Delivery Drones - Just a Hype? Towards Autonomous Air Mobility Services at Scale

Sara Ellenrieder
Technical University of Darmstadt
sara.ellenrieder@tu-darmstadt.de

Nicolas Jourdan
Technical University of Darmstadt
nicolas.jourdan@tu-darmstadt.de

Melanie Reuter-Oppermann
Technical University of Darmstadt
oppermann@is.tu-darmstadt.de

Abstract

While hype often arises around emerging technologies, delivery drones have received a significant share of attention in recent years. A variety of applications for drone networks formed, from delivering medical goods to drone-delivered pizza. Nevertheless, high expectations did not yet result in a widespread deployment of drones to improve logistic networks. We conducted semi-structured interviews with drone and aviation experts to derive a structured overview of challenges for autonomous drone operations and gain practical insight into promising solution approaches that could transform the current hype into sound business models. Our findings comprise a multitude of operational, technical, social and legal issues that have not been identified in literature. Societal adaption and the development and interaction with AI-based systems pose a major challenge to provide autonomous air mobility services in the near future.

Keywords: Drones, Unmanned Aerial Vehicles, Technology Adoption, Artificial Intelligence

1. Introduction

Technological advances in robotics and artificial intelligence boosted the rapid development of autonomous drones in the past decade. In general, an Unmanned Aerial Vehicle (UAV) or drone is "a pilotless aircraft which is flown without a pilot-in-command on board and is either remotely and fully controlled from another place or programmed and fully autonomous" (International Civil Aviation Organization, 2011). Following an early adoption of drones in military operations, the attention shifted towards commercial drones in the early 21st century. Developments in the civilian drone sector accelerated in 2016 when multiple global players launched drone programs for parcel and food delivery (Giones and Brem, 2017). Amazon set a milestone in the U.S. in December 2016 with its PrimeAir service that delivered the first parcel to a customer by a drone only 13 minutes after the order was placed online (Amazon, 2016; Levin, 2016). In addition, Google Wing (Levin, 2016) conducted test deliveries with drones in 2016 and multiple entrepreneurial startups entered the growing drone market during this phase (Giones and Brem, 2017), also know as the "rise of the drones" (Allianz, 2016). In recent years, much attention has also been paid to drones by the healthcare industry and test flights were conducted to deliver for example blood, vaccines, medications and even defibrillators (Krey, 2018; Scott and Scott, 2017). Looking back at this development, one would expect autonomous drones to significantly impact our daily lives today. However, up until today a widespread adoption of this technology by logistic networks worldwide did not occur and media as well as research started to explain past developments as the result of a hype (e.g., Giones and Brem, 2017; Middleton, 2021). The Gartner hype cycle model for drones and mobile robots (Ray, 2020) also suggests that the hype level has significantly decreased. Nevertheless, they assess commercial drones to reach a turning point now and as business models for drone operations and technology matures, drones are likely to be deployed by various organizations in 2-5 years. Industry forecasts support this theory by estimating a strong growth of the UAV market size with a compound annual growth rate of 7-11% between 2022 to 2027 (Bachal and Mutreja, 2021; Mordor Intelligence, 2021). With this work, we aim to better understand what impeded the widespread adoption of autonomous delivery drones in the past and to support implementation efforts in the future. In order to achieve this, we first conduct a literature review before gaining practical insights and discuss current challenges and solution approaches in an exploratory interview study with drone and aviation experts. By doing so, we aim to answer the following research questions:

(1) Which challenges will the drone industry likely have to face and how can they overcome those to reach a widespread deployment of delivery drones in the near

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future, and

(2) which research topics are emerging from current developments?

In general, we focus on drones that are deployed for logistics purposes where the most disruptive potential of drones is seen in literature (Merkert and Bushell, 2020) and only consider civilian applications. While a variety of different drone types exists today, this study primarily focuses on drones with vertical take-off and landing (VTOL) capabilities that generate lift through downward airflow and have successfully been deployed in multiple delivery test flights in the past (e.g., Amazon, 2016).

