A Framework for the implementation of drones in German automotive OEM logistics operations

The thesis is submitted in partial fulfilment of the requirements for the award of the degree of Doctor of Business Administration of the University of Portsmouth

Date: 27.12.2020

Student-ID: UP838682

Name: Sebastian Hartl

Portsmouth-Reutlingen DBA Cohort

Unit: U20765/U24087, 2016/17

Word Count: 53272*

(*refers to main body excluding ancillary data, references or appendix)

ACADEMIC DECLARATION

Doctor of Business Administration at Portsmouth Business School, University of Portsmouth.

"Whilst registered as a candidate for the above degree, I have not been registered for any other research award. The results and conclusions embodied in this research are the work of the named candidate and have not been submitted for any other academic award."

Sebastian Hartl

27th December 2020

The work is dedicated to my beloved wife, Julia Hartl.

For her patience and her endless love,

for making my journey possible

only by her caring support.

ABSTRACT

Intralogistics operations in automotive OEMs increasingly confront problems of overcomplexity caused by a customer-centred production that requires customisation and, thus, high product variability, short-notice changes in orders and the handling of an overwhelming number of parts. To alleviate the pressure on intralogistics without sacrificing performance objectives, the speed and flexibility of logistical operations have to be increased. One approach to this is to utilise three-dimensional space through drone technology. This doctoral thesis aims at establishing a framework for implementing aerial drones in automotive OEM logistic operations.

As of yet, there is no research on implementing drones in automotive OEM logistic operations. To contribute to filling this gap, this thesis develops a framework for Drone Implementation in Automotive Logistics Operations (DIALOOP) that allows for a close interaction between the strategic and the operative level and can lead automotive companies through a decision and selection process regarding drone technology.

A preliminary version of the framework was developed on a theoretical basis and was then revised using qualitative-empirical data from semi-structured interviews with two groups of experts, i.e. drone experts and automotive experts. The drone expert interviews contributed a current overview of drone capabilities. The automotive experts interview were used to identify intralogistics operations in which drones can be implemented along with the performance measures that can be improved by drone usage. Furthermore, all interviews explored developments and changes with a foreseeable influence on drone implementation.

The revised framework was then validated using participant validation interviews with automotive experts.

The finalised framework defines a step-by-step process leading from strategic decisions and considerations over the identification of logistics processes suitable for drone implementation and the relevant performance measures to the choice of appropriate drone types based on a drone classification specifically developed in this thesis for an automotive context.

Keywords: Drones, automotive OEM logistic operations, framework

ACKNOWLEDGEMENT

In my more than four years as a doctoral student, I have developed a deep appreciation of the individuals and the institutions that have allowed me to pursue my research interests and to develop my skills as a researcher. Without their help, advise and patience, this doctoral thesis may not have been completed.

Firstly, it is my wish to thank Dr. Jana Ries for serving as my supervisor for all these years and for helping me overcome many obstacles. Dr. Ries has always helped me focus on my academic work and on pursuing my intellectual interests. I deeply appreciate all the time she afforded to provide me with motivating feedback and the attention with which she addressed my concerns, especially in the final completion phase of this thesis. I truly felt part of the academic community during all our phone conversations calls, online meetings and personal encounters in Portsmouth.

I also wish to express my gratitude to my second supervisors, Dr. Debbie Reed and Professor Dr. Daniel Palm for the numerous and intense supervisory meetings and the tremendous treasure of advice and insights they provided in matters of methodology and logistics research. They supported me throughout my work on this thesis and their guidance helped me navigate my thesis through challenges and thematic changes. I am deeply thankful to Dr. Valerie Anderson and Professor Dr. Daniel Simonovich for making it possible for me to embark on my DBA journey. I extent my thanks to all the academic staff at both the University of Portsmouth and Reutlingen University; teaching in the first year, but also in the annual conferences provided me with valuable insights and tools, but also with motivation and with the sheer joy of intellectual enquiry.

I am deeply grateful to my fellow students Dominik Forner and especially Erik Lerche for their constant support and motivation. I will continue to enjoy the close and sincere friendship we formed.

Finally, I would like to express my gratitude to my whole family. Without my parents, who have always supported their children in their learning, my path may not have led to the rewards of an academic education that I can reap now. You have cut down on yourselves to provide for your children and your example and support have kept me focussed throughout all my studies.

TABLE OF CONTENTS

LIST OF FIGURES

List of Tables

List of Abbreviations

AGV	Autonomous guided vehicles
AKL	Automatic small parts storage
BTO	Build-to-order
DDC	DIALOOP drone class
DIALOOP	Drones in automotive logistics operations (framework)
GLT	Big carriers
IT	Information technology
JIS	Just-in-Sequence
JIT	Just-in-Time
KLT	Small carriers
KPI	Key performance indicators
LO	Logistic operations
OEM	Original equipment manufacturer
RFID	Radio frequency identification
SCC	Supply Chain Council
SCM	Supply chain management
SCOR	Supply chain operations reference (model)

1 INTRODUCTION

The topic of aerial drones in automotive intralogistics is gaining in importance as an increasing need for fast and accurate delivery of parts within a factory setting intersects with a growing modularisation and flexibilization of the manufacturing environment, which makes surface area a scarce resource. In response to this need for speed in conjunction with space restrictions, the third dimension of space offers significant potential to be used. The implementation of drones is thus a logical, forward-looking way of enabling manufacturing and intralogistics to meet new challenges.

This introductory chapter is divided into three sections. Section 1.1 elucidates the problem background and, thus, the motivation for this thesis. Section 1.2 defines the research questions. In section 1.3, the research objectives are presented along with the structure of the thesis. Last section 1.4 focusses on the thesis scope.

1.1 PROBLEM BACKGROUND AND RESEARCH MOTIVATION

The motivation for this thesis originated in the author's professional experience as a consultant for automotive companies with a speciality in the logistics operations of original equipment manufacturers (OEMs) as well as current fundamental influences in the industry (section 2.1.1).

In this capacity, the author observed that trends such as modular production increasingly moved to the forefront of automotive discourse, which implied a nascent awareness in the industry that its operations need to be rethought against the background of new technologies and changing environments. This anecdotal evidence reverberated with findings in the research literature which indicated that logistics increasingly confront the problem of horizontal limits in the plant environment (Scholz et al., 2017), and that the complexity of the manufacturing environment is increasing (Kern et al., 2017). Although currently used autonomous guided vehicles (AGV) address flexibility and agility requirements of new modular production sites (Kern et al., 2017), they also lead to denser traffic in the OEM plants. In contrast to AGVs, drones feature a high degree of manoeuvrability as they are able to use the entire three-dimensional space and, as a result, offer the advantage of direct, time-saving routes by taking the "beeline" path to their destination. With an eye to more flexibility, which can be achieved through a "single-piece flow", and to even more variation in products (Scholz et al., 2018), a vision for the use of drones to improve speed and precision in logistics is yet to be developed.

The technology of drones in automotive OEM logistics environment can be a solution alongside other technologies (Maghazei & Netland, 2019). Winkler & Zinsmeister (2019) are listing trends of digitalisation in intralogistics and name drones beyond many others. In relevance of this thesis, looking at technology in intralogistics mainly the named trends of 3D-shuttle systems, AGVs, automated picking-systems, collaborative robots, grid sorters, picking robots or self-organising conveyor or storage systems might be comparable technologies in the research. All systems aim towards a high performance in this environment. Within the automotive manufacturing process the logistics operations require multiple variants of technology that are mainly following given process requirements. With mostly using forklifts, tow trains, driverless AGVs or cranes the sheer amount of parts and even heavier parts are handled within automotive OEMs (Klug, 2018). Further processes like kitting in car sets are often used for commissioning smaller parts into car-specific sets out of the sequencing area (Klug, 2018). In case of small part emergency logistics Klug (2018) mentions pneumatic tube networks for specific use cases, however this solution is very static.

First single use cases identify drones to be useful in indoor logistic requirements (Olivares et al., 2015). However, applicability may be reduced due to various requirement restrictions, e.g. weight and space limitations, and other transporting technologies applied. This is comparable to the multiple technologies stated in the findings of Winkler & Zinsmeister (2019), that list drones besides many other technologies yet drones seem to have less importance in current technology overviews. For that reason, drone application and thus the research tends itself to identify very specific niche implementation cases of drones in automotive OEM logistics operations. The usage of drones is mainly pioneered by leading companies such as Amazon (Hern, 2016) with a focus on long-range deliveries, operating subject to numerous legal regulations as well as considerations of safety and security. However, specifically in intralogistics, drones can be seen as a technology in a niche function. Müller, Rudolph, Janke, & Deutsches (2019) state that functional requirements change and technology alter and further more transportation can possibly be more expensive for the case of the niche function in parcel delivery. Furmans, Seibold, & Trenkle (2019) differentiate between connection-based and trip-based systems and highlight that drones could similarly as AGVs be a variable track system on trip basis and be free moving. Free movement could lead to specific requirements for drone technology, which are still to be identified. Hüring (2019) further states, that drones should only be used for parts, which occur only in small size and number and have less economic impact to producing companies. Landrock & Baumgärtel (2018) additionally highlight, that drones are not only usable on camera basis but also for delivery purposes. They similarly conclude that the weight of the transported goods might be too high in industrial application and see smaller single parts as the main purpose for drone-based transportation. Looking at a specific focus on the efficiency of drone in intralogistics, Fritzsch, Namneck, Stonis, Schwab, & Kirchner (2020) outline that drones cannot carry parts of high weights that which may regularly need to be handled in intralogistics. They equally state, that drones are only useful at single small-weighted parts if it comes to time pressure and the need of speed. Similarly, Lieret, Kogan, Doll, & Franke (2019) emphasise drone inhouse usage for small and lightweight parts to be very useful instead of conveyer belts, AGVs or even transportation by car or bike.

Overall, many sources see large yet very specific and unexplored application cases for drones in intralogistics. Especially the change from high-output practice towards flexible individual production will change requirements for intralogistics (Bozkurt et al., 2020). For this reason, this research will focus on intralogistics with drones and explore this topic in one specific industry, where this change in production philosophy is already very applicable.

Although government conferences have aimed at reducing drone regulation unclarities (EASA, 2018), there are still many open questions. For this reason, this research is focused on the application of drones within the confines of corporate real estate, which allows for an operation of drones under less regulatory pressure as drone usage in public space. As a result, this thesis can pursue a process-oriented approach toward its topic with limited deviation into legal terrain.

The following sections further specifies the research question, the research objectives, and the thesis structure.

.

1.2 RESEARCH QUESTION

The following research question is to be answered:

“Can drones be implemented in automotive original equipment manufacturers (OEM) logistics operations and how can this be achieved?”

1.3 RESEARCH OBJECTIVES AND THESIS STRUCTURE

The aim of this thesis is to find out if and how drones can be used in automotive original equipment manufacturers (OEM) logistics operations. In order to explore the "if", it is necessary to identify potential areas for the implementation of drones in current automotive OEM logistics operations. In case of the "how" potential logistic operations and addressable performance measures for drones need to be identified. A tool needed to this end, however, a *framework for drones in automotive logistics operations* (DIALOOP), does not yet exist and has to be created in this thesis. It evolves from the research process and is intended for a later use by researchers and automotive executives.

The following research objectives are pursued:

Research objective 1: Define automotive OEM logistics operations and performance measures

First, literature on logistics operations is analysed with regard to existing frameworks for, and models of, logistics operations. Then, inhouse processes (Boysen, Emde, Hoeck, & Kauderer, 2015; Jafari, 2015), also called intralogistics (Scholz et al., 2017), are defined and broken down in their constituent sub-processes. In addition, relevant performance measures from the areas of supply chain management and logistics, particularly manufacturing logistics, are identified and systematised. A major task is to chart the process landscape by segmenting the overarching intralogistical process into process areas, each containing a number of processes. This facilitates a systematic approach to the analysis of drone-implementation potentials. This is necessary as the processes' terminology and sequential arrangement varies greatly in the literature. Some studies structure the processes as incoming warehouse, handling areas and point of use, linked by transportation (Kern et al., 2017), and others differentiate between receiving, storing and delivery (Boysen et al., 2015). The latter refers to parts supply in the automotive industry. Moreover, Kern et al. (2017) discuss modular manufacturing systems. Only a few authors (Dörnhöfer, 2016; Kern et al., 2017; Klug, 2018) address intralogistics processes at a detailed level, and only Dörnhöfer (2016) presents a detailed framework for logistics operations and performance measures in automotive OEM. Thus, operations and performance measures that are discussed in the literature have to be systematised and updated in this thesis in order to form a foundation for the further research process.

Research objective 2: Classify drones to explore their application in automotive OEM logistics operations

In addition to logistics operations and performance measures, current drone definitions, classifications and use cases are dealt with as part of the literature review. Existing classifications of drones (Arjomandi, Agostino, Mammone, Nelson, & Zhou, 2007; Custers, 2016; Ghazbi, Aghli, Alimohammadi, & Akbari, 2016; Hassanalian & Abdelkefi, 2017) are discussed, which use, among others, size or weight, wing type and flight ability or environmental characteristics as criteria for classification. There is a large number of classifications and each classification is designed for a special purpose. The most recent comparison of classifications (Hassanalian & Abdelkefi, 2017) partly lends itself to the purposes of this thesis, because it includes hybrid drones, i.e. drones that combine characteristics of several drone types, such as rotor drones and fixed-wing drones or ground-moving and flying automated vehicles (Fraunhofer IML, 2016). This is particularly relevant due to multiple restrictions in public air space by the German government (Dobrindt, 2017), which make it necessary to adhere to a weight maximum of 25 kg of combined drone weight and payload weight and other safety and security concerns (Cho, Lim, Biobaku, Kim, & Parsaei, 2015; Hassanalian & Abdelkefi, 2017; Loh, Bian, & Roe, 2009; Pauner, Kamara, & Viguri, 2015; Weibel & Hansman, 2004). A useful classification for the purpose of this research is lacking in the literature and therefore has to be developed in this thesis. The objective is to classify drones specifically for the use in automotive OEM logistics operations.

Research objective 3: Explore the preconditions under which drones can meet current the requirements of automotive OEM inhouse logistics operations and identify related performance measures

As is the case in other first forays into drone implementation, for example Olivares, Cordova, Sepulveda, & Derpich (2015); Škrinjar, Škorput, & Furdić (2019) or Troudi, Addouche, Dellagi, & El Mhamedi (2017), this research on drone implementation in the context of OEM intralogistics needs to take a structured approach to the level of detail. This research objective is twofold. On the one hand, the logistics operations, which can be handled by drones, have to be identified. On the other hand, suitable performance measures are mandatory to be able to determine the drone implementations that add value to the logistics process. In addition, the research aims to identifying future changes that influence drone implementation and that need to be addressed to make use of the full potential of future drone application.

Research objective 4: Establish a framework for the implementation of drones in automotive OEM logistics operations

As a final junction of all of the above research steps, a framework for drones in automotive logistics operations is developed. It orientates on existing logistics frameworks (Marchesini & Alcântara, 2016; Mentzer & Kahn, 1995; Mentzer, Min, & Michelle Bobbitt, 2004; Saatcıoglu, Denktas-Sakar, & Karatas-Cetın, 2014; Vidal Vieira, Ramos Toso, da Silva, & Cabral Ribeiro, 2017), on frameworks for logistics innovation (Grawe, 2009) or innovation in general (Kamal, 2006), for technology & production (Garrido-Vega, Ortega Jimenez, De Los Ríos, & Morita, 2015; Gladysz & Santarek, 2015), for performance (Ghalayini & Noble, 1996; Trienekens, van Uffelen, Debaire, & Omta, 2008) and strategy (Davila & Epstein, M.J., Shelton, 2013; Neely et al., 2000). The framework helps to structure and connect both research areas, automotive logistic operations and drone implementation, and serve as tool for future work of identifying if drones can be implemented and how.

