and issues concerning autonomous driving, as well as the regulation of laws in the airspace, from no-fly zones to duties for pilots, or operators in general. In principle, interest groups such as the Bundesvereinigung Logistik (BVL) in Germany could also benefit from the study, as the decisive CSFs of a legal and technical nature have now been listed.

By prioritizing the CSFs using the AHP (Saaty, 1980), an overview has emerged of which techniques must necessarily function smoothly for users and LSPs to believe in the introduction of AGVs and drones, which can be insightful for technical developers.

Furthermore, possible technical weaknesses of the technologies were uncovered, which need to be improved in order to ensure a smooth introduction into the logistics operations of service providers.

5.3. Limitations

This study is limited by a few interrelated factors. The first factor that brings limitations to the actuality of the research is the time frame, which reflect the legal CSFs for drones and AGVs in Germany only during the period of the study. Nonetheless, legislative and regulatory basis are always changing to reflect the morals and values of the society. The second issue related to the time factor is the acquisition of primary data. The group of respondents answered in a fixed, rather short period. The third factor of limitations is the respondent group itself. Considering the qualification of the experts and their educational background in logistics and supply chain, the survey was primarily answered from the perspective of operations and operational hurdles. Unfortunately, no specific legal experts have been part of the respondent group. In addition, only a small part of the respondent group had a tangible technical background and thus prioritized the CSFs from an operational point of view.

5.4. Suggestions further research

First, it is possible to adapt the framework of the research for any other country than Germany and thus to investigate a different legal situation. The second aspect that could be investigated is the comparison of the legal situation from several different countries. Technical solutions could also be compared based on diverse alternatives. Technical CSFs such as the energy source, or the recharging process of drones and AGVs could be examined in more detail with reference to other issues such as sustainability and economic profitability, or the connection to certain processes such as return management or customer service. Additional relevant indention could go on the direction of contextual elements such as “security of the parcel”, “physical space at delivery place” as CSFs. An interdisciplinary research looking into variables related to locational context, security issues at certain areas and/or countries, cultural matters etc. could expand the understanding of security and space at the delivery, to measure the risk and/or possibility of theft or damage. Future studies could also focus more on moderators of the conceptual model such as company size, company revenues, or professional experience of the respondents. Another suggestion to continue this study would be the aspect of the loudness of drones, which was revealed by the expert interview B.

CRediT authorship contribution statement

Christian Fehling: Writing – original draft, Methodology, Software, Formal analysis, Investigation, Resources, Data curation. **Adriana Saraceni:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization.

Declaration of Competing Interest

None.

Data availability

Extra data attached

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Appendix A. Supplementary data

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