2. Theoretical Background

While many models exist to analyze the adoption of technological novelties, the Gartner hype cycle model is especially helpful to separate hype from the real drivers of a technology's commercial promise (Freeman and Freeland, 2015). A high level of uncertainty and hype in the industry made the hype cycle model highly suitable to extract the hype's underlying real challenges and target the engineering and business related challenges that should be addressed by researchers in the near future. A large variety of successful test flights in the healthcare sector and recent industry forecasts undermine the hype cycles underlying assumption that this technology will mature and become viable in the upcoming years (Mordor Intelligence, 2021; Scott and Scott, 2017). The hype cycle model was introduced in 1995 by Gartner Inc., a firm that conducts research on information systems and emerging technologies (Freeman and Freeland, 2015). The model shows how expectations towards an emerging technology evolve over time until a widespread implementation takes place in the market (Fenn and Time, 2007; Freeman and Freeland, 2015). As shown in Figure 1, the hype cycle model comprises five phases (a-e). Following a *Technology Trigger* (a), such as a public announcement of a new and disruptive technology, an overly positive and often irrational reaction can be seen that results in a steep climb of the hype curve. The number of applications for a technology that are expected to be beneficial rapidly increases over time, which raises interest by mass media and large organizations (Freeman and Freeland, 2015; O'Leary, 2008). This phenomenon has also been detected for commercial delivery drones after Amazon and Google's parent company Alphabet publicly launched their first drone delivery programs (Amazon, 2016; Levin, 2016). Since the gap between hype and reality continuously increases while the first failures occur and prototypes do not meet expected performance goals, *The Peak of Inflated Expectations* (b) is reached afterwards. Throughout the third stage, the *Through of Disillusionment* (c) drawbacks of the emerging technology are analyzed (Fenn and Time, 2007; Freeman and Freeland, 2015). For commercial delivery drones, media primarily reported on technological failures and risks of delivery drone prototypes (e.g., Middleton, 2021), while academia provided insights into public acceptance issues of drones and legal barriers for drone service providers during this phase (Merkert and Bushell, 2020). While product and business models mature over time (d), implementation risks decrease and the technology's adoption rate accelerates as its full potential is recognized. Finally, the technology reaches a *Plateau of Productivity* (e) and is successfully implemented by around 20% of originally targeted organizations (Dedehayir and Steinert, 2016; Freeman and Freeland, 2015). In 2019 and 2020, Gartner assessed commercial drones as well as other emerging technologies such as autonomous vehicles and light-cargo delivery robots to slide down the hype curve into the *Through of Disillusionment* (Ray, 2020). While Gartner expects commercial drones to sufficiently mature in 2-5 years (Ray, 2020), we undertake a qualitative, industry-centric approach in this study that allows us to evaluate that assessment in detail. O'Leary (2008) analyzed which information system research opportunities arise, while a technology evolves along the hype curve. For technologies that undergo the *Through of Disillusionment*, such as drones, it is crucial to analyze past challenges and define existing limitations to allow for an implementation of the emerging technology in various organizations in the future. By looking beyond the hype around drones, we aim to identify and structure interdisciplinary challenges that should be addressed in the near future so that business models and technology mature sufficiently.

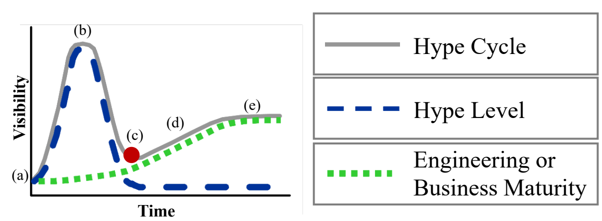

Figure 1. The Gartner hype cycle with its current assessment for commercial drones (red dot). Adapted from (Fenn and Time, 2007; Freeman and Freeland, 2015; Ray, 2020).