Research objective 5: Validate the framework, including the content that reflects present-situation, transient conditions and assessments (in the following called contemporary core content), within automotive OEMs

This research objective aims to validate the results on the classification of drones, on logistics operations and on performance measures as well as the DIALOOP framework itself. To do so, semi-structured expert interviews are conducted solely with automotive experts. This empirical approach reduces the limitations of a purely conceptual development of a framework, which are exacerbated by the exploratory nature of this research.

1.4 THESIS SCOPE

The research at hand takes part in the area of German automotive OEM logistics. The author's professional experience helped identify different restrictions such as legal limitations for drones on public ground as well as certain optimisation potentials in the automotive industry. German OEM are significantly leading in innovation and technology leadership and "*produces by far the largest number of premium vehicles worldwide. Almost two thirds (63 percent) of all premium passenger cars sold are made by a German OEM*" (Bormann et al., 2018, p.9). Furthermore German OEMs are leading the ranks in research and development (Bormann et al., 2018). German OEMs have made significant headway in certain areas of innovative technology and processes, which are described in section 2.1.1, also compared to other industry sectors (Hofbauer, 2020). They can thus be viewed as likely early adopters of novel technological solutions, such as drone technology. In international comparison especially also industry-leading Japanese manufactures, which still mostly focus on productivity, German automotive manufacturers already try to improve their future production by aligning production and logistics or even implement modular production systems (Toma, 2020, p.79-80). Additionally, German automotive OEMs are said to be very innovative in world-wide comparison (Kerna & Wolff, 2019). They further state, that adoption of technology is higher in developed countries – like Germany - as for example in China those technologies would be less applied because of currently still low wages (Kerna & Wolff, 2019, p.13).

Today's challenges, however, is to be more flexible and competitive. The reduction of the research scope to inhouse logistics OEM operations mainly results from legal restrictions on the use of drones in public spaces, yet also from examples, of other technological developments, such as autonomous vehicle evaluation cases on company ground (Unger, Markert, Müller, Markert, & Trade-off, 2018), which were all pioneered on company ground and in a small-scale version before being rolled out into public space.

2 LITERATURE REVIEW

This chapter presents the results of a literature review to establish a theoretical foundation combining the aspects of automotive OEM logistics operations, drone application and frameworks for technology implementation. The first part of the literature review focusses on logistics operations in automotive OEMs. On the basis of an overview of process areas and logistics operations, important performance measures are identified. The review of literature on drones takes account of definitions and classifications of drones and then elucidates current applications, challenges and success factors. Subsequently, frameworks for technology implementation are reviewed and an outline for the implementation of drones in automotive OEM intralogistics operations is developed. This outline also guides the further research process. Finally, the chapter conclusion defines research gaps identified in the literature review that are relevant to this research and highlights that these gaps are sufficiently addressed by the research objectives stated in section 1.2.

2.1 LOGISTICS OPERATIONS IN AUTOMOTIVE OEM PRACTICE

Research in logistics is not as established as other research areas, which is why it can be beneficial for logistics research to borrow and adapt theory from neighboring areas (Kovács & Spens, 2007). This is also appropriate because logistics is intensely affected by technological and other innovations (Stark, 2015). The technology in the focus of this research is drone technology, which is specifically viewed in respect of its potential deployment in automotive OEM logistics operations. Technology is an important factor in logistics, as logistics in general faces numerous challenges (Maloni, Carter, & Carr, 2009; Tuan, 2017). The following section explores these challenges with reference to recent and ongoing trends and paradigms relevant to automotive OEM logistics.

2.1.1 Fundamental influences on logistics operations in automotive OEMs

This section presents an overview of the most important influences on logistics operations in automotive OEMs based on the literature review. In a first step, the research area of logistics is outlined.

Logistics as research area

Logistics management, supply chain management and logistics as research areas each set a different focus and relate to each other in different ways. According to a definition for logistics management used by several authors, which subordinates logistics management to supply chain management (SCM), "*logistics management is that part of Supply Chain Management that plans, implements, and controls the efficient, effective forward and reverse* *flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customer requirements.*" (Ballou, 2007, p. 338; Klingenberg & Boksma, 2010 p. 4877; Mentzer et al., 2004, p. 607). Elements of this definition, especially the element of an efficient and effective forward flow, are revisited in later sections of this chapter (section 2.1.3). By contrast, Lambert, García-Dastugue, & Croxton (2005), in a publication on SCM, report that different authors equate SCM with logistics, operations management or procurement and even all three together. Logistics management processes can be seen as part of supply chain management (SCM), understood as a strategic, rather overarching discipline, which, according to Ballou (2007), also includes supplier management and the collaboration with different partners in the supply chain. He further states that *"SCM is viewed as managing product flows across multiple enterprises […] whereas logistics is seen as managing the product flow activities just within the firm" (Ballou, 2007 p. 339)*. Following this definition, a logistics system encompasses, at a micro-level, the material flow as well as the information flow (Tuan, 2017). The definition offered by *Ballou (2007 p. 339)* is used in the research. This thesis follows these definitions in that it assumes that logistics should nowadays be understood as a part of an overarching SCM.

Further, the literature review shows that most of the studies have a strong strategic focus, which often results in a lack of process orientation and an weak concern with questions of implementation (Dörnhöfer & Günthner, 2015). This thesis aims to narrow the gap between a strategic perspective and an operations and implementation perspective. However, the still nascent research on drones does not yield much insight in operational and implementation aspects. To compensate for this, this thesis narrows its focus to logistics operations that take place on enterprise property and indoors, and which thus corresponds to Ballou's (2007) definition of *logistics*. This narrowed approach allows for taking account of operational issues to a sufficient, but by no means exhaustive extent.

Industrie 4.0

In recent years, the author observed in his professional work an increasing interest, and concern with, trends summarised under the term *Industrie 4.0*, sometimes also referred to as *the Fourth Industrial Revolution*. The concept of *Industrie 4.0* comprises a visionary change in industrial thinking with developments in various fields ranging from strategic decision-making to diversification and modularity in production, manufacturing and products: *"the Fourth Industrial Revolution can be best described as a shift in the manufacturing logic towards an increasingly decentralised, self-regulating approach of value creation, enabled by concepts and technologies […] and smart factories, so as to help companies meet future production requirements"* (Hofmann & Rüsch, 2017, p. 33). Although *Industrie 4.0* is still in its beginning phase, it already has a massive impact on industries (Strange & Zucchella, 2017). Nevertheless, the paradigm *Industrie 4.0* is at risk of being a mere management fad, which, according to Hofmann & Rüsch (2017), means that this paradigm has moved very quickly into the focus of the industries, but that it not leads to major changes after all. Regardless of its long-term fate, this new paradigm affords industries the opportunity to improve their horizontal or upstream and downstream integration (Scholz et al., 2017). Industrie 4.0 in recent years sill has many drivers, like agility, customisation, need for accuracy or efficiency, as well as cost reduction, quality increase, stock reduction and transparency (Ghadge, Er Kara, Moradlou, & Goswami, 2020, pp.673-675). By contrast, Industrie 4.0 is facing barriers including financial matters, lack of management support or change mentality or even legal restrictions (Ghadge, Er Kara, Moradlou, & Goswami, 2020, pp.673-674).

M. Kumar, Tsolakis, Agarwal, & Srai (2020) highlight specifically the relevance of reducing lead time of production and decoupling inhouse manufacturing. Industrie 4.0 is required by companies because of an existing "*demand for shorter delivery time, more efficient and automated processes, higher quality and customized products*" (Bigliardi, Bottani, & Casella, 2020, p.322). Bai, Dallasega, Orzes, & Sarkis (2020) are linking Industrie 4.0 with "*with emergent and disruptive intelligence and information technologies*" (Bai, Dallasega, Orzes, & Sarkis, 2020, p. 1) and further suggest a careful evaluation in every single case. Logistics is a major focus for potential improvements within the *Industrie 4.0* movement (Große-Puppendhal, Lier, Roidl, & ten Hompel, 2016) and this momentum can be used to generate progress if frameworks are employed to react to challenges and meet new requirements (Hofmann & Rüsch, 2017). The regional focus of this research is supported by Industrie 4.0 having its roots in Germany (Bonaccorsi, Chiarello, Fantoni, & Kammering, 2020, p.2). Especially because of Germany's focus on manufacturing technology (Bonaccorsi, Chiarello, Fantoni, & Kammering, 2020, p.14) drone implementation present a feasible solution to be applied. *Industrie 4.0* also has implications for the research topic as drones can be an element of a new logistic paradigm under Industrie 4.0 (Beke et al., 2018, p.191), especially with regard to self-regulation of drones, value creation and the integration of new technologies. This thesis views drone technology as a potential enabler of the paradigmatic shift labelled *Industrie 4.0*.

Mass customisation

The concept of *Industrie 4.0* can partly be understood as a reaction to the rise of *mass customisation* as a recent phenomenon. Mass customisation is a major challenge for many companies as it establishes new, as of yet often conflicting requirements to be met (Engelhardt-Nowitzki & Zsifkovits, 2007). After all, it "*aims at offering customized products in a high variety but for still low prices and within short delivery times*" (Meyr, 2004, p. 447).
In doing so, it exacerbates a situation in which *"exorbitant product variety, very limited space, and other factors, organizing efficient and timely deliveries of parts and subassemblies to final assembly within the factory is one of the most pressing problems of modern mixed-model assembly production"* (Emde & Gendreau, 2017, p.255).
In recent years mass customisation moved towards mass personalisation (Aheleroff, Philip, Zhong, & Xu, 2019), allowing for even more customer integration into manufacturing. Although mass customisation is very product driven (Aheleroff, Philip, Zhong, & Xu, 2019, p. 1398), this research is relevant in the context as drones could help getting more affordable impact or insight in a required depth, like a trade-off of transparency and costs whilst considering "*all factors involved in tailored functionalities and appearances under Industry 4.0*" (Aheleroff, Philip, Zhong, & Xu, 2019, p. 1398).
Mass customisation in mixed-model assembly production thus requires to solve the problem of frequently conflicting goals, such as high variety, low price, short delivery time and space limitations, at the same time. With its focus on automotive OEMs and their logistics operations, this research highlights potential drone-based solutions to problems of mass customisation.

European build-to-order manufacturers

In the automotive industry *Build-to-order* (BTO) initiatives are seen as another way to meet changing requirements. The BTO "*strategy reflects the idea that value-adding activities such as assembly and manufacturing are triggered by customer orders*" (Roehrich, Parry, & Graves, 2009, p.1). Mondragon, Lyons, Michaelides, & Kehoe, (2006) argue that a BTO strategy and implementation can yield a competitive advantage because products are no longer pushed through manufacturing but are pulled through by customer demand. This change from a push to a pull process requires flexibility in production lines and a reduction in lead times, which implies that an implementation of BTO must be accompanied by significant upgrades, which in the long run offer important advantages. Vehicles ordered by the customer from Automotive OEMs today must be delivered within highly-restricted time horizons already (Klingebiel, 2006). However, the time horizons become even shorter as OEMs offer the customer the opportunity to change the car order shortly before production starts (Boysen et al., 2015). Also the customer demand for express delivery of BTO cars increases time pressure in the automotive industry (Olbert, Protopappa-Sieke, & Thonemann, 2016). In addition to shortening the time horizon, BTO may also have beneficial effects in terms of inventory turnover, increase of data usage and production-facility changes (Mondragon, Lyons, Michaelides, & Kehoe, 2006). The resulting low inventory demands a high logistics performance in order to ensure the needed supply within automotive OEMs (Dörnhöfer & Günthner, 2015). Logistics operations thus have a key impacts on the improvements that can be reached by applying a BTO strategy (Holweg & Miemczyk, 2003). However, the warehouse-stock driven philosophy adhered to by automotive OEMs leads to increasing cost, and alternative philosophies that abstain from a focus on cost-intensive stock are required (Holweg & Miemczyk, 2003). In addition to the already mentioned flexibility and reduction of the throughput-time, a BTO strategy in the automotive sector requires immediate reactions in case of disruptions (Klug, 2017). If these conditions are met, then BTO can deliver the advantages identified by Roehrich et al. (2009), i.e. a high degree of flexibility and the ability of an on-demand fulfilment of time-sensitive customer requirements. These authors conclude that a BTO strategy improves competitiveness and consider innovative logistics as a key factor in unlocking the potential offered by BTO (Roehrich et al., 2009). Likewise, Parry & Roehrich (2013) assume that innovation in production, supply and logistics, information flow and material flow can support the BTO approach. BTO impacts identified in the literature concern time and inventory as well as flexibility, especially in disruption management, and these areas affected by BTO are also addressed in this research with its focus on German premium BTO automotive OEMs. Nevertheless, there are also barriers to an implementation of BTO: Roehrich et al. (2009) mention costs, administrative effort and adjustments in the organisation and plant, both layout and equipment. The literature shows that there is a valuable potential in the implementation of a BTO environment. A BTO implementation in automotive OEMs could be supported by drones, if their application logistics operations are aimed at improvements in the performance measures pertaining to BTO.

Modular and smart manufacturing environment

Industrie 4.0, mass customisation and BTO make it necessary for OEMs to implement a modular environment. In turn, modularisation is a key enabler of the *Industrie 4.0* paradigm (Hermann, Pentek, & Otto, 2016). Große-Puppendhal, Lier, Roidl, & ten Hompel (2016) observe that the required modularity can be reached by applying cyber-physical systems aiming for more flexibility and transformability in production. Already in the form of process modules, *modularity* can lead to a higher degree of efficiency, which is necessary to compete successfully in an environment marked by an increasing demand for personalisation and a quickly changing market situation (Foith-Förster & Bauernhansl, 2016). Thus, modularisation may offer an avenue to solving the problems posed by differentiation, shortening product lifecycles and the flexibilization of manufacturing (Kern, Rusitschka, & Bauernhansl, 2016) because a modular assembly leads to more flexibility as an answer to contemporary requirements (Kern, Rusitschka, Kopytynski, Keckl, & Bauernhansl, 2015). Also modular logistics can play a crucial role in increasing performance (Fredriksson & Gadde, 2005). The advantages offered by modularisation can be complemented in the concept of *smart manufacturing*: *"Smart Manufacturing objectives are not just about applying IT, but about game-changing promise to energize innovation, address productivity, achieve new and structurally different performance goals, and drive the competitive advantage of investments"* (Davis, Edgar, Porter, Bernaden, & Sarli, 2012, p.147).

Smart factories need to be reconfigurable and adaptable (Furmann, Furmannová, & Więcek, 2017). Therefore, modular production also requires adequate logistics operations, which are flexible and support transformation enablers. Feldhütter, Steck, Hawer, & Ten Hompel, (2017) point out that inhouse logistics in automotive OEMs are affected by product complexity. A modular and smart environment could influence logistics in a positive way, which is why future solutions should address the requirements put forth by modularity and smart factories. Applying smart factory considerations, whilst "*enabling technologies […] are more likely to obtain greater opportunities in terms of flexibility, speed, increased production capacity, decreased errors and costs, and an improved product quality and ability to meet customer needs*" (Büchi, Cugno, & Castagnoli, 2020, p.8), can match with requirements derived from other influences in this sub-section. The research therefore aims at contributing to the nascent body of knowledge on if and how drone implementation could be done and help fulfil these requirements now and in the near future.

Autonomous ground vehicles

As a potential part of the above-mentioned smart manufacturing environment, autonomous ground vehicles (AGVs) have a long history and are known by diverse terms, such as *"driverless transportation system", "automatic guided vehicle"* or *"autonomous ground vehicle"* (Kunze, 2016, p. 291). AGVs are typically suitable to operate in delivery operations characterised by small-scale supply requirements (Scholz et al., 2017). Generally, AGVs can contribute to enabling the above-mentioned modular and smart environments; however, their potential has to be developed further (Kern et al., 2017). Smart transportation can, for example, optimise warehouse and delivery operations (Stefansson & Lumsden, 2008). In practice, AGVs are increasingly integrated in logistics environments. Micieta, Hercko and Botka (2016) describe potential reductions in time and mistakes to be gained through AGVs and assume that further innovations can lower the costs of AGV implementation while increasing productivity as well as competitiveness. Many sources in the literature mainly highlight the scalability and flexibility of AGVs (Kern et al., 2017; Scholz et al., 2017), but also consider how these advantages depend on a smaller size and a lower energy consumption of these vehicles. AGVs may be a driver in the implementation of new, flexible, non-linear assembly lines and also feature a high degree of reliability and productivity (Flämig, 2016).

Their efficiency, especially the time used for manoeuvring, could further be optimised by employing data-based techniques regarding route planning to ensure the *“shortest possible delivery time”* (Stefansson & Lumsden, 2008). Finally, more and more autonomous decisions have to be made to meet the customer requirements (Scholz et al., 2017).

While AGVs are said to be highly flexible and are considered to play an important part in the future of transportation, they cause too much traffic in intralogistics (Scholz et al., 2017). This already significant traffic problem will only increase with having more AGVs and lead to adverse developments in logistics operations. Drones, in contrast, “*do not occupy space on the ground but on the other hand their operating space and autonomous movement may be constrained in some cases by ground obstacles and other UAVs*” (Deja, Siemiątkowski, Vosniakos, & Maltezos, 2020, p.533)

They can expand autonomous transportation into three-dimensional space and thus offer a suitable solution with a high applicability (Fornasiero et al., 2018). It thus appears plausible to view AGVs as a technological platform, in which drones are integrated to expand or even replace some applications while offering a solution to the challenges currently faced by AGVs.

In summary, this section has traced out a development towards new paradigms, which most likely change the way logistics contribute to the overall manufacturing process and which affect existing logistics and performance measures.

2.1.2 Process areas and logistics operations

This section investigates the research on process areas within automotive OEMs. The literature strongly emphasises that performance measures are aligned with processes (Dörnhöfer, 2016). It is therefore necessary to describe the processes and logistics operations in the focus of the research to extrapolate relevant performance measures. A process focus also enhances the practice orientation and, thus, the practical relevance of the research (Dörnhöfer & Günthner, 2015). The main process areas identified in the literature are ‘goods receipt’, ‘storing including inventory handling’, ‘picking & sequencing’ and ‘delivery to line’, with the ‘line’ including the location of goods usage. These process areas are summarised in Figure 2.1.

Authors	Process areas; In-house log./Intralogistics							
	Goods receipt	Storing (/Transport and inventory)				Picking/ Sequencing	Delivery to line	
Mentzer et al. (1991)				Warehousing	Inventory control	Logistics Administration		Order processing
Frazelle (2002)	Receiving	Put-away	Storage			Order Picking	Shipping	
Autry et al. (2008)		Order management	Storage		Inventory		Oder processing	
Klingenberg et al. (2010)				Warehousing	Repacking	Order Picking, kitting, sequencing,	Buffering	
Garcia et al. (2012)	Production (&Bottling)			Warehousing	Inventory Management		Distribution and Transportation	
Saatiouglu et al. (2014)				Material handling	Inventory	Packaging		Transportation
Boyson et al. (2015)	Receiving		Storing			Sequencing	Line side presentation	Delivery to Line
Jafari (2015)			Order processing	Warehousing	Material handling, Finished goods inventory		Packaging	Transportation
Olivares et al. (2016)						Picking		Delivery
Hedler et al. (2016)	Receiving		Storing			Picking	Shipping	Delivery
Kern et al. (2017)		Storing (handling)	Transport		Handling (area)		Buffering (Point of use)	Transport
Vidal Vieira et al. (2017)	Receiving	Put-away				Picking	Shipping	

Figure 2.1 Process areas to be included in the DIALOOP framework, Source: The author

Some of the relevant publications focus on a particular process or bundle of processes, e.g. on warehousing (Hedler Staudt, Alpan, Fugate, & Taboada, 2015; Klingenberg & Boksma, 2010; Saatcıoglu et al., 2014), others contribute to research on modular automotive logistics and assembly (Boysen et al., 2015; Hedler Staudt et al., 2015; Kern et al., 2017). Boysen et al. (2015) investigate parts logistics in automotive OEMs – a topic highly relevant to this research – in great detail. Dörnhöfer (2016) in his work on performance measures in automotive OEM logistics operations comprehensively covers the entire inhouse process including the pertaining performance measures. The following paragraphs present the process areas in more detail and, where applicable, further differentiate individual process areas into logistic operations. The logistic operations are used later in this thesis to analyse which logistic operations are suitable for drone application.

First, the ‘goods receipt’ process is considered. Incoming parts gain importance as the supplier landscape increases in size (Angappa Gunasekaran & Ngai, 2012). The receiving of parts at the gates or dock doors includes the steps of *registering, unloading and scanning* and of *booking* the parts into the OEM’s system (Boysen et al., 2015). Other publications identify the sub-processes of ‘Goods receipt’ as *checking, packing and labelling and giving to put-away* (Vidal Vieira et al., 2017). Discrepancies in concepts and terms in the literature can result from a divergent industry focus, e.g. if packing is already part of the “Goods receipt” in distribution-based businesses. The literature for manufacturers also indicates that goods receipt may contain the logistics operations *register*, *scan*, *check* and *book*, *unload* and *label* (Boysen et al., 2015; Paião, 2014; Vidal Vieira et al., 2017), and that the receiving process is likely to be identical in all industries.

The process area subsequent to ‘goods receipt’ is ‘storing’. The storing of parts is the process of taking them to a warehouse area or storage location, where they remain until delivery to the line, with a differentiation between central storage and a storage nearer to the line (Boysen et al., 2015). Generally, there are different types of put-away (Paião, 2014), i.e. directly put-away, put-away by Warehouse Management System (WMS), sorting and putting away in batches or gathering to avoid empty travel. Vidal Vieira et al. (2017) further added *storage location assignment* and *replenishment* as important operations in storing. Many authors address warehousing (Hedler Staudt et al., 2015) or inventory handling. The summary process can be named ‘Storing’. For the purpose of this research, the process area of storing is defined as containing *put-away*, *sorting, gathering, location assignment, replenishment* and *warehousing*.

Directly succeeding ‘Storing’ is the process area of ‘picking & sequencing’ the parts, which mostly aims at putting items in the correct order for their later delivery to line (Boysen et al., 2015). Sequencing can take place in different variations, such as parts-to-pickers and pickers-to-parts (Boysen et al., 2015). Other authors identify *picking, auditing, packing* and *handling* as logistics operations in the process area of ‘storing’ (Vidal Vieira et al., 2017). It can be assumed that picking and sequencing will gain in importance in a more complex and modular flexible environment because of the concomitant decrease in space availability in the assembly environment. For this thesis, the sub-processes of *picking*, *auditing*, *packing* and *handling* are adopted.

The final process in this specific automotive setting is the ‘delivery to line’, which is typically done by fork lift, tow trains or conveyer systems (Boysen et al., 2015). The ‘delivery to line’ process comprises the tasks of *scheduling inhouse transport* vehicles (Emde & Gendreau, 2017) and *the line feeding process* in a mixed product-model line (Kern et al., 2017). According to Golz, Gujjula, Günther, Rinderer, & Ziegler (2012), the process incorporates the operations of *identification of parts* and s*cheduling peak shuttle demands*, which is similar to Emde & Gendreau's (2017) *scheduling inhouse transport* vehicles. The delivery-to-line process poses many challenges such as the balancing of stock, scheduling or material flow control (Golz et al., 2012). Interestingly, Golz et al. (2012) argue that it is important to minimize the number of shuttle drivers in the logistics area, as a reduction of staff in favour of automation leads to more control. For the purpose of this research, the logistics operations in the process area ‘delivery to line’ are summarised as *identification*, *scheduling* and *line feeding*.

The - process areas discussed above are commonly referred to in the literature, using the same or an equivalent terminology or focussing on the same or similar research area. Some process areas are further broken down in logistics operations. The process areas are used to structure the framework to be developed (section 2.3) and as a guideline for the design of the data-gathering process of the empirical part of this research. The framework brings together process areas, performance measures (section 2.1.2) and drone classification (section 2.3.1).

2.1.3 Performance measures from automotive process areas in relevance for this research

This section gives an overview of the performance measures identified in the research on automotive OEM logistics operations. Performance measures are used to evaluate the potential of drone implementation within these operations.

Performance measures

Instead of the term *performance measures*, some authors use the synonymous terms *performance attributes* (Garcia, Marchetta, Camargo, Morel, & Forradellas, 2012) or *performance indicators* (Hedler Staudt et al., 2015). However, all three terms – performance measures, attributes, and indicators – have the same meaning in that they refer to the same elements of performance, such as quality, time, logistics costs and productivity/capacity.

Furthermore, some authors indicate *performance measures* to be linked to, and informed by, performance indicators (Fugate, Mentzer, & Stank, 2010; Hedler Staudt et al., 2015; Irfani, Wibisono, & Basri, 2019). Over the years Gunasekaran & Kobu (2007) and other researchers have shaped the terminology used in such a way that the term *performance measures* has become dominant.

Other authors discuss *performance measures* that specifically pertain to automotive OEM logistics (Dörnhöfer, Schröder, & Günthner, 2016). Especially Dörnhöfer and peers have comprehensively analysed the field of automotive OEM logistics operations with respect to performance measures (Dörnhöfer & Günthner, 2015; Dörnhöfer, 2016; Dörnhöfer et al., 2016). However, Dörnhöfer & Günthner (2017) point out that there is a lack of literature on performance measures in an automotive OEM context. The thesis follows Dörnhöfer and peers in using the term *performance measures*.

Performance measures in automotive OEM logistics

After the terminology has been clarified above, the following paragraphs present an overview of performance measures.

Efficiency and effectiveness are long-standing performance measures in an automotive logistics and supply-chain context. Efficiency concerns *“the ratio of resources utilized against derived results”* (Tuan, 2017, p. 603). As efficiency aims to minimise the amount of resources needed to reach a specific result or to maximise the results that can be reached with a given amount of resources, efficiency can be defined as *“the ability to make good use of resources providing the desired product/service mix”* (Marchesini & Alcântara, 2016, p.16), which strengthens Tuan’s (2017) definition.

Effectiveness, by contrast, concerns the degree to which a predefined objective is achieved (Fugate et al., 2010; Marchesini & Alcântara, 2016; Mentzer et al., 2004). Effectiveness is thus predicated on, and can only be measured against, predefined goals (Marchesini & Alcântara, 2016, p.16).

Keebler & Plank, (2009), Mentzer et al. (2004) and Rafele (2004) distinguish between a strategic and an operational level and discuss how strategic-level efficiency and effectiveness in a supply chain relate to, or can be broken down to, operational-level efficiency and effectiveness. Similarly, Hedler Staudt et al. (2015) present an overview over performance measures pertaining to a supply chain and systematise these measures according to the two paradigms efficiency and effectiveness. There is thus a strong focus on efficiency and effectiveness in supply-chain performance, which is confirmed by Lemghari, Okar, & Sarsri (2018, p. 1), who observe that *“with the growing importance of logistics, the evaluation of logistics effectiveness and efficiency is gaining increased attention”*.

However, firms increasingly have to consider factors beyond efficiency and effectiveness to remain competitive (Fugate et al., 2010). A third performance measure that has currency in the literature because of its strong relation to competitiveness is *differentiation*. Differentiation is *“the ability to provide customers with the best comparative value”* (Marchesini & Alcântara, 2016, p. 16). This relation to customer value also applies to differentiation in logistics (Fugate et al., 2010; Marchesini & Alcântara, 2016), and logistics performance which should therefore be viewed as an important determinator of competitiveness (Fugate et al., 2010). From a supply-chain perspective, differentiation is also an important factor in establishing logistics networks (Kemppainen & Vepsäläinen, 2007) and therefore might be of equal importance for logistics as efficiency and effectiveness. Differentiation, along with other measures, can be used to compensate for high production costs in high-wage countries (Brettel, Klein, & Friederichsen, 2016). With differentiation as a driver of customer value, it can be concluded that

> *"logistics capabilities, thus, contribute to a firm's competitiveness through […] market-based (differentiation) values"* (Mentzer et al., 2004, p. 613).

In summary, *"logistics performance is defined as the degree of efficiency, effectiveness, and differentiation"* (Tuan, 2017, p.602). Most logistics activities create value through a combination of efficiency and effectiveness and/or through differentiation (Marchesini & Alcântara, 2016). Nevertheless, the link between competitiveness and performance is strongest in the case of differentiation as a performance measure (Marchesini & Alcântara, 2016). The most important performance measure is value to the customer (Gunasekaran, Patel, & McGaughey, 2004), which can take a range of shapes in the area of automotive OEM logistics operations. Yet, not only for this reason is differentiation a suitable performance measure besides efficiency and effectiveness; it is also of relevance as it bundles multiple other possible measures. Efficiency, effectiveness and differentiation are closely interrelated with each other as well as with other measures, as Fugate et al. (2010) point out, thus escaping the dualistic "either-or" thinking regarding efficiency and effectiveness. An alternative outlook perceives all three measures as impacting customer value creation (Marchesini & Alcântara, 2016). Marchesini & Alcântara (2016) conclude in their paper, in which they design a "*conceptual framework to guide the implementation of the logistics activities in the key business processes of SCM*" (Marchesini & Alcântara, 2016, p. 15), that most logistics activities create additional value through higher effectiveness, and efficiency as well as differentiation. The sources mostly consider efficiency and effectiveness to pertain to the supply chain, e.g. Marchesini & Alcântara (2016) or Gunasekaran et al. (2004). In contrast, differentiation has a wider focus, which includes customer satisfaction. Overall, differentiation incorporates multiple approaches, such as universality, mobility, scalability and modularity (Kern et al., 2017, p. 961), and may lead to more flexible systems that are able to react swiftly and adequately to changes in the environment, like increasing complexity (Kern et al., 2017).

The following paragraphs narrow the scope from a supply-chain perspective to an inhouse and manufacturing logistics perspective on performance measures. In doing so, the following discussions draw on the presentations of trends such as Industry 4.0 and smart and modular manufacturing in section 2.1.1. As already mentioned in section 2.1.1, the BTO paradigm demands more variants to be handled, with less stock in less time, which requires manufacturing to be more flexible and responsive, while maintaining the same level of quality (Roehrich et al., 2009, p. 2). Wagner & Silveira-Camargos (2011, p.5726) add, apart from high variety, small batch size to the factors that require flexibility and reliability, especially in

Just-in-Sequence environments. Kern et al. (2017) similarly highlight the need for a dynamic flow and short times and conclude an urgent need for automation within production. Also energy efficiency thinking has been suggested to be similarly important as throughput, availability and performance (Creutznacher, Berger, Lepratti, & Lamparter, 2016, p.174). Reconfigurable assembly systems are a response to high volatility and mass customisation; however, some of them are already reaching the limits of flexibility, with far-reaching consequences for efficiency, which they can only maintain within a certain flexibility range (Foith-Förster & Bauernhansl, 2016, p. 230). A further aspect in manufacturing is modularity, as modularity and the flexibility afforded by it can ensure competitiveness (Diffner, Björkman, & Johansen, 2018, p. 5). Ghobakhloo (2018, p. 919) mentions predictiveness as another measure besides quality and efficiency.

Overall, performance measurements such as *time, quality, flexibility, reliability, throughput performance, automation* and *efficiency* can be interpreted as requirements that need to be met in manufacturing, while *automation* and *modularity* as well as *predictiveness* figure as potential solutions to the problem of meeting these requirements.