3. Qualitative Research Methodology

Due to the rapid developments in the drone industry, it is a difficult task to assess the current state of commercial delivery drones. Therefore, we performed a literature review on crucial challenges that delivery drones have faced in recent years, and additionally conducted semi-structured interviews with drone and aviation experts to gain practical insights on relevant challenges and further required development efforts. We performed the literature review with the AISeL, IEEE Xplore and Web of Science databases according to the principles described by Webster and Watson (2002). The search string consisted of ”drone” OR the synonyms ”unmanned aerial vehicle” OR ”unmanned aerial system” AND ”challenge” OR ”issue” OR ”problem” which resulted in a total of 395 articles. Duplicates and articles that were older than 20 years or were not relevant for the civilian delivery drone industry were removed. Afterwards, articles targeting a similar challenge were grouped together and sorted by date of publication before the most recent development stage was identified. Outdated statements were removed which resulted in a total of 26 articles. Following the review, a semi-structured interview guideline was derived according to the principles of Sarker et al. (2013). In the past, academia primarily payed attention to legal and social challenges of drone mobility services (Merkert and Bushell, 2020). However, we aim to derive an extensive overview of all aspects of autonomous drone flights that will play a central role throughout the next 2-5 years and thus interviewed experts with many different backgrounds. Overall, 13 expert interviews were conducted via video call from February to May 2022. Ten of the participants work in the drone industry in research and product development, operations, engineering or customer service departments or conduct commercial (test) flights as drone pilots. These drone experts (DE) work in the management and operational level at different manufacturers ranging from start-ups to large aviation companies and gained experience on drone deliveries in North and South America, Africa and Europe. However, drones will be integrated into a highly regulated airspace and it is crucial to consider affected stakeholders as well. Thus, we further interviewed three experts from the aviation industry, all of which have more than 25 years of experience. Combining in-depth knowledge of autonomous drone technology with expert knowledge of the aviation industry resulted in a comprehensive overview of interesting topics for future research in the field of Information Systems (IS). Following mutual agreement, we recorded all interviews and transcribed them afterwards with the NVivo 12 software (NVivo, 2019). Afterwards, we performed a content analysis to evaluate and categorize the qualitative data (Myers and Newman, 2007; Weber, 1990). According to the guidelines of Saldana (2021), a multi-cycle coding process was performed. During the first cycle, attribute coding allowed us to extract descriptive data regarding the participants from the transcripts. In addition, we applied descriptive coding to identify and categorize challenges, solution approaches and feasible application areas. However, this analysis resulted in a large number of codes and we summarized the statements by applying pattern coding in the second cycle. The authors performed both coding cycles individually before they compared and discussed the results. A final structured overview of challenges was derived based on the outcomes of this discussion.

Table 1. Interview participants from the drone and aviation industry.

Case	Drone Expert	Aviation Expert	Area of Work
DE 1	X		Product Development
DE 2	X		Product Development
DE 3	X		Product Development
DE 4	X		Product Development
DE 5	X		Product Development
DE 6	X		Operations Mgmt.
DE 7	X		Operations Mgmt.
DE 8	X		Customer Service
DE 9	X		Drone Pilot
DE 10	X		Drone Pilot
AE 1		X	Operations Mgmt.
AE 2		X	Airline Pilot
AE 3		X	Airline Pilot

4. Challenges for Commercial Delivery Drone Operations

Challenges that were identified in the expert interviews and in literature are either categorized as operational management, technical, legal or social challenges as outlined in Table 2.

Operational Challenges While commercial drones are not yet deployed at scale, a variety of drone types and sizes already exist, which further increased the need for standardization in the industry in the past (Carr, 2013). Especially for air traffic management, it is a great challenge that different drones do not have the same equipment and are less standardized than manned aircraft (DeGarmo, 2004; Duvall et al., 2019). Drone design varies greatly from manned aircraft and performance characteristics such as slower cruise speeds and higher agility require an adaption of existing procedures to ensure safe interaction

Table 2. Identified challenges for commercial delivery drones.

Category	Subcategory	Challenges
Operational Management	△⁎ Cost-efficiency	• High costs for production, personnel, operation planning and flight approval; realize economies of scale
	△⁎ Traffic management	• Missing procedures, risk of congested airspace • Restricted airspace; forced to avoid other airspace users • Inefficient routing • High level of flexibility and adaptability required
	△ Willingness to pay	• Lower willingness to pay in high-income countries and urban areas
	△⁎ Infrastructure	• Missing infrastructure such as vertiports • Insufficient space and support for retrofitting urban/ semi-urban residential areas
	△ Standardization	• Lack of standardization for Ops, maintenance, training, ground handling procedures • Heterogeneity of drone types that need to operate in one network
	△ Maintenance	• Difficult to predict the demand for hardware maintenance before large scale operations take place • Software maintenance for AI-based systems required if the autonomy level continuously increases
	△⁎ Performance	• Speed, range and payload limitations
Technical	△⁎ AI-based object detection and collision avoidance	• Lack of training data for AI-based applications • Difficult to define and train all possible scenarios
	△ Communication	• Difficult to visually detect drones (VFR) • Commercial aviation & traffic management: requires integration into existing systems while avoiding information overload
	△ Computing resources	• Installation space, weight and power consumption limitations restrict capabilities of AI-based systems
	△ System redundancy	• Ensuring redundancy for all systems
	△ Commanding multiple drones by one (or w/o) pilot	• Ensuring situational awareness in BVLOS flights • Responsibility, design of human-AI interaction
	△⁎ Position control	• Hacking (e.g. GPS spoofing) or GPS reception problems
	△ Market driven	• Resource shortage delays development
	△⁎ Weather impact	• Snow, rain and fog may degrade the performance of visual AI-based systems • Minor impact on hardware/performance
Social	△⁎ Acceptance	• Privacy concerns (e.g. surveillance) • Security concerns (e.g. accidents, smuggling) • Missing governmental support
	△⁎ Environmental impact	• Noise and impact on nature reserves, animals
Legal	△⁎ Regulation	• Harsh regulatory restrictions, missing regulation or uncertain requirements especially for AI-based systems
	△ Ownership and insurance	• No dominant business model (drone manufacturers as service providers or OEMs) and lack of standardized services
	△⁎ Certification	• Missing certification especially for AI-based systems

One or multiple challenges associated to this subcategory are discussed in: △ *Interviews* ⁎ *Literature* of autonomous unmanned and manually controlled manned vehicles in a common airspace (DeGarmo, 2004). In addition, cost-efficiency of large scale drone delivery networks is seen as a great hurdle for a successful implementation (e.g., Lagkas et al., 2018; Park et al., 2016). Decision making must evolve from human-operated flights to fully autonomous decision making. Besides optimizing drone routing, this is especially relevant for reducing personnel costs in order to realize competitive advantages over manned aviation or land delivery networks (Lagkas et al., 2018). Moreover, infrastructural requirements to provide air mobility services and scale beyond test flights pose a key challenge (Duvall et al., 2019; Park et al., 2016). While infrastructure such as charging stations and vertiports for take-off and landing in cities are not required until large scale drone networks become a reality, the development, construction and search for building sites for such infrastructure should be addressed now in order to avoid delays in the near future (Duvall et al., 2019).