Developments such as Industry 4.0, modular manufacturing and BTO (section 2.1.1) highlight inhouse logistics and, thus, position intralogistics as a centrepiece of, and major influence on, the supply chain at large. Similarly, Industry 4.0 which focuses on global value chains for cost reasons (Strange & Zucchella, 2017), cannot stop at the factory gate, but, instead, also pervades in-house logistics. BTO initiatives are said to highlight *cycle time reduction and inventory reduction*, but also *data gathering* and data *networking* (Mondragon et al., 2006). An enhanced gathering and processing of data is necessary to ensure the *speed* in processes that is needed to keep the promise of on-time delivery to the customer *without* massive stockpiling (Parry & Roehrich, 2013). While BTO integrates the external supply chain, important steps toward BTO can be taken in the inhouse environment as well.

Overall, this research has collected common performance measures such as *reliability, time, quality, costs*, *productivity* and *flexibility* (Bhatnagar & Teo, 2009; Caridade, Pereira, Pinto Ferreira, & Silva, 2017; Hedler Staudt et al., 2015; Keebler & Plank, 2009; Klingenberg & Boksma, 2010; Lafou, Mathieu, Pois, & Alochet, 2015; Mentzer et al., 2004; Rafele, 2004; Gregory N. Stock, Greis, & Kasarda, 2000; Gregory Neal Stock, Greis, & Kasarda, 1998; Vázquez-Bustelo, Avella, & Fernández, 2007). Other authors identify the same (e.g., q*uality, cost, flexibility, time*) and similar (e.g., *delivery reliability*) performance measures and add further finance-focused performance measures such as *assets and days in inventory,* but also measures such as *employee* and *customer satisfaction* or *safety* (Ishaq Bhatti & Awan, 2014). Irfani et al. (2019) indicate the logistics performance measures of *reliability,* *responsiveness, flexibility, asset management, costs* or *safety*, which largely correspond to the measures named by the above authors.

However, forward-looking perspectives on technology in intralogistics require novel performance measures such as "*scalability, convertibility, diagnosability, customization, modularity and integrability have emerged as a basis for living factories for next generation manufacturing*" (Koren, Gu, Badurdeen, & Jawahir, 2018, p. 1). These more nascent aspects are confirmed by other sources that emphasise the need to focus on performance measures like *changeability* and *flexibility*, which gain in importance in the course of the decentralisation of manufacturing systems (Wehking, Korte, & Hagg, 2018).

The literature review on performance measures has shown that performance measures are richly interconnected with each other and influence, and are influenced by, numerous factors. *Efficiency* measures are *costs, productivity* and *utilisation of production equipment*, and the *time* aspect is equally linked to efficiency and to effectiveness (Keebler & Plank, 2009). Fugate et al. (2010) emphasise *utilisation* and link this measure to certain value-creating elements such as *availability, timeliness* and *consistency*, which, in turn, could be subsumed under differentiation. Keebler & Plank (2009) equate *utilisation* with *efficiency* and *effectiveness*. The literature links *efficiency*, as well as f*lexibility*, to many other measures. In some cases, *efficiency* appears very similar to, or the equivalent of, flexibility. Thus, for example, flexibility in put-away is defined in terms of time expenditure for order arrival and response (Paião, 2014). By contrast, Dörnhöfer et al. (2016) state that *flexibility* may only influence *efficiency* and *effectiveness*, but that it is not their equivalent. A contrary opinion interprets efficiency and effectiveness as outcomes of flexibility (Yu, Cadeaux, & Luo, 2015). Furthermore, Mentzer et al. (2004, p. 614) consider flexibility as an essential logistics quality and distinguish four dimensions of flexibility: *"timeliness, availability, delivery quality, and related communication with customers"* (Mentzer et al., 2004, p. 614), It can be plausibly assumed that those dimensions influence efficiency, effectiveness and/or differentiation.

Dörnhöfer et al. (2016), whose research has a strong automotive focus, use "e*ffectiveness to summarise logistics effort and quality dimension*" (Dörnhöfer et al., 2016, p. 9). They further state that the "*efficiency of logistics has become more important than a cost-only perspective*" (Dörnhöfer et al., 2016, p.9).

While Dörnhöfer et al, (2016) engage with metrics at a detailed level, many high-level performance measures discussed by them are applicable in the entire company (Dörnhöfer et al., 2016). In addition, the authors highlight that "*a typical trade-off that can be found in automotive logistics is the prioritisation of cost reduction or increased productivity*" and argue that this should not come at the cost of *timeliness* and *quality*.They also attribute a high level of importance to flexibility as the "*capability of maintaining or further improving the current* *level of efficiency and effectiveness in the future*" (Dörnhöfer et al., 2016, p. 9). Additionally, Dörnhöfer (2016) argues that there are certain levels of performance measures, which correspond to the differences between performance measures and, for example the performance indicators identified in this research, which should be structured hierarchically in a cascade form so that cause and effect relationships could be traced accurately. Other authors with a focus on the automotive industry adhere to a cost-centred paradigm by highlighting *efficiency* or *stockpile reduction* as preconditions for meeting the requirements of the customer (Caridade et al., 2017). Flexibility and efficiency are also predicated on accurate information on available storage space (Paião, 2014). While storing does not add value, it is needed to ensure efficiency (Manzini, Bozer, & Heragu, 2015). Thus, flexibility in warehousing is closely related to efficiency (Paião, 2014). Manzini et al. summarise the core concern of logistics:

> *"The basic mission […] is to cost-effectively ship products to the right place, at the right time, and in the right quantity without damage or alterations"* (Manzini et al., 2015, p.711)

The measures from warehousing can be subsumed under the overarching measure of *perfection*. In an automotive context, perfection represents multiple other measures regarding logistics such as *right part*, *quality*, *location* and *packing* (Dörnhöfer et al., 2016). Dörnhöfer et al. (2016) identify *efficiency, perfection* and *lean logistics* as top-level dimensions, whilst working logistics performance measures for the automotive sector. While *"lean principles, e.g. the reduction in set-up times, continuous improvement programmes, realisation of the pull principle, the shortening of lead times, as well as smaller lot sizes, show a positive influence on product quality performance*" (Dörnhöfer et al., 2016, p. 5), could also be subsumed under the top-level dimensions of efficiency and differentiation. While lean logistics is not in the focus of this research, efficiency and perfection are highly relevant in the implementation of drones. As Dörnhöfer et al. (2016) offer an automotive-specific and highly systematised overview of performance measurements, this research adapts their structure of top-level and subordinate measures and the collection of measurements compiled by them, but, in contradistinction to these authors, limits its scope to in-house logistics. The main adaptation consists in the replacement of lean logistics with a more differentiation-oriented category in bearing with the above considerations. In going beyond the perfection and lean implementation focus pursued by Dörnhöfer et al. (2016), it is necessary to explore and update the performance measures they suggest. The performance measures used in this research with its focus on intra-logistics need to be tailored to recent developments affecting inhouse logistics operations, in particular modularity and smart manufacturing, so that potential gains in efficiency and effectiveness can be identified, and measured, accurately. Thus, this research uses efficiency, effectiveness and differentiation as leading performance measures, with perfection and lean logistics (Dörnhöfer et al., 2016) being subsumed under differentiation.

In summary, the superordinate performance measures efficiency, effectiveness, and differentiation, along with performance measures subordinate to them, are used in this thesis to analyse the potentials for implementing drones.

2.2 Drones and drone application

The previous sections addressed the industrial background as well as key literature on operations and performance measures in automotive OEM logistics. In this section, the literature review addresses drones in general, their classification and their current application with a focus on logistics operations.

The term *drone* in this research is understood as *aerial drones*, "*aerial vehicles that fly without an on-board pilot, as well as the systems that support them to do so*" (Boucher, 2015, p.1394).

Early estimates of the drone market predicted a market of 6 bn US dollars in early 2013, but also awaited a growth to the volume of 11bn dollars (Stuart & Anderson, 2015). Other authors expected a strong market growth for drone applications from 2 bn US dollars to 127 bn US dollars in 2020 and predicted that drones will be as ubiquitous in the near future as smartphones are today (Giones & Brem, 2017). Another source estimated 100 bn US dollars of spending in different drone categories by 2020 ("Drones, Technology Driven Innovation," 2017). While there are numerous predictions in the literature concerning the drone market, the prognosticated numbers in growth and value vary significantly. However, more recent sources qualify these numbers to be optimistic at most. They state that the drone market is "generating 22.5 billion USD in 2020 [and] it will grow at a CAGR (Compound Annual Growth Rate) of 13.8% to almost double that in 2025" (Schroth, 2020). Another source is giving a similar outlook for the next five years, expecting drone markets to "grow to $63.6 billion by 2025, and Insider Intelligence predicts consumer drone shipments will hit 29 million by 2021" (Intelligence, 2021). Specifically the "German drone market will grow from 840 million euros to over 1.6 billion euros by 2025" (von Randow & Thum, 2021) and slightly could outnumber the overall market growth according to this expert. Goodchild & Toy (2017) observe that there are only a few authors addressing drones for transportation, and, therefore, the market value of this segment of drone usage is yet to be explored. Similarly, Maghazei & Netland (2019) highlight, that most applications are seen in information-based applications. Nevertheless, the above-mentioned numbers show that drone technology is considered highly influential so that an in-depth investigation of drone implementation in a key function such as logistics appears to be necessary.

2.2.1 Current drone applications

Currently, there are numerous publications on the application of drones in multiple areas. This section reviews literature on different applications in order to identify the types of drones with practical applicability and the benefits they can bring to automotive intralogistics. A first differentiation of drones distinguishes civil and military applications, but also tasks and size as well as other characteristics (Hassanalian & Abdelkef, 2017; Watts, Ambrosia, & Hinkley, 2012).

The use of drones began in the early 1900s, to support high-risk military operations, albeit drone usage was limited for technical reasons in the early years (Giones & Brem, 2017). The military use encompassed surveillance, which demanded flying at extreme altitudes. Later, military drones were also used to engage an enemy on a battlefield and to carry out targeted killing operations, which has led to widespread scepticism toward drone technology in Germany (Selchow, 2015). However, the type of drone used in military operations is mostly characterised by fixed wings and a large size, which enables long-range travel, and drones with these properties are generally not useful in an industrial context as investigated in this thesis. However, a certain utility of larger, fixed-wing drones in an industrial environment cannot be excluded for niche applications. Despite their military history, drones can be a benefit in civilian environments, as Choi-Fitzpatrick (2014) points out. Civilian uses of drones are the focus of the following paragraphs.

There are multiple examples of drone usage (Hossein Motlagh, Taleb, & Arouk, 2016), and the literature discusses the use of drones for example in a policing context, for border-control purposes or with a view to surveillance tasks (Custers, 2016). Surveillance encompasses a broad range of use scenarios for drones. Indeed, the majority of the research on drones in non-military contexts addresses surveillance applications and many of these publications focus on surveillance operations in smart cities (Jensen, 2016; Mohammed, Idries, Mohamed, Al-Jaroodi, & Jawhar, 2014; Rao, Gopi, & Maione, 2016). Surveillance drones in public spaces, including smart cities, are frequently discussed in the literature with a focus on ethics and legal aspects (Luppicini & So, 2016). Some publications focus on unmanned aerial vehicles (UAVs) use for traffic monitoring and analyse multiple sources and practical examples (Barmpounakis, Vlahogianni, & Golias, 2016).

Other specialized use scenarios for drones, include medical device transportation (Thiels, Aho, Zietlow, & Jenkins, 2015). Speedy long-range delivery in urgent medical cases is a scenario often discussed in literature, and most of the scenarios focus on the long-distance delivery of medical supplies, as described by Bryan (2014), who discusses a pilot project to deliver medical supplies to a German island (Bryan, 2014). Value is thus generated by long-range delivery, as Haidari et al. (2016) point out.

Regarding research on the use of drones in logistics, there are multiple sources that address the delivery of goods, and even cases of pizza delivery by drone have been discussed (Murphy, 2016). To date, most of the applications take place within research projects of distributors, e.g. DHL and retailers, such as Amazon, and concern the long-distance delivery of diverse packages (DHL, 2016; Hern, 2016). These projects are also mentioned by Murray & Chu, who discuss a specific routing solution supported by drones (Murray & Chu, 2015). A significant topic in the discussion of drones in future logistics operations will be delivery or distribution. About 42 % of companies that transport cargo plan to use drones in order to reduce costs or to meet growing demand (Lin, Dimpudus, & Hsu, 2017).

In addition to long-distance delivery, another focus in literature lies on urban delivery. Many publications, for example Troudi, Addouche, Dellagi, & El Mhamedi (2017) address the so-called last mile in urban parcel delivery as an appropriate setting for drone usage. Drones can be quite useful in last-mile delivery and be compared to truck delivery (Tavana, Khalili-Damghani, Santos-Arteaga, & Zandi, 2017). One of the future trends identified in the literature is that drones bring goods to people so that people do not have to get them (Custers, 2016). Many publications focus on long-range delivery to suburban areas. However, the benefit of drone usage in transportation largely depends on the specific case (D'Andrea, 2014). As already mentioned, some deliveries exceed the payload restrictions of drones in size or weight. This has led to testing the combined deployment of multiple drones (Bernard, Kondak, Maza, & Ollero, 2011).

In general, there are multiple further scenarios for drone usage, for example in agricultural settings or for the inspection of infrastructure and industry (Flämig, 2016). Giones & Brem (2017) mention civilian use cases from the beginning of the 1990s, such as mapping and photography applications and industrial inspection, and later also drone usage in filming and broadcasting as well as logistics. The private use of drones has developed much faster than their military utilisation, which has been an effect of miniaturization and further technological developments, e.g. advances in material science, computing, and camera technology (Giones & Brem, 2017).

In summary, the main theme in the current application cases discussed in the literature is the use of drones for surveillance and fast delivery. Drone usage in an intralogistics environment is addressed by only a few authors. Their focus is on optimising costs with regard to flight time (Cavalcante, Bessa, & Cordeiro, 2017) or routing, transported weight and battery ability (Olivares et al., 2015) in an indoor environment. The literature on non-automotive, non-inhouse applications shows that usage scenarios for drone applications still need to be defined in more detail.

Maghazei & Netland (2019) even highlight the need of further research in manufacturing, even framework development and specific, even though design-based,

> "*guidelines for different applications*" (Maghazei & Netland, 2019, p.15)

They confirm a extensive need of operational, managerial and social development to be done (Maghazei & Netland, 2019). So far, the literature mostly concentrates on use scenarios characterised by long ranges and the availability of extensive space. The majority of application is currently based on see and sense applications, yet with little focus on transportation and transformation tasks (Maghazei & Netland, 2019). The automotive environment has not been considered yet as a setting for drone usage. Therefore, this research explores if there are possibilities for drone implementation and if so how drones can be implemented in automotive OEM intralogistics even if such applications may are challenging and be confined to a niche.

2.2.2 Definition and classification of aerial drones

A general definition of aerial drone is necessary to ensure a clear concept of the research subject and a proper delineation of this thesis' contributions to research and practice. However, literature shows that there are multiple different definitions of the term 'drone' and that a generally-accepted definition is lacking. Thus, Custers (2016) takes recourse to the original meaning of the term 'drone', as a male bee, in his detailed work on the future use of drones. A rather general and non-specific definition of drones is the following:

> "*objects that fly without carrying a human pilot during flight*" (Stepanić, Kasać, & Merkač, 2014, p. 52).

Another definition takes size differences into consideration:

> *"Drones are flying robots which include unmanned aerial vehicles (UAVs) that fly thousands of kilometres and small drones that fly in confined space"* (Hassanalian & Abdelkefi, 2017, p. 99).