Interviewees significantly extended the operational management challenges found in literature and provided in-depth insights. As the number of drones in logistic networks will increase and cost-efficiency will become a major goal in the upcoming years, efficient routing using intelligent algorithms poses a key challenge for realizing potential benefits offered by drones (DE1,2,5,6,9). Multiple interviewees argued that new traffic management rules are required to reduce delays for drone operations and to ensure safety of all airspace users (DE1,2,4,5,6,7,8,9,AE1,3). Separated airspace corridors for drones could allow to reach full autonomy for drones in the near future (DE9,10). Autonomous and efficient routing of drones and the introduction of such airspace corridors would provide great flexibility for adapting services to dynamically changing environmental or market related conditions in the future (DE1,2,6,9,10,AE2,3). Moreover, missing infrastructure such as vertiports impose additional challenges. Rural areas usually offer more space and flexibility to adapt or retrofit the infrastructure and are thus feasible for test flights. However, experts argue that drones offer a unique possibility to improve logistic chains, reduce congested roads and pollution in urban areas and future city planning should consider infrastructural requirements to realize these benefits (DE2,9,10). Buying power in rural areas is much higher and urgently needed for financing drone deliveries that are often more expensive or at least require more energy than other transport modalities today (DE1,2,5,7,9,AE1,2). While rural areas provide feasible conditions for test flights, drone experts argue that *"drone operations will move from rural to urban areas over time"* (DE1). Nevertheless, it remains a key challenge that the willingness to pay for drone flights remains low in high-income countries (DE3,8,9). While drone service providers still struggle to offer competitive pricing, many opportunities were mentioned to improve cost-efficiency of drone deliveries in the future. First, it is crucial to increase the autonomy level of delivery drones to allow a pilot to monitor multiple drones at once, thus reducing personnel costs (DE1,9,10). Second, realizing economies of scale through mass production of delivery drones and the consolidation of multiple deliveries in one flight will create further savings potential (DE2,3,4,6,7,8,9). Nevertheless, multiple interviewees argued that improving cost-efficiency will not lead to the first wave of widespread adoption of drone technology. Instead, it will be crucial to derive business models for which drones can already offer unique benefits. For example, in many healthcare logistics networks, reducing the delivery time could outweigh additional costs and drones could already provide value (DE2,3,4,7,8,9,AE2). When being asked about maintenance procedures, multiple interviewees mentioned that besides hardware maintenance, it will be a crucial challenge to continuously maintain software systems throughout the first years of commercial use (DE1,2,3,5,8). Since the autonomy level of drones should increase over time, Artificial Intelligence (AI)-based systems must continuously acquire additional capabilities (DE1,3,5). As business models and application areas extend and mature, it will become a major challenge to manage continuous software development and deployment for delivery drones that are already being operated in large scale delivery networks (DE1,3).

Overall, respondents believe that solutions to operations management challenges will be one of the most important factors for delivery drone business models to mature in the near future and meet the expectations of the Gartner hype cycle model. These challenges have not received much attention in the beginning. However, interviewees suggest that the ongoing shift in public attention to these criteria will further reduce the hype and allow adoption of the technology in more areas (DE1,2,4,8,9,10).

Technical Challenges While drone technology has rapidly evolved in recent years, technical capabilities should further mature for a large scale adoption as estimated by the Gartner hype cycle model. In literature, it is often mentioned that harsh weather conditions pose a major challenge for any drone operation (DeGarmo, 2004; Jeelani and Gheisari, 2021). Besides weather, other environmental conditions such as interfering operations of other airspace users heavily impact the success of future large scale drone deliveries. According to FAA regulation FAR Part 91.113 (Federal Aviation Agency, 2014), collision avoidance systems must reliably work for all aircraft at all times (DeGarmo, 2004). The development of reliable and autonomous object detection and collision avoidance systems remain a major challenge for drones today and simultaneously represent a mandatory capability for any drone delivery network (Duvall et al., 2019; Trujillo et al., 2015). Disrupted data links, signal interference or cyber-attacks such as GPS spoofing may further pose a critical risk especially for navigation of the drone and communication between the drone and its ground station (Carr, 2013; Jeelani and Gheisari, 2021). Reducing human error in the design and operation of aircraft has characterized past developments in the aviation industry. While there is no human on board of a drone, human factors still pose several safety risks. Smart concepts to ensure situational awareness must be developed for ground-based pilots and procedures for safe human interference in otherwise autonomously performed operations are urgently required (DeGarmo, 2004).