Both definitions focus on the level of autonomy by mentioning the absence of a human pilot or by considering drones to be robots, and the second definition adds size, range and the type of space traversed (open aerial space or confined space). For the purpose of this research, drones are defined as flying or partly flying robots, which have a certain level of autonomy and which operate over short or medium distances in closed or open-air spaces on company real estate to fulfil intralogistic tasks.

2.2.2.1 Size and weight

In addition to definitions, there are also classifications of drones in the literature. The following sections present an overview of classification features. Besides the classification as *unmanned aerial vehicle* (*UAV)*, there are also terms such as *micro unmanned air vehicle (µUAV)*, *micro air vehicle (MAV)* and *nano air vehicle (NAV)*, *pico air vehicle (PAV)* as well as *smart dust* (SD) (Hassanalian & Abdelkefi, 2017).

Other classifications use similar features to distinguish drones. Thus, Gupta, Ghonge, & Jawandhiya (2013) propose a classification that is comparable to the one by Weibel & Hansman (2004), who distinguish *micro, mini, tactical, medium altitude* and *heavy* drones (Weibel & Hansman, 2004). The focus of their classification appears to be still on outdoor air vehicles, which is most likely rooted in the military application of drones.

This shows that many drone classifications use size and weight as primary distinguishing features. Accordingly, this section of the literature review introduces different size- and weight-based drone classification systems. The size and weight ranges used for classification in the literature vary greatly. Looking at the larger scale, UAV classifications are strongly influenced by the at first exclusively military background of these vehicles and classify very large drones, with wing sizes from two to 61 meter (m) and a weight between five and 15.000 kilograms (kg) from much smaller drones, such as so-called *smart dust* with a size below 1mm and a weight of less than 0.005 kg (Hassanalian & Abdelkefi, 2017). In contrast, there are UAV classifications with *no more than five kg* (Arjomandi et al., 2007; Hassanalian & Abdelkefi, 2017). Other authors classify drones as UAVs which have a wingspan of under two m and weigh under 15 kg (Bernard, Kondak, Maza, & Ollero, 2011). In this case, they classify UAVs as significantly smaller than described above. Weibel & Hansman (2004) additionally mention mini UAVs with a range of 0.5 to 20kg. Another group are micro unmanned aerial vehicles (µUAV), which in general follow the classifications of UAVs, but are smaller in size so that they are portable by a person; they are classified by a wingspan of one m to two m and a weight of two kg to five kg (Hassanalian & Abdelkefi, 2017). The class of micro UAVs may be relevant for the described intralogistics operations. In contrast, Kumar & Michael (2012), in their publication on micro UAVs, limit the wingspan to 0.1 m to 0.5 m and the weight to 0.1 kg to 0.5 kg. Also the classifications of micro UAV use strongly varying distinctions, e.g. a maximum size of 15 centimetres (cm) (Cai, Dias, & Seneviratne, 2014).

A third class, following the same classification pattern, are the micro air vehicles (MAV). They are smaller in size, 15cm to one m and in weight, two kg to 50 grams (g) (Hassanalian & Abdelkefi, 2017; Szczepański, 2015). Contrary to these specifications, González-Jorge, Martínez-Sánchez, Bueno, & Arias (2017) describe *micro air vehicles* as unmanned aerial systems weighing less than one kg. Others also define "local UAVs" or *mini, micro and nano UAVs* with a maximum size of one m (Szczepański, 2015). A last classification is for nano air vehicles (NAV), which feature the same characteristics as micro air vehicles, but are limited to a maximum size of 15 cm, a maximum weight of 50 g (Hassanalian & Abdelkefi, 2017), and a flight distance of about one km (Hassanalian & Abdelkefi, 2017; Petricca, Ohlckers, & Grinde, 2011).

The literature also mentions small autonomous drones, which show a great potential (Floreano & Wood, 2015). Coppejans & Myburgh (2015, p.30058) state that

> *"autonomous MAVs [micro-UAVs] are becoming more prevalent and are already being applied for various applications. The potential of MAVs is near limitless".*

The classification systems described above all start at a very large wingspan, size and weight. However, against the background of regulatory requirements in Germany (Dobrindt, 2017), this research classifies drones for automotive OEM logistics operations using a smaller scale, as described in section 2.3.1. With a maximum weight below 25kg, many drone classification systems or drone classes may not be applicable, especially niche classes suggested in individual publications. Additionally, there are currently no applicable classification ranges regarding the size of drones in automotive OEM logistics operations in general. It is therefore appropriate to this thesis to limit the classification span to 'drone' and to add another classification criterion.

2.2.2.2 Wing type and flight properties

Wing abilities and flight properties are of central importance for drones that fly in in-door automotive spaces. With these different features of drones, it is necessary to determine which drone type can be used for a specific purpose or in a particular environment. The foundation for such a determination is a categorisation of wing types. Categorisations in the literature distinguish wing types such as *fixed wing, multi-rotor* and *other systems* (Custers, 2016) or wing abilities such as *fixed wing, rotary wing* and *flapping wing* (Ghazbi et al., 2016, p.310).

In the rotary wing class, a further differentiation is applicable that reflects the number of rotors, which can range from four to twelve, (Hassanalian & Abdelkefi, 2017; O'Connor, 2013). A higher number of rotors translates into a higher degree of safety in case of rotor failure (Moschetta & Namuduri, 2017). Many authors focus on quadcopters, for example drones with four propellers, which are mostly known from civilian camera-based applications (Ghazbi et al., 2016; Olivares & Cordova, 2016; Vempati, Choudhary, & Behera, 2014) and are also known by the term quadrotor (Czyba et al., 2014; Hassanalian & Abdelkefi, 2017; Olivares & Cordova, 2016).

Drones belonging to the category of fixed-wing UAVs are often used for long distances or high altitudes (Ghazbi et al., 2016). They are not as widespread as rotor-based drones or hybrid drones, which are discussed next.

Apart from rotor and fixed-wing drones, also diverse types of mixed drones, often called *hybrids*, are discussed in the literature. Hybrid solutions can combine the advantages of both fixed-wing and rotor drones. One type of hybrid are *horizontal take-off and landing* (HTOL) drones, which can be distinguished into "*tailplane-aft*", *"tailplane forward", "tail-aft on booms"* and "*tail-less or flying wing UAVs"* (Hassanalian & Abdelkefi, 2017). Kückelhaus (2014) suggests a classification of hybrids ranging in size from larger *fixed wing* versions, *tilt-wing* and *unmanned helicopters* to *multicopters*, which are typically small. Additionally, further mixed versions are imaginable. Hybrid versions of vertical take-off and landing (VTOL) and HTOL drones offer the ability of vertical take-off and landing as well as a high cruise speed (Hassanalian & Abdelkefi, 2017). Hybrid UAV versions of drones can feature tilt-rotors, tilt-wings and tilt-bodies, with tilt-rotor version offering the best performance in hover flight and tilt-wing versions the highest efficiency in cruise flight (Hassanalian & Abdelkefi, 2017).

Drones that fly only parts of their itinerary while rolling most of the way in order to reduce safety and security risks as well as energy consumption are another type of hybrid (Fraunhofer IML, 2016). Similar hybrids are discussed by Moschetta & Namuduri (2017), who investigate rolling as an additional mode of movement of flight-enabled drones in a lab environment. However, there is no literature on specific application cases of hybrids that combine flight and rolling as modes of movement.

The literature review has shown that wing types and flight properties are equally suitable for the classification of drones, as both classification approaches can inform the choice of a drone type for a specific use cases. Figure 2.2 presents a comparison between the three characteristic wing types.

(High: ⊕, Medium: ⊖ , Low: ○)

	Rotary wing	Fixed wing	Flapping wing
Maneuver [14]	⊕	○	⊖
Cost [15]	⊖	○	⊕
Construction and Repairing [16-18]	⊖	○	⊕
Civilian Application [12, 15, 19, 20]	⊕	○	⊕
Military Application[11]	⊖	⊖	⊖
Energy Consumption[11, 12]	○	⊖	⊕
Flight safety [16, 17]	⊖	⊕	○
Range[11]	⊖	⊕	○

Figure 2.2 Comparison rotary wings, fixed-wings and flapping wings, from Ghazbi et al. (2016, p.311)

Fixed-wing drones are quite limited to application settings characterised by narrow indoor spaces and flapping-wing drones are too complex (Moschetta & Namuduri, 2017). Therefore, the application scenario in intralogistics would demand the use of rotor-based drones because of their excellent behaviour in the hover mode and their very good manoeuvrability (Hassanalian & Abdelkefi, 2017; Schauwecker, Ke, Scherer, & Zell, 2012). Because of these characteristics, they are highly suitable for deployment in small, cluttered areas and in enclosed environments, such as indoor spaces (Kanellakis & Nikolakopoulos, 2017). Nevertheless, there are also applications were fixed-wing drone implementation could be possible, due to large production plants in automotive facilities.

2.2.3 Benefits of aerial drone implementation

Clothier et al. (2015) propose to increase the acceptance of drones by explaining their technology, benefits and risks. Following this approach, the present and the following section address the benefits and, respectively, the challenges of drones. Drone technology has already been illuminated in the previous sections.

As far as logistics in general is concerned,

> *"the use of UAV primarily results in optimization of logistic processes, with the aim of reducing inventory costs, significantly shortening the process, reducing use of human resources, and so on"* (Škrinjar, Škorput, & Furdić, 2019, p. 365).

The same may apply to intralogistics, as *productivity, reliability* and *flexibility* in in-house transportation can also be improved to a great extent by the use of autonomous vehicles (Flämig, 2016) which can include drones. However, Olivares, Cordova, Sepúlveda, & Derpich (2015), in investigating the integration of drones in internal parts logistics, conclude that drone usage yields gains in *efficiency* and *effectiveness* in the investigated case of transporting boxes. Especially in the field of intralogistics, drones may have an important role to play, as optimisations in production, processes, time and costs move into the focus of attention (Kückelhaus, 2014) and authors discuss the effect of drones on variables such as *lead time, cycle time, time for waiting, utilization* as well as *inventory levels, inventory turnover* and *in-process inventory* (Olivares & Cordova, 2016). Olivares & Cordova (2016) use these variables to develop a model for drone-fleet-based delivery in production companies.

In case of a stock-out scenario, additional fast delivery by air supply could be applied (Boysen et al., 2015), which would increase delivery speed, an important driver of improvements in the area of automotive OEM intralogistics. The delivery speed reached by the

> *"use of drones can reduce significantly the traffic-based uncertainty of the shipping process, providing a faster and more reliable service"* (Tavana et al., 2017, p. 94).

The ability of drones to fly the '*beeline*' route in case of express delivery is an element of future trend scenarios in logistics (Kunze, 2016). Indeed, the requirement of fast deliveries is considered to be a major reason for the inclusion of drone technology in logistics operations (Tavana et al., 2017). Also, using drones and, thus, three-dimensional space instead of autonomous guided vehicles (AGV) and two-dimensional space may offer additional benefits beyond gains in speed. AGV can only use the crowded shop floor (Olivares & Cordova, 2016), while the use of drones in logistics, as Lin et al. (2017) point out, could lead to a *reduction of traffic* as well as *pollution*.

In addition, the current state of technology allows for the formation and use of drone swarms (Hassanalian & Abdelkefi, 2017), which would be able to handle parts of higher weight exceeding the payload limitations of a single drone. Especially rotary-wing systems with multiple rotors offer significant advantages not only in *payload* but also in *agility* (González-Jorge et al., 2017) and are therefore well-suited for a deployment in swarms. Although it may be difficult for a single human worker to oversee swarms and co-operate with them, drone swarms could help the worker in multiple ways as "*larger, more complex tasks can be performed by smaller, simpler UAVs via cooperative swarm behaviour*" (Hocraffer & Nam, 2017, p.67). Swarms may however also lead to a higher service level (Troudi et al., 2017). Given the trend toward highly personalised goods, shortened delivery times, and manufacturers' increased exposure to liability issues, *connectivity* and *analytics* are seen as key enablers (Lade, Ghosh, & Srinivasan, 2017). Another possible benefit of drone usage can be *cost-effectiveness*, as stated by D'Andrea (2014), whereas Derpich, Miranda, & Sepulveda (2018) consider the use of drones in warehouses to *minimise energy consumption*.

In summary, there are only few publications on performance measures for drone usage and only a small number of such performance measures has been identified in the literature Those measures found in the literature are listed in Table 2.1.

Table 2.1 Performance measures positively influenced by drones, from literature, Source: The author

	efficiency	effectivness	process improvement	time	costs	utilization	inventory	turnover	productivity	reliability	felxibility	human ressource reduction	traffic reduction
Olivares et al. (2015)	x	x		x		x	x	x					
Kückelhaus (2014)				x	x								
Tavana et al. (2017)				x						x			x
Flämig (2016)									x	x	x		
Škrinjar et al. (2019)			x		x		x					x	
Lin et al. (2017)													x
Kunze (2016)				x									
Boysen et al. (2015)				x									
Lade et al. (2017)				x									

These performance measures are compared to the logistics operations performance measures in the conclusion of this literature review (section 2.4) and are later discussed in the context of the expert interviews. The aim is to find out if drone-specific performance measures can also be used in the context of automotive OEM intralogistics operations.

2.2.4 Challenges of drone implementation

The implementation of drones can be addressed from a project management view and defined as a handling of multiple challenges of a technological, human and organisational nature (Idries, Mohamed, Jawhar, Mohamed, & Al-Jaroodi, 2015). In order to implement drones successfully, it is necessary to identify the challenges to be met and to draw on expert knowledge in addressing them. A ranking of challenges according to their severity and the effort of addressing them may be a valuable tool for a potential drone implementation.

Considering drone applications as part of manufacturing innovation, economic aspects have a significant high impact (Boysen et al., 2015; Floreano & Wood, 2015; Olivares & Cordova, 2016; Rao et al., 2016). Besides *economic issues*, the interdependency between the *different technologies* or *multiple innovation paths* in operations are also important considerations pertaining to drones in manufacturing logistics (Das & Nair, 2010; Kunze, 2016; Mohr & Khan, 2015; Phillips & Linstone, 2016; Tang & Tomlin, 2008; Thun & Hoenig, 2011; Wu, Rosen, Wang, & Schaefer, 2015). Finally, different technologies and manufacturing infrastructures require the consideration of the physical environment as a precondition for a successful implementation (Avanzini, De Angelis, & Giulietti, 2016; Gatti, Giulietti, & Turci, 2015; Hocraffer & Nam, 2017; Hossein Motlagh et al., 2016; Murray & Chu, 2015; Olivares & Cordova, 2016; Olivares et al., 2015; Tang & Tomlin, 2008).

From an economic perspective, drone *delivery costs* and *time* in comparison with truck delivery in last mile delivery should be taken into account before a decision on drone implementation is made (Tavana et al., 2017). While drones are expected to lower transportation cost (D’Andrea, 2014), these gains may only materialise, as Wang (2016) points out, if delivery frequency and the number of deliveries in a delivery area are high enough. Overall, Kückelhaus (2014) states that

> *“smaller, affordable UAVs are still disappointingly expensive, and large unmanned helicopters almost rival their manned counterparts in terms of cost, maintenance, and infrastructure requirements, eliminating their major advantages”* (Kückelhaus, 2014, p.18).

Regarding technical challenges, one of the most important factors is *battery performance* (Hassanalian & Abdelkefi, 2017; Olivares et al., 2015) and the resulting *range, payload and speed capabilities* (Murray & Chu, 2015). Although there are some potential innovations, such as using laser beams to reload batteries during flight (Hassanalian & Abdelkefi, 2017), limitations in the battery performance of drones are a fundamental concern for the time being. However, battery development has recently made significant progress (Olivares et al., 2015). Further developments are needed to improve the indoor delivery capacity of drones. Apart from range, payload and speed, battery performance also determines the reliability *of* drone-transport services (Olivares & Cordova, 2016). Recent literature focuses on *maximum endurance* (Gatti et al., 2015) or optimal performance and the *sizing of batteries* (Avanzini et al., 2016). Only few battery performance within the context of specific use-cases. In practical try-outs on factory premises, the drones employed had a maximum flight time of about 30-40 minutes (Staedtler & Haberstroh, 2018). Olivares & Cordova (2016) suggest a drone-fleet model that calculates the number of drones necessary to ensure deliveries because battery endurance is still a severe concern (Hassanalian & Abdelkefi, 2017).

Payload significantly influences the use of drones in intralogistics from a technical, and not only cost-related, perspective (Kückelhaus, 2014). In the DHL test of medical supply delivery, the drones' weight was 5 kg and the transported load weighed about 1,2 kg (Bryan, 2014). The Amazon's Prime Air service is able to handle 2,2 kg, which matches or exceeds the weight of about 86% of Amazon's delivered goods (Liu, Balke, & Lin, 2008; Tavana et al., 2017). Contrary to these sources, Olivares et al. (2015) use in their battery try-outs a drone of five kg weight and an additional 20 kg of payload. These use cases would comply with German government regulations, which currently allow the operation of a smaller drone below 25 kg of weight including payload without a larger permission process, which is required if drones are heavier (Dobrindt, 2017).

The drone delivery concept DelivAIRy of the Fraunhofer Institute IML is able to handle 5 kg of payload (Fraunhofer IML, 2016). Using the classification suggested below in section 2.3.1, the payload aspect may affect the selection of the DIALOOP drone class (DDC) for possible implementations. Analysing the literature on the technical challenges of drones, battery performance emerges as the leading factor followed by payload and endurance. In the future, battery density as an aspect of battery performance may show the steepest development curve. However, hybrid versions of drones, which are also able to travel on the ground, may offer energy efficient solutions, and the potentials of their implementation should therefore be explored.

Within *organisational considerations*, a number of aspects have to be addressed such as the *acceptance* of drones by employees, *ethical considerations* in the application of drones and human-machine interactions (Arroyo, Lucho, Roncal, & Cuellar, 2014; Bauernhansl, Hompel, & Vogel-Heuser, 2014; Moniz & Krings, 2016; Pauner et al., 2015; Phillips & Linstone, 2016; Rao et al., 2016; Vincenzi, Terwilliger, & Ison, 2015; G. Zhang, Liang, & Yue, 2015; T. Zhang, Li, Zhang, Liang, & Li, 2017). Drones need to be able to deal with complex tasks in difficult environments, such as with *obstacles to avoid* (Trujillo et al., 2015). Trujillo et al. (2015) also point out the importance of an effective human-machine interaction. There, especially the *risk of collisions* needs to be taken into account (Zhang et al., 2017). Apart from collisions, also *noise emissions* are of concern in environments shared by humans and machines (Kunze, 2016). Clothier et al. (2015) consider *safety and security* as complexity drivers for drone implementation. Challenges to drone usage that result from drones' social impact in commercial environments can be summarised as *security, safety, ownership, privacy* and *regulation* (Rao et al., 2016).

Although there are solutions to some of these challenges, such as boundaries for flight space to avoid collisions (Khosiawan & Nielsen, 2016), Luppicini & So (2016) suggest in their literature review, which focuses on *safety, ethics & morals, legal aspects, privacy, and air* *space* and *information integrity*, that more research on the social and ethical aspects of drone usage is needed. Indeed, while there are fewer concerns with regulations and privacy on private property (Kückelhaus, 2014), the empirical results of this research show that the welfare of the employees on corporate ground figures prominently in the minds of the interviewed experts.

In special perspective to intralogistic requirement a basis for autonomous vehicles is given by Fottner, Hormes, Freitag, & Beinke (2021) who identify specific challenges by process areas. Although drones are not explicitly named, they can be seen as one element of the addressed AGVs in Johannes Fottner et al. (2021). The following Table 2.2 summarises the logistic process area differentiation with main influences on the research at hand.

Table 2.2 Intralogistic challenges for autonomous vehicles, adapted from Fottner et al. (2021)

Process Area	Challenges for autonomous vehicles
Transportation	Identification and localisation, safety by cameras and lasers, communication networks, routing, and bypass
Storage	Uniform loading equipment, high automation, real time data usage
Order Picking	Multi-level picking, splits, heterogeneity of orders and range, masses and volume, sensors and gripping technology, more human interaction lead to mor safety requirements and sensors
Handling and packing	Assignment and handling challenges, identification of products
Summary future challenges of intralogistics	Multiple flexible systems, humanoid and flexible, AI driven, human-machines interfaces. Overcome challenges of technical and societal nature, importance of forming process together with technology

With a special focus on drones in intralogistics only few sources discuss implementation in literature review. The main element clearly was identified to be manoeuvrability (Beul et al., 2018) in strong relation to navigation in indoor environment and positioning (De Croon & De Wagter, 2018; Wawrla et al., 2019; Winkvist et al., 2013). Intralogistics therefore requires a special focus on path planning (Li et al., 2018) in combination with high obstacle avoidance ability (Olivares et al., 2015). This has to include the reduction of risk of damage on facility and workers accordingly (Khosiawan & Nielsen, 2016). Multiple routings and high number of parts (Olivares et al., 2015) as well as the payload (Wawrla et al., 2019) are increasing the complexity level intralogistics in automotive environment.

Maghazei & Netland (2019) specifically focus on a differentiation of challenges in categories and list those in terms of importance, stated in Table 2.3.

Table 2.3 Challenges for drone implementation in manufacturing, adapted from Maghazei & Netland (2019)

Categories	Challenges
Technical	Because of battery, followed by navigation and data transfer, safety, and noise
Operational	Need of sight and skilled pilots, challenging environment, needed redundance e.g. parachutes, propulsion
Organisational	Skilled pilots, understand drones and tasks of operations, digitisation in the background for drone usage
Legislation and regulation	Variation between countries, lack of responsibility and unknown application cases
Social and mental	Based in safety and privacy concerns and knowledge of drones in military application

Comparing the two approaches to listing challenges, the author concludes, that both are comparable with some elements of Maghazei & Netland (2019) being found in Fottner et al. (2021). Especially technical and operational matters are highlighted and less organisational, legislative and social matters are addressed if the adoption of Fottner et al. (2021) is organised in the categories of Maghazei & Netland (2019), see *Table 2.4* below.

Table 2.4 Categories of challenges, Source: The Author

		Categories by Maghazei & Netland (2019)				
	Process Area	Technical	Operational	Organisational	Legislation and regulation	Social and mental
Differentiation by Fottner et al. (2021)	Transportation	Identification and localisation, safety by cameras and lasers, communication networks,	Routing and bypass			
	Storage	Uniform loading equipment	High automation, real time data usage			
	Order Picking	Multi-level picking, splits, sensors and gripping technology	Heterogeneity of orders and range, masses and volume	Human interaction		Safety requirements
	Handling and packing	Handling challenges, identification of products				

By contrast, although not named in detail by Fottner et al. (2021), the organisational, legislation and social factors are more explicitly highlighted by Maghazei & Netland (2019).

However, as Maghazei & Netland (2019) are the only source found in the literature that address drones explicitly, the researcher adopts their evaluation of significance as listed in above, see *Table 2.3*.

A precise understanding towards automotive OEM logistic operations in combination with drones is yet to develop and will be part of this research.

2.3 Positioning of the contribution of the literature towards a framework

This section contains two sub-sections. The first presents a final conclusion on the review of the literature on drone classifications and proposes a classification system specifically for the purpose of this research. The second section proposes a preliminary draft of the DIALOOP framework, which bridges the area of automotive intralogistics on the one hand and the area of drone application on the other. The framework draft is the object of, but also provide a structure to, the further research process in this research. It is drafted on a literature basis, drawing on existing frameworks in neighbouring areas. In the course of this research, empirical data are gathered and used to refine the framework and supplement it with a knowledge base reflecting the current state of OEM intralogistics operations and drone technology and application. The applicability and ease of use of the finalised framework are of concern already at this drafting stage, and, for this reason, a user-friendly multiple-step approach is embedded in the framework.

2.3.1 Drone classification system for automotive OEM intralogistics

This sub-section summarises section 2.2.2 on drone classifications as a first step to develop a tentative model for the DIALOOP framework. As there are numerous applications but no specific standards, a valid classification is absent (Rao, Gopi, & Maione, 2016), but are developed in this research in a preliminary form. The more indicators are integrated and linked to each other, the stronger will the future framework be (Neely et al., 2000). The framework furthermore needs to include all key indicators for the integration of drones (Dewangan & Godse, 2014).

Many authors suggest a classification using both size and weight (Gupta et al., 2013; Hassanalian & Abdelkefi, 2017); others only use weight for their respective drone classifications (Arjomandi et al., 2007; González-Jorge et al., 2017; Szczepański, 2015; Weibel & Hansman, 2004).

Two approaches to classifying drones are used in this research. Besides size, the second classification used in this research is based on a drone-type classification using elements presented in section 2.2.2.2. This classification approach distinguishes rotor-based drone, fixed-wing drones and hybrid drones.

Table 2.5 Suggested classification for drones in automotive OEM logistic operations, Source: the author

Conceptual classification

Rotor-based	Fixed-Wing	Hybrid	Max. Takeoff-weight
DC* 1-R	DC 1-F	DC 1-HT	small [<2kg]
DC 2-R	DC 2-F	DC 2-HT	medium [<10kg]
DC 3-R	DC 3-F	DC 3-HT	large [<25kg]

*DC = DIALOOP Class

In Table 2.5, the DIALOOP drone classification is presented. For intralogistical applications, the size always should be as small as possible, and, therefore, size is only of secondary rank as a classification differentiator in this research. Instead, weight is used as a leading differentiation. The upper weight limit of DC Class I is two kg (Hassanalian & Abdelkefi, 2017; Szczepański, 2015). The upper weight limit of DC Class II drones was set following different authors. Five kg were indicated as a useful limit by Hassanalian & Abdelkefi (2017). Additionally, as transportation plays a major role, the possible weight of the payload is considered as well. The payloads mentioned ranged from one kg (Bryan, 2014) to about 2.2 kg (Liu et al., 2008; Tavana et al., 2017) and up to five kg (Fraunhofer IML, 2016). For the purpose of the classification system developed here, drone weight and payload of medium DC Class II drones are added, and the resulting upper weight limit is ten kg. The largest class, DC Class III, then has an upper limit of 25 kg of take-off weight, which is in agreement with the regulations of the European Union (EASA, 2018b). As already observed in section 2.2.2.1, over the years and in the context of different applications, multiple size classification have been suggested in the literature. Yet, drone technology can change developments in logistics (Stark, 2015) if applied in a suitable way.

2.3.2 Concept of the DIALOOP framework

The following section develops a DIALOOP framework using elements identified in the literature. The structure of the framework aligns with intralogistics requirements (Boysen et al., 2015; Jahre, Pazirandeh, & Wassenhove, 2016; Paião, 2014).

The logistics framework developed by Marchesini & Alcântara (2016) with its five steps that reflect logistical activities in the supply chain is comparable to the five step “ART framework”, an evaluation matrix for technology (Gladysz & Santarek, 2015). The basic element of the ART framework, the actual-target comparison, has been shown to be adequate for assessing RFID technology (Dovere, Cavalieri, & Ierace, 2015); hence, it can also be used in the context of drone implementation. Any step-wise approach similar to the ART framework can be used to reach a greater depth of detail as demonstrated by Klingbiel’s (2006) build-to-order reference model by differentiating between tasks and activities (Klingebiel, 2006). This would allow for a more in-depth analysis of logistics processes and process areas in a combined approach. However, the framework developed by Dörnhöfer et al. (2016) offers a solid structure for assigning measures and indicators to processes without specifying the assignment approach. The authors state that their performance measure definition sheet is applicable throughout the entire automotive supply chain and that it can help address the problem of insufficient standardisation of processes in the automotive sector (Dörnhöfer et al., 2016). The framework is based on logistics processes and, therefore, features a minutely detailed approach to single measures. This multi-perspective capability is important because, as Dörnhöfer (2016) points out, a performance measurement system has to align with a company’s aims and strategy.

Many of the papers reviewed in this thesis have successfully used an overarching approach. The structure of the framework to be developed in the following combines the aspects of drone application (section 2.2.1), drone classification (section 2.3.1) and performance measures within automotive OEM intralogistics operations (section 2.1.3). From a content design perspective the framework should contain the following elements, which are derived from the following framework analysis.

The performance pyramid, also called “SMART” system (Ghalayini & Noble, 1996) offers a useful basis for the approach to framework development taken in this thesis. Its dual starting perspective – a vision perspective and a market perspective – lends itself to developing objectives and is adopted in this research. The objectives derived in this dual-perspective approach lead to a set of decision parameters in operations (Ghalayini & Noble, 1996). This is of advantage to the framework developed here because this framework should be applied on the basis of performance measures similar to the decision parameters.

Logistics operations, measures, strategy and characteristics are furthermore addressed from a structural point of view in the framework established by Vidal Vieira et al. (2017), which, however, only focuses on distribution centres. Nevertheless, this structural approach is highly applicable. It incorporates a strategic view, a listing of activities highly comparable to process areas, and activities, which are largely equivalent to logistics operations. The authors also address the characteristics of the operations and develop a table for comparing the sub-activities, which in the case of the adapted version of this table used in the thesis are the logistics operations. Using a scoring system, Vidal Vieira et al. (2017) compare and rate the technological alternatives according to different criteria. The combination of strategy, activities and sub-activities as well as characteristics of the logistical process is suitable to the approach taken in this thesis. The framework can be adapted to focus on a strategy, a process, a cost, a supply and an item's view (Vidal Vieira et al., 2017). The framework established by Vidal Vieira et al. (2017) furthermore contains elements that structure the design of the DIALOOP framework. Taking logistical strategy into account can help broaden the approach to correlate the strategic with the operative level. By contrast, a rating of sub-activities of logistic operations in the research at hand may not be possible because of the still nascent nature of the research topic of the lack of detailed descriptions of those activities.

Marchesini & Alcântara (2016) describe a more narrow, conceptual framework that can be applied in a multiple-step mode and addresses logistics activities against the background of supply chain business processes. In a first step, their framework defines logistical core activities and, in a second step, characterises these logistical activities with regard to their necessity (e.g., optional and mandatory), their impact on customer-value creation and their impact on logistics service elements such as order-cycle speed or flexibility in the distribution system. In a third step, logistics activities appropriate for the company at hand are selected and, in step four, their requirements in terms of coordination and integration with functional areas and business processes is identified. In step five, their performance after integration is measured (Marchesini & Alcântara, 2016). These main steps can be applied the research at hand in order to identify logistics activities suitable for drone usage and to evaluate the benefits of drone deployment in these activities. The framework above would be particularly suitable to this goal in that it helps match logistics operations with performance measures.

The framework created by Klingebiel (2006) focuses on the BTO process, and is comparable to the frameworks mentioned previously. The BTO framework is more similar to the following approach taken by Gladysz & Santarek (2015) than to that of Marchesini & Alcântara (2016) because the former take a more strategic perspective while the latter provides more into detail in identifying logistics operations. The elements of the BTO framework include an actual-state analysis, the identification of the field of action and relevant processes and the specification of the target process (Klingebiel, 2006). This division in steps as well as integrating the strategic perspective seem suitable to the approach taken in this research. This research adopts a combination of these step-based structures.

Likewise, Gladysz's & Santarek's (2015) approach to developing an evaluation matrix for a technology, specifically RFID, can also serve as a basic platform for developing a drone and logistics framework. Their framework first focuses on strategic matters. In this phase, company and market data as well as technology data are gathered. Then, process data is gathered, followed by choosing and rating the application area. In a comparison of as-is processes with to-be processes, the influence of the new technology on the area in focus is determined. In the final stage, the technology is evaluated.