Interviewees stated that autonomous drones must possess the ability to detect and avoid (DAA) other airspace participants if they are to be deployed in a shared airspace (DE1,2,3,6,7,8,9,10,AE2,3). While the majority of airspace participants transmit their state using protocols such as ADS-B, FLARM and RemoteID, these transmitters are still not legally required and can therefore not be assumed to be available in all circumstances. Other modalities like computer vision, for example, are thus required for detection, which often rely on AI for data processing (DE1,2,4,7). Interviewees mention three major challenges when developing AI-based DAA systems: First, these systems require large computing resources with high demands regarding power consumption and physical size, which are both strongly constrained in small drones (DE1,3,5). Secondly, large amounts of diverse training data are required to ensure generalization to various circumstances and environments, which is expensive to obtain as it usually involves multiple aircraft (DE3,6,8,9,10). Lastly, the standards and associated requirements for DAA systems in drones are not yet finalized by the relevant authorities (FAA / EASA), which leaves companies with a high degree of uncertainty during development (DE1,2). In addition to in-built DAA systems, drone to drone and drone to manned aircraft communication is mentioned as another challenge. This becomes especially relevant when the number of drones in a shared airspace is high (DE2,4,5,9,AE1). With regards to robustness, varying weather conditions were frequently mentioned as a challenge by the interviewees. Regarding rain and fog, sealing of the electronics is required which poses challenges for manufacturing and maintenance and in addition reduces the range of optical sensor, e.g., for DAA systems (DE2,3,6,8,10). Multiple challenges were mentioned with regard to autonomous decision making by drones and the interaction between autonomous control systems and drone pilots. Commercial drones are expected to fly beyond visual line of sight (BVLOS) of their respective pilots and may lose data links intermittently. Thus, the drone needs to be able to autonomously navigate and land safely without pilot input. In case of emergencies, the operator needs to be alerted and takeover certain decision authorities from the autonomous system. An associated challenge is given by the human-AI-interaction, as the operator needs to process the state and perception input from the drone, which may be erroneous in some cases (DE1,2,9,10,AE2,3). This becomes even more demanding when one pilot is in charge of multiple drones simultaneously (DE2,10). Interviewees describe software errors or bugs as the major source of problems during the development, which requires comprehensive testing, both offline as well as in-flight, while hardware-related challenges are mostly related to the redundancy of electronic components (DE6,8). Lastly, the chip and material shortage due the COVID-19 epidemic are currently slowing procurement and supply chain activities around the world (DE2,4,6,8).

Overall, the majority of interviewees rate the technical challenges as the main reason why the hype around drones has died down significantly in the past. The increase in technical maturity, that the hype model calls for in the current phase, will be driven primarily by future improvements in software-based drone features such as AI-based object detection and collision avoidance systems (DE1,2,3,4,6,9,10).

Social Challenges Early on, social challenges associated with commercial drones received great attention by academia and multiple studies already analyzed the public perception of drones in the past (e.g., Eißfeldt and End, 2020; Miethe et al., 2020). In this process, researchers repeatedly argue that the acceptance of drones as a new emerging technology will have a major impact on the success of integration and scaling of commercial use (Macias et al., 2019; Rice et al., 2018). The German Aerospace Center conducted a survey in Germany in 2020 with 832 participants on the acceptance of drone deliveries and showed that 59% of the respondents disapprove drone delivery applications. In addition, participants which stated that they would frequently use delivery drones, would not agree with delivery drones to fly across their property (Eißfeldt and End, 2020). Multiple studies further showed that acceptance of delivery drones greatly differs in regard to the use case. Delivery drones for emergency situations or disaster management received much higher support than commercial parcel deliveries or the transport of people in autonomous air taxis (Aydin, 2019; Lin Tan et al., 2021; Miethe et al., 2020). In general, privacy and safety concerns were mentioned most often to impact public perception (e.g., Eißfeldt et al., 2020; Macias et al., 2019; Rice et al., 2018). Even though delivery drones do not primarily intend to capture sensitive video data or monitor people, they can impose stress and anxiety since they can easily create a feeling of "being watched" (Jeelani and Gheisari, 2021; Rice et al., 2018). While privacy concerns are often described as more severe, safety of drone flights and environmental concerns such as noise were also often mentioned by the public (e.g., Eißfeldt et al., 2020; Jeelani and Gheisari, 2021; Macias et al., 2019). Since acceptance for a technology emerges on the balance of potential benefits and inconvenience associated with the technology (Macias et al., 2019), it will be crucial to educate people on the benefits of drone deliveries and inform them about the real impact drones would have on people's privacy, safety and the environment at the same time. Studies have showed a positive correlation between public drone knowledge and acceptance of the technology in the past (Aydin, 2019; Eißfeldt et al., 2020).