The described framework is partly adopted for the data-gathering phase, in which through semi-structured expert interviews data on the as-is state in all the process areas is collected. Other parts of Gladysz & Santarek's (2015) framework cannot be used as no extensive comparison between as-is and to-be processes is possible. While current solutions are identified, they cannot be numerically compared to the nascent drone technology given the latter's relative novelty. Additionally, this research does not implement an evaluation stage based on listed or rated indicators because this would require a high degree of speculation. While the still nascent nature of the research topic demands a data-gathering approach with a high level of interpretation and flexibility, the goal is to collect, and use, data solidly based in empiricism.

The approach is also strongly informed by Dörnhöfer et al. (2016), who develop a performance measurement system and suggest a modular structure with a focus on processes and systematically organised key performance indicators (KPIs). Their approach is based on a comprehensive analysis of the literature and a case study. However, the authors' highly detailed process analysis in current logistics cannot be adopted in this research because of the research topic's nascent nature. Instead, the research takes a rather strategic perspective. Dörnhöfer (2016) highlights the importance of the usability and expediency of a performance measures framework. Additionally he suggests a multi-step approach to the implementation of the performance measurement system in a German automotive OEM. He also recommends to start with the definition of company-wide goals followed by a definition of as-is processes and performance measures (Dörnhöfer, 2016). The proposed actual-target comparison is similar to the one in the framework developed by Klingebiel (2006).

To combine the features of the discussed frameworks that are relevant to the research at hand, the framework to be developed should encompass:

1. **A strategy-based multistep structure**
2. **A detailed matrix of logistics operations**
3. **A detailed matrix of performance measures**
4. **An outline of the effects of the future changes**

Regarding performance measures, the nascent theory of drone application can draw on the quite mature field of logistics in automotive OEMs. The above review of frameworks suggests that the framework to be developed should use a matrix structure to link the strategic and operational dimensions of drone applications in automotive OEM intralogistics operations.

The outlined DIALOOP framework steps thus informs the research process, including the data-gathering process, while the research process complements the framework outline with concrete elements. A proposed structure is then given in chapter 5.

2.4 CHAPTER CONCLUSION

In the course of the literature review, the following observations are made that outline the research gaps, which this thesis aims to fill.

Observation 1: There is a large body of literature on logistics operations, but there are only few sources on automotive OEM logistics operations

The literature review on logistics operations (section 2.1), showed that there are multiple perspectives on this topics and that logistics operations are subject to numerous influencing factors. Section 2.1.1 reviewed literature on diverse areas ranging from supply-chain to small-scale logistics. It was found that supply-chain-based paradigms such as mass customisation and BTO tend to influence plant logistics and manufacturing within automotive OEMs. In this regard, Industry 4.0 and smart manufacturing appeared to be highly significant. With new assembly alternatives (Kern et al., 2017), the focus in the literature has again shifted in recent years to in-house processes. Therefore, Lafou et al. (2015) highlight the importance of research in operations. Concerning manufacturing, Vázquez-Bustelo et al. (2007) suggest that a flexible production model could be a solution to the problems posed by a fast-changing environment, as it combines agility with a focus on low costs, an increase in service level and a shortening of delivery times (Vázquez-Bustelo et al., 2007). Gunasekaran & Kobu (2007) state that

> *“the main challenge is to identify the key performance measures for value-adding areas of an organization and then the factors that will affect the core*

business processes that create wealth to customers" (Gunasekaran & Kobu, 2007, p. 2821).

All systems are constantly changing (Melnyk, Bititci, Platts, Tobias, & Andersen, 2013) and, hence, performance attributes or metrics need to be revised frequently. Against the background of the need for constant revision, Dörnhöfer et al. (2016) propose to expand the performance measurement system for automotive OEMs. This research therefore contributes to the body of knowledge through semi-structured expert interviews on current logistics operations in up-to-date process areas to confirm or expand the findings generated (section 2.1.2). Furthermore, this research contributes to the state of the art regarding existing performance measures in automotive OEM logistics operations (section 2.1.3) considering identified influential paradigms and trends. The literature review has thus confirmed the importance of research objective 1 (section 1.3).

Observation 2: Lack of literature on drones in automotive OEM logistics operations

There are only a few sources concerning drone experiments in automotive OEM logistics operations environment (section 2.2.1) and none considers automotive intralogistics. Furthermore, there is a lack of literature on the implementation of UAVs (Bechtsis, Tsolakis, Vlachos, & Srai, 2018), although, as Idries et al. (2015) argue from a project management perspective,

> *"UAV applications offer great opportunities for providing cost-effective solutions for diverse applications that require different capabilities for the various tasks involved"* (Idries et al., 2015, p. 1).

There is thus a need for research that investigates if drones can function as enablers in these environments and how they affect process areas and logistics operations. It can be assumed that drones are also useful in indoor environments (Khosiawan & Nielsen, 2016), although only a few publications were found in the area of drone usage, e.g. in internal parts logistics (Olivares et al., 2015), and no publications on drone usage in automotive manufacturing logistics seem to exist. This also means that to the best of the authors knowledge there is no framework for the implementation of drones in this area.

It can be summarised that there is no research specifically on the use of drones in automotive OEM logistics operations. The literature discusses a number of applications of drones (section 2.2.1) and performance measures influenced by drone applications (section 2.2.3). The results are, however, difficult to generalise as the technical specifications of drone types vary greatly (section 2.2.2). This research therefore aims to identify logistics operations in automotive OEM intralogistics operations in which drones can be applied along with performance measures that could be affected by drone implementation. Overall, this observation shows the relevance of research objectives 2 and 3 (section 1.3).

Observation 3: Lack of a framework for drones in automotive OEM logistics operations

Currently, there are numerous frameworks regarding the use of conventional aircraft, but there is no framework for the application of small drones (Chatzimichailidou, Karanikas, & Plioutsias, 2017). There is thus a need for research on frameworks for drone solutions (Idries et al., 2015). Such frameworks should be based on application experience and cases and should address drone performance in order to reduce the challenges that go along with drone implementation (Idries et al., 2015). Presently, given the only marginal degree to which the topic has been investigated, there is no framework based in empirical evidence. Idries et al. (2015) highlight that there is a

> *"lack of existing technologies and management methodologies that can be utilized to effectively develop UAV applications"* (Idries et al., 2015, p. 1).

This research addresses this research gap with respect to management methodologies, in this case a framework. Future research is suggested to investigate business models, emerging technologies and enabling factors (Esmaeilian, Behdad, & Wang, 2016). In general, a scoring-based framework should be created, to which end, areas and factors need to be determined that influence, depend on, or are interdepend with the application of drones (Benaim, 2015). In the research at hand, these factors are the performance measures. Clothier et al. (2015) propose to concentrate on fostering an understanding of technology, benefits and risks, which may help to create a greater acceptance of drones among stakeholders, such as employees. As there are many organisational units involved in the technology integration in logistics operations, a well-developed understanding is definitely a benefit.

Furthermore, chapter 2 summarised the literature on drone classification (section 2.3.1) and suggested a conceptual outline for the DIALOOP framework (section 2.3.2). This framework is designed to include the as-is state of a company's logistics operations, a drone classification, a determination of logistics activities suitable for drone implementation, and performance measures and to be able to address certain challenges and changes (section 2.2.4).

Observation 3 informs research objective 4 as well as research objective 5 (section 1.3).

The literature review has thus confirmed both the relevance as well as the scope of the research objectives, which therefore continues to be used as a guide for the further research process.

3 METHODOLOGY

This chapter presents an overview of the methodological choices made in this research to answer the research question and to accomplish the research objectives. In addition, the chapter presents information about the sample and its selection, describe the planning and implementation of the empirical data-gathering process as well as the methods used to analyse the collected data and to assure the quality of the research.

3.1 RESEARCH PHILOSOPHY

This section is about the research philosophy. *"Research philosophy refers to a system of beliefs and assumptions about the development of knowledge"* (Saunders, Lewis, & Thornhill, 2016, p.124).

A research philosophy rests on two sets of philosophical assumptions: ontology and epistemology. While "*ontology refers to assumptions about the nature of realities*" (Saunders et al., 2016, p.127), epistemology "*concerns assumptions about knowledge, what constitutes acceptable, valid and legitimate knowledge*" (Saunders et al., 2016, p.127).

It is thus one of the challenges faced by researchers to determine and define the foundational assumptions about the nature of reality and knowledge that inform their work and methodological choices (Saunders, Lewis, & Thornhill, 2016). The philosophical position defined in the following sections is the basis for the subsequently described choices concerning the research method.

3.1.1 Constructionism as an ontological stance

Within business research, there are two competing paradigms, namely objectivism and subjectivism (Bryman & Bell, 2015, p.35). According to Saunders, Lewis, & Thornhill (2009), *objectivism* is *"an ontological position that asserts that social entities exist in a reality external to, and independent of, social actors concerned with their existence"* (Saunders et al., 2016, p. 722). In contrast, subjectivism as a philosophical view means that the researcher is mostly interested in perceptions and opinions as they shape reality, which means that there can be different subjective realities (Saunders et al., 2016). A less extreme form than subjectivism is social constructionism, which means that social interaction creates a reality that the actors have at least partly in common as their perceptions, assumptions and interpretations partly overlap (Saunders et al., 2016). This view lends itself as an appropriate anchor for this research because the individual interviewees create meaningful information based on their knowledge and experience gained in a shared professional context. Subjectivism, as an element inherent in constructionism, acknowledges the existence of multiple perceptions of reality (Saunders et al., 2016), which is particularly valuable for an understanding of actors in an (industry) environment. Bryman adds to this perspective that few suggestions for changes can be made (Bryman & Bell, 2015). As it is the purpose of this thesis to create a framework for exploiting the potential of implementing drones in automotive OEM logistics operations, the data gathered from the interviewees has to be assumed to result from, and reveal, a commonly shared, although partly subjectively interpreted, reality. Following these arguments, *constructionism* is chosen as an ontological perspective.

The following section presents an epistemology suitable to the above-outlined ontological view.

3.1.2 Critical realism as an epistemology for interpreting research data

A basic differentiation in epistemology is often made between the two dominant philosophies of *positivism* and *interpretivism* (Saunders et al., 2016, p.129).

Positivist researchers consider themselves as observers of an objective reality not shaped by perceptions, and they therefore frequently prefer measuring as an approach to their subject of study, which often involves the testing hypotheses (Bryman & Bell, 2015, p. 27). The implementation of drones within automotive OEM logistics operations is as of yet a nascent field that does not provide measurable data and still has to be explored further before hypotheses can be formed. A positivist paradigm is thus not suitable for guiding research at this early stage of development of this field. It would also not harmonise with the constructionist view outlined above, which considers a reality as a shared set of assumptions, expectations and perceptions. Instead, positivism would be in agreement with objectivism in its assumption that reality is an objective, and objectively measurable, entity.

Interpretivism is a perspective contrary to positivism. Interpretivism focuses on the interpretation of the meaning of data (Saunders et al., 2016, p.141). Quinlan et al. (2018, p.59) even emphasise that all knowledge results from interpretation. Interpretivism also acts as an implicit criticism of positivism in the context of social sciences (Quinlan et al., 2018, p. 59) because people and social institutions can hardly be analysed using methods of the natural sciences (Bryman & Bell, 2015, p. 28).

In recent decades, other epistemological perspectives than interpretivism and positivism have developed. *Critical realism* can be seen as a trade-off between positivism and interpretivism (Georges, 2020, p. 52). Critical realism puts its focus on understanding, describing and interpreting the social world and individual and collective experience while assuming that there is a common reality underlying all observable phenomena (Bryman & Bell, 2015; Fleetwood, 2005; Saunders et al., 2016). In exploring phenomena, critical realists have to reduce complexity in order to arrive at explanations for their data (Havar-Simonovich, 2012), which is an inevitable and necessary aspect of creating models or, in the case of this research, frameworks.

Postmodernism emphases "*the role of language and of power relations, seeking to question accepted ways of thinking*" (Saunders et al., 2016, p.141). Although postmodernism has some similarities with constructionism (Saunders et al., 2016, p.142) as the ontological stance of this thesis, its focus on language and power does not lend itself to investigate questions of practical applications of technologies (such as drone implementation) and it is therefore not suitable for the thesis.

In *pragmatism*, "*reality matters [...] as practical effects of ideas, and knowledge is valued for enabling actions to be carried out successfully*" (Saunders et al., 2016, p.143). However, pragmatism's focus on the effectiveness of action may, in situations in which effectiveness cannot be observed, lead to a practice of knowledge-generation that is, in the final analysis, subjective, for example if fieldwork with many individuals is carried out (Georges, 2020; p.53). It is thus unsuitable for the research at hand, which also cannot observe effectiveness for lack of an implementation of drones in the researched context.

The final decision is thus made in favour of critical realism as it corresponds best to need to address an objective reality (the technical and economic effects of drone implementation) through socially constructed, partly subjective perceptions and opinions (the data gathered in expert interviews).

3.2 RESEARCH APPROACH

Saunders et al. (2016) distinguish three research approaches in their so-called research onion: deductive, inductive and abductive.

The *deductive approach* is based on a large variety of literature and data and thus aims at forming a theory. Also, it typically produces a set of hypotheses later to be tested using data (Saunders et al., 2016). In the case of this research, the deductive approach is partly applicable as there is a body of literature on logistics operations and on drones (Kovács & Spens, 2005), which is drawn on to define process areas and performance measures and to classify drones.

However, as the research approaches a new field and relevant literature is still lacking, an *inductive approach* would be more appropriate as it involves gathering and analysing relevant data (Saunders et al., 2016). As this thesis's first part gathers current knowledge on logistics operations in automotive OEMs and addresses the implementation of drones in this on a literature basis to draft a framework that is thus based on a theoretical foundation, a deductive approach is implemented. The result can be used to inform further research

(Andreewsky & Bourcier, 2000). However, the second part of this thesis employs an inductive approach as induction involves identifying patterns, for example in the expert interviews conducted for this thesis, and, on this basis, creating theory or, in this case, a conceptual framework (Saunders et al., 2016).

The described combination of approaches is in agreement with Saunders et al. (2016), who state that different approaches can be applied in the same study. In contrast, Knox (2003) concludes, that only one approach should be chosen for a single topic. To mitigate the conflict between these views, the *abductive approach* can be used, which is discussed regarding its application in a logistics context by Kovács & Spens (2005). Abduction is a combination of deduction and induction (Roy Suddaby, 2006). Based on its meaning in Latin, Kovács & Spens (2005, p. 138) define abduction as a way *"to present a plausible but not logically necessary conclusion"*. They argue that abduction breaks the boundaries, implicit in deduction, of basing research only on already existing theory and knowledge (Kovács & Spens, 2005). Although Kovács & Spens (2005) identified possible translation errors by quoting ancient sources and that abduction would have possibly had to be translated as retroduction, they decided to furtherly use abduction for their work. Overall, abduction and reduction are said to take place in different phases of theorising, seeing "abductive conclusions provide the starting point for retroductive inferences" (Ritz, 2020, p.462). Further, Olsen & Gjerding (2019) argue, that both abduction and reduction are the backbone of critical realism and are at some parts overlapping, stating that "abduction is a necessary preliminary—and a partial aspect of—retroduction" (Olsen & Gjerding, 2019, p.14). For the above reasons, this thesis employs abduction in its nascent research process, by using a foundation of theoretical knowledge on logistics operations and to the extent available, on drone technology and its applications to arrive at a conceptual framework, which, in a further research step, is tested and potentially revised using data specifically gathered for this purpose.

With abduction having been chosen as the research approach employed in this thesis, the question of what kind of data to collect and how to collect this data needs to be answered. This is the subject of the following sections.