Interviewees consistently mentioned that privacy and especially surveillance concerns arise when test flights are conducted (DE2,3,5,6,7,8,9,AE3) and community sensitivization is a crucial part of every drone operation (DE3,7,9). However, major differences in the severity of privacy concerns were found for different applications and regional areas of operation (DE2,4,6,7,8,9,10). The public perception in European countries and the United States is more negative than in developing countries. Besides that, governments are also more hesitant in Europe and Northern America than e.g. African governments, which currently strongly support the implementation of the emerging technology (DE3,6,7,9,10). Interview participants frequently argued that it is easy to outline the benefits offered by drones in rural areas due to bad road conditions or poor logistic chains and business models can easily be derived. Companies that aim at offering drone mobility services in urban areas often struggle with outlining significant benefits to the public that outweigh their current risk perception (DE3,7,8,9). Overall, applications within the healthcare sector received greater support by the public in the past than other commercial drone applications (DE4,7,6,8,10). While safety concerns by the public are also addressed by drone experts, they are seen to be less severe. Aviation experts however argue that the public trust in the safety of the new technology will be a major challenge when services expand to areas with a higher population density. Criminal activities that could be carried out with drones may intensify safety concerns of the public when the number of drones deployed increases (AE2,3). Drone experts further mentioned noise concerns by the public to become an issue when operations take place in areas with a higher population density (DE7,9,10). Overall, the majority of drone experts showed a very strong awareness of public acceptance problems (DE2,3,4,5,6,8,7,9) and evaluated the public perception of commercial delivery drones to be *"one of the greatest challenge that currently impedes delivery drones from entering the market in multiple regional and application areas"* (DE9).

Respondents consistently mentioned that public enthusiasm for the new technology has driven the hype around drones in the beginning, while emerging acceptance issues are responsible for the current low point. However, with the increase in successful test flights, experts are convinced that growing acceptance will spread in some industry sectors, positively influencing business model maturity. Even if the demand side is not yet sufficiently mature, the results thus support the forecast of the hype cycle (DE2,3,4,5,7,8,9).

Legal Challenges Today, multiple initiatives exist to derive safe and efficient concepts for drone operations in very low level airspace (Lieb and Volkert, 2020). European regulation (2018/1139, 2019/945, 2019/947) and U.S. regulation (14 CFR Part 107) for drones aim to guarantee safety, efficiency and provide standards to control the environmental impact (Bassi, 2020; European Union Aviation Safety Agency, 2021; Federal Aviation Administration, 2020). However, many countries still set their own policies on the use of drones (Tsiamis et al., 2019). In addition, current regulations define a variety of operational requirements that impede or severely restrict use cases for the deployment of delivery drones (Lieb and Volkert, 2020). According to the regulations mentioned above, flights above public areas such as hospitals or gatherings of people are in general prohibited (European Union Aviation Safety Agency, 2021; Tsiamis et al., 2019). Moreover, drone pilots should always fly within their visual line of sight (VLOS) and cannot operate the drone at night (Calandrillo et al., 2020; Federal Aviation Administration, 2020). Waivers of these regulations in the U.S. or approval of so-called *specific* or *certified* operations in Europe can be granted if the operator proofs that flights can be conducted safely under deviating conditions. Nevertheless, tedious processes make it impractical to gain these waivers for each commercial flight within a network where drone deliveries should be conducted at scale (Calandrillo et al., 2020).

Besides legal operational requirements for drone deliveries, uncertainty towards ownership and insurance was often mentioned by drone experts to impose additional challenges. Up until today, no dominant business model for drone manufacturers and/or operators has emerged. Thus, it is difficult to say whether drone manufacturers will either sell drones to specified operators or offer drones services on their own in the future (DE2,3,4,7,8). Missing global standardization leads insurance companies as well as legal authorities to restrain from providing clear assurance of supporting operations (DE3,6,8,9,10). Besides imprecise requirements when applying for approval of delivery test flights, missing certifications were also discussed by multiple interviewees. Especially for AI-based systems such as computer vision-based detect and avoid systems, legal authorities want to test systems beforehand to establish requirements. This iterative certification approach imposes various risks to the industry that may develop costly systems which cannot be certified later (DE1,3,4,5,6,8,9,AE2,3). However, aviation experts argue that this approach was also applied in manned aviation whenever a new technological solution was proposed by a manufacturer. Legal challenges may ensure safety of drone flights which provides the basis for every sustainable business model in modern aviation (DE10,AE1,2,3). In addition, technological advances in the field of AI and especially for explainable AI offer new possibilities to proof that an AI system can outperform or equally perform as a human. While multiple interviewees from the drone industry expressed confidence towards certifying required AI systems in the future (DE1,3,4,6,8,9), one participant explicitly stated that he/ she is *"[...] fully convinced that AI-based systems will become certifiable, even in the aviation industry"* (DE1).

Overall, respondents see an indirect link between regulatory challenges and the waning hype around drone technology, as the public has witnessed the discontinuation of a variety of drone programs but rarely has insight into the actual regulatory causes. Nonetheless, there is a risk that legal challenges will stall both technical development and the development of mature business models, potentially failing to meet the expectations of the Gartner hype cycle model (DE2,3,6,7,8,10).

5. Discussion and Outlook

Overall, expert interviews have significantly extended findings from the literature review. Our results show that rural areas provide feasible environmental conditions (DE2,4,5,6,7,9,10). However, due to a higher buying power in urban areas of developed countries, experts expect autonomous drone delivery services to move towards urban areas in the long-run (DE1,3,4,5,9,AE1). Besides regional areas, use cases in healthcare and disaster management are feasible in the near future and experts expect drones to create value by providing faster deliveries than other transport modalities (DE1,2,4,5,AE2,3). Nevertheless, the potential market share for last-mile deliveries by drones is still limited by current performance characteristics and drones are likely to primarily target high-value, low-weight and -bulk deliveries that would benefit from a faster delivery time (DE1,2,4,8,10,AE1). These limitations support the hype cycle model, which estimates a threshold of 20% in terms of successful adoption of drones by initially envisioned organizations (Fenn and Time, 2007). Our study contributes to research in several ways. First, we look beyond the hype around drones and identify, structure and contextualize challenges that researchers and the drone industry should address in the near future for business models and the technology itself to mature sufficiently. To the best of our knowledge, prior studies in IS research on autonomous delivery drones focused on a specific challenge such as public acceptance of drones. Our comprehensive analysis that includes experts from various fields within the drone and aviation industry results in many interdisciplinary challenges for which the IS research community is particularly well equipped to make important contributions in the years ahead. Second, we outline explanations into why the actual results of drone-based delivery systems is disproportionate to the amount of publicity and public interest in recent years. Our study provides guidance on how to close that gap in the future by identifying relevant research topics that allow to closer align ongoing research with the needs of the mobility industry, thus increasing relevance of scientific publications. Third, as we identify challenges and research topics through an industry-centric approach, we hope to inform future research that analyzes the currently immature demand-side on limitations and potentials as well as required platforms to connect the drone industry with the general public. However, this study also faces limitations that need to be considered when using the results or designing further studies. The number of experts that were interviewed is limited and the majority of interviewees lack prior experience in large scale logistic networks which should be addressed by future research. Moreover, a majority of experts gained experience with delivery drones in the healthcare sector where fast delivery is often more important than cost- and energy-efficiency which can lead to some bias. Nevertheless, due to the in-depth knowledge of drone experts and the vast experience of participants from the aviation industry, we see validity in the results derived through this study. As the autonomy level of delivery drones increases, new research opportunities emerge. First, concepts for human-AI-interaction to enable a ground pilot to monitor multiple drones and intuitively interact with AI-based systems will pose a long-term challenge that should be addressed by future studies. Second, besides operators, autonomous drone systems will also interact with untrained humans and in general customers to retrieve deliveries that do not possess extensive knowledge about these autonomous systems. Safe human-AI-interaction as well as the general development of platforms to connect service providers with customers should also be addressed from this point of view by future studies. Third, social challenges were consistently mentioned by interviewees (DE1,3,4,5,7,9,AE3) to have the *"[...] potentially largest impact on the implementation success of delivery drones"* (DE3). Thus, studies that show how to improve the acceptance of drone technology in the future are urgently needed. Lastly, research should derive solutions on how to maintain, retrain and proof reliability of AI-based systems in continuously evolving business models while autonomy levels simultaneously increase.

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