3.3 METHODOLOGICAL CHOICE

This section discusses methods of the type of data to be collected and the method of data collection. The first choice to be made concerns the type empirical research to be conducted: quantitative, qualitative and a mixed research approach (Creswell, 2009; Vogt, 2016). Knox (2004) links quantitative research to more positivistic and qualitative to more interpretivist ontological and epistemological stances. A qualitative approach is also often used with abductive research (Saunders et al., 2016; Yin, 2014). As the choice of an approach depends to a large part on the maturity of the research done so far on a topic, the first of the following two sections addresses the maturity of drone research in logistics and the second section outlines the decision process regarding the methodological choice taken in this thesis.

3.3.1 Maturity of the research topic

Edmondson & Mcmanus (2007) differentiate the maturity levels of nascent, intermediate and mature for research topics and present the implications of these maturity levels for the research process ranging from the research to the theoretical contribution. For a research topic that is still at a nascent stage, the research question is typically be open-ended inquiry, the type of data collected is usually qualitative and the data are collected through, e.g., interviews with the goal to discern patterns to which end the data then needs to be analysed thematically, e.g. by coding it, so that a first theory can be suggested (Edmondson & Mcmanus, 2007).

The research topic of drones in intralogistics is still at a beginning stage as there is, as of yet, no literature with a focus on this area. There are publications in neighbouring fields, such as in the fields of drones in general and drones in last-mile delivery, but even the domain of intralogistics as such is not particularly well researched. The topic is thus nascent.

3.3.2 Choice between qualitative and quantitative research

As the author has chosen constructionism as well as critical realism as ontological and, respectively, epistemological paradigm, and because the research topic has been shown to be at a nascent stage, *a qualitative research approach lends itself for the purpose of this thesis*. Constructionism, with its subjectivist elements, favours a qualitative methodology (Leung, 2015). A qualitative approach furthermore allows this thesis to draw conclusions on the basis of verbal data instead of numerical data (Saunders et al., 2009), which, given the absence of quantitative data is preferable. Because of a lack of a solid base of measurable data, context is important, as are processes, qualities and meanings (Gephart, 2004).

> *“Qualitative researchers also seek to explain research observations by providing well-substantiated conceptual insights that reveal how broad concepts and theories operate in particular cases”* (Gephart, 2004, p.455).

This quote from Gephart (2004) captures exactly what this thesis set out to do. It aims to generate insights in how current logistics operations are carried out and how drones could be implemented. The research finally focusses on those particular cases in which drones can be used. The task thus described requires the researcher to learn about a phenomenon by integrating context, situation and insights, which is a strength of qualitative research by interviews (Silverman, 2016).

In contrast, a quantitative approach would not be suitable for this thesis. Quantitative methods often rely on numerical data (Saunders et al., 2009), which are gathered in a precisely defined, standardised way. This data is then processed mathematically and statistically (Gephart, 2004), based on measures. Although literature on logistics operations is reviewed, the research focuses on the experience and also feelings and perceptions of specific experts and therefore does not produce numerical, measurable, statistically useable data. Because of the nascent nature of the drone topic and the identified research gaps, which is manifest in a general absence of directly relevant literature, a quantitative method would not be feasible for this research.

Instead, a *qualitative study* is carried out, which means that qualitative data and analysis are used (Saunders et al., 2016), in this study two datasets are used This approach can be described as sequential and exploratory (Creswell, 2009; Saunders et al., 2016). Creswell (2008) argues that this sequential exploratory method is suitable for a development of an instrument, which in this research is the to-be-developed DIALOOP framework. The first phase consists in gathering qualitative data and the second phase in designing the instrument. In the first stage, the first set of data was gathered using semi-structured interviews with experts from automotive OEM logistics operations. In addition, semi-structured interviews were conducted with experts on drone environments, which can also be from a non-automotive context. The interview results lead to a definition of the potential for drone implementation in automotive OEM logistics operations.

Overall, the research was planned as a *cross-sectional study*. The main reason for this decision is the fast-changing environment of drone technology combined with the need to create a first foundation for the nascent area of research addressed by this thesis.

3.4 RESEARCH STRATEGY

The research strategy links the research philosophy with the concrete methods with the aim to create a coherent research design (Saunders et al., 2016). This section describes the research strategy based on the above-mentioned multi-method qualitative approach. The strategy used in this thesis, the semi-structured interview, are explained in the following section, the section after that explains the decision taken with recourse to other strategies that were rejected as less suitable.

3.4.1 Semi-structured interviews

The purpose of this research can be described as predominantly exploratory. It aims to find out how something works, in this case via developing a framework (Saunders et al., 2016). To achieve a research goal, which may involve, or amount to, answering a research question, researchers have to create a plan for their approach and procedure, and this plan is their strategy (Saunders et al., 2016). The first part of the strategy chosen in this research is the semi-structured expert interview. Such interviews afford an opportunity to gather significant amounts of data (Bryman & Bell, 2015). Interviews can be held in many different forms. According to Silverman (2016), they range from

> *"highly structured, standardized, quantitatively oriented survey*
>
> *interviews, to semi-formal guided conversations"* (Silverman, 2016, p. 68).

Semi-structured interviews are often linked to a qualitative methodology (Saunders et al., 2016). They are frequent in exploratory research as well as in evaluative research (Saunders et al., 2016). This research combines an exploratory character in that it identifies potentials of drones implementation and an evaluative character in that it evaluates a framework in the second stage of qualitative data gathering. Of a particular benefit is the opportunity to explore new aspects of a topic that have formerly not been taken into consideration by the researcher (Saunders et al., 2016) by letting the interviewees answer freely and divagate to a certain extend. These properties of semi-structured interviews make them particularly useful for the research and they are therefore employed as research strategy. The semi-structured interviews allowed the researcher to move the interviews along the itinerary of important themes outlined in the interview guide, yet also afforded an opportunity to discuss all topics openly.

3.4.2 Discussion of other strategies

As stated by Saunders et al. (2016), there are also other strategies for qualitative research, and some of them are discussed in the following section.

The strategy of *archival research* uses archives and documents which are already available and are considered to be secondary sources (Saunders et al., 2016). However, there are no documents suitable for the purposes of this thesis, albeit a certain body of knowledge that can be drawn on exists in the experience and understanding of experts and can be accessed using interviews. For this reason, an archival approach is not possible.

Also a *case-centric approach* is not suitable as this research follows a process-area-centred approach. For similar reasons, a case-study approach is not feasible as it would require actual cases of drone application in the researched field of automotive OEM intralogistics operations, but such cases do not exist in actual practice.

Ethnography as a strategy focusses on groups and is often employed to study social and urban problems from a cultural perspective (Saunders et al., 2016). It is further a strategy that may require researchers to partly live or work among those they study and observe directly (Silverman, 2016), mostly with a focus on their behaviour and language and on themes and incidents (Saunders et al., 2016). Therefore, the ethnographer is involved actively in the everyday interactions of members of the observed population (Bryman & Bell, 2015), which would not be possible in the present case. Although this research aims to access the experience and understanding of experts, it does not focus on discovering differences between cultures or to find patterns of group behaviour. Therefore, ethnography was not chosen for this research.

Action research as a strategy is applied in an iterative way mostly in a problem-solving environment in which the researchers participate. This enables them to take part in steps such as identification, planning, action and evaluation as phases of a problem-solving cycle (Saunders et al., 2016). For this reason, action research is not suitable for this research. Although the researcher explores or identifies potentials for drone implementation, there is no subsequent planning for this implementation and no action. As the participants are from different companies, a continuous action or problem-solving cycle cannot be observed. Finally, the research is of a cross-sectional nature, whereas action research has a longitudinal character (Saunders et al., 2016).

Narrative inquiry as a strategy is used to gather information from a coherent story told by study participants, which enables the researcher to identify chronological connections and sequences as well as meanings and interpretations in the participants' narratives (Saunders et al., 2016). This research addresses several perspectives and fields of inquiry, which cannot be gathered in a coherent story as these information seemed to be very punctual. Finally, narrative inquiry also takes grammar, wording and the position of the audience during the narration into account (Silverman, 2016), which is suitable for research addressing social and psychological issues, but not for research with a technical and economic focus.

3.5 TIME HORIZON

The time horizon in a study can be of a longitudinal character or a cross-sectional character (Saunders et al., 2016). A cross-sectional study is typically conducted in qualitative research, especially in cases using unstructured or semi-structured interviews (Bryman & Bell, 2015). In cross-sectional research, data are collected in a so-called snapshot, meaning a certain point in time (Saunders & Lewis, 2012). Thus, cross-sectional studies analyse a particular situation at a particular point of time (Saunders et al., 2016). Longitudinal studies are generally used to investigate changes, which demand that data are collected over a period of time, e.g. before and after a particular event (Bryman & Bell, 2015); however, longitudinal study design are infrequent because of money and time concerns (Bryman & Bell, 2015). The type of study used in this research is cross-sectional, because the focus is on a current state of technologies and their potentials and, in addition, there is no change or development that could be investigated to answer the research question. A longitudinal study on this topic may be feasible in the future once automotive OEMs embark on projects to implement drones and cross-sectional before-and-after comparisons become possible.

3.6 DATA COLLECTION PHASE

The following part provides an overview of the data collection phase, which is the most important part of a research (Bryman & Bell, 2015). This section introduces the targeted group, the basic population and the sampling as major decision milestones for this research.

3.6.1 Sampling strategy and sample

The research population are logistics operations managers at build-to-order automotive OEM plants, in particular of German premium OEMs, as well as experts and managers of drone companies, which develop different applications for drones, as well as aerospace experts and researchers in logistics and drone topics.

In the research purposive sampling strategy is applied, which “ *is about purposively selecting specific participants for the study*“ (Y. Zhang & Wildemuth, 2017, p.137). They further state, that one “*will try to identify those participants who can provide you with the richest data on the phenomena*” (Y. Zhang & Wildemuth, 2017, p.137). Purposive sampling thus can be applied if combined with good quality of the research, meaning to “*include an explanation* *and justification of the choice of […] recruitment and selection of participants*” (V. Anderson, 2017, p. 4).

The research population can be divided into two main groups:

(i) ***Automotive experts*** from automotive OEMs with a focus on the BTO principle and high flexibility requirements because of high product variations are the first group. More precisely, the focus is on managers and experts with a proven record of experience in logistics-operations innovation in automotive OEM in-house-logistics. Also, managers and experts of drone activities in logistics with a focus on short-range delivery and potential in-house applications are considered, as well as experts focussing on logistics and production operations in automotive OEMs.

(ii) ***Drone experts*** include experts who focus on using drones in the logistics-operations field or experts from a non-automotive background with a focus on applying drones in multiple areas. Further, researchers with an automotive or non-automotive background focussing on research related to drones are considered.

The first research population, automotive experts, is comprised of employees in specific companies in the German automotive sector, who are in direct contact with logistics-operation innovation and development. Furthermore, automotive companies under consideration have to pursue to a very high degree a BTO strategy. The focus on those car manufacturing companies and interviewees results from the thesis' scope on German car manufacturers (Germany Trade & Invest, 2020). Although these companies employ thousands of people, the author identified about 100 which are seen as a relevant logistic operations – based population. This number based on the authors' professional understanding whilst using company organisation charts as a guiding indication. The charts were accessible as an element of the authors employment as a business consultant.

The second research population, drone experts, includes drone experts from research institutes and drone start-ups, or developers. These interviews allow for the integration of drone experts' knowledge about the abilities of drones as a base for a possible integration in automotive OEM logistics operations. The size was – at the best of the authors' knowledge – assumed to be about 30 experts in Germany with relevant experience in logistics. This assumption is based on experience from drone conference speaker list as well as results from LinkedIn. Here the author used related search terminology as in the literature review. All experts are required to have a minimum of three years of relevant experience in the research field. Further details to the recruiting are described in the following section 3.6.2.

Validation interviews

Depending on the answers of the participants, it was planned to conduct validation interviews with the same group of automotive experts. During the research, the author changed jobs and was then working for one of the automotive OEMs. Participants from competitors were presumably no longer able to support the research and were not allowed to because of provisions of German cartel law. The new situation led to a high risk of interview cancellations, which in turn would result in a significant delay in the completion of this thesis. The number of validating interviews therefore shrank to the number of respondents within the company to which the author had changed. Finally, three validation interviews were conducted as only three interviewees replied to the request of another interview.

Dual verification of expert level

The interviewees' expertise level was validated in a two-step process. In the first step, the expert level was queried in the interviewee search phase: the invitation letter specified a minimum of three years relevant work experience in the respective sector as a precondition to participate in an interview. In the second step, verification questions about the experience of the individual participant were asked at the beginning of the interview (Appendix C). These questions also allow to distinguish different levels of experience in the interviewees and, thus, make it possible to evaluate the quality of the data gathered from an interviewee.

3.6.2 Recruitment of interviewees

Contacting possible interview partners was done by e-mail. The e-mails contained the information sheet and the consent form (Appendix C). For the recruitment of drone experts, invitations were sent via e-mail to their e-mail addresses, which were found on their online profiles or in professional social media networks, e.g. LinkedIn. The information sheet as well as the consent form were attached to the e-mails. In some cases, initial contact with drone experts was made at conferences; the names of these experts were gathered by the author from press articles or publications during the course of this research. Contacting for the two sets of interviews took place in the first six months of 2019.

The following paragraphs describe the inclusion criteria for automotive and, respectively, drone experts.

<u>Automotive interviewees</u>

In the search for interview partners, OEM companies applying a high build-to-order strategy in the automotive sector are considered. From these companies, individuals for the first interview session were invited who meet the following inclusion criteria. Automotive experts were selected if they were in direct everyday contact with relevant logistics operations and corresponding processes. They were also eligible if they professionally dealt with logistics devices and vehicles or the development of those. Apart from experts in logistics operations, processes and assets, also experts in logistics innovation or logistics planning were eligible depending on their knowledge about logistics processes and their involvement in logistics topics. Also experts in other, neighbouring topic areas, such as smart factory, were eligible.

In an ideal case, experts in automotive OEM logistics operations have dealt with drones in the past or are dealing with drones in their current environment. In summary, the most suitable candidate for the interview is an expert or manager who is familiar with all process areas of an automotive OEM and with the relevant logistics operations. Further, the candidate still works with drones in this environment and deals with innovation in logistics, plant strategy and relevant technological and organisational change towards autonomous transport systems.

Drone interviewees

The search of drone experts focused on academic institutions, younger, newly founded companies with an institutional background, drone-building companies, non-automotive companies applying drones or working on the development of drone use cases, aircraft companies with longstanding experience in drone development, or military institutions. Experts should work or have worked in an environment concerned with strategies for logistics operations or drones or should be, or have been, responsible for strategic development. Further, experts were eligible if they had direct contact to, or were responsible for, logistics operations with drones in an organisation or were responsible for logistics processes or for drone strategy, development or usage. As with the interview group of automotive experts, also drone experts with a background in innovation in the field of drone technology were qualified.

Exclusion Criteria**:**

Exclusion of participants would have taken place if the expert did not meet any of the above-outlined inclusion criteria. An indication of the expected expert level was given in the invitation letter. Exclusion could take place at any time of the data gathering.

Number of experts

The number of automotive experts used for this analysis was set to nine interviewees, as a saturation was reached in the coding (section 3.6.3). By using his personal network and platform-supported listings of relevant experts, the author identified about 100 experts as possibly meeting the inclusion criteria. These listings were accessible to the author through his position in a consultancy firm. The responses the author received indicated that many experts have worked together, partly on topics such as innovation or even drones. Many pointed to small teams or individual experts leading in try-outs for drone technology in OEMs. Thus, the most experienced individuals could be identified and were invited to take part in this research. This reduced the number of potential participants significantly. Initially, ten experts confirmed to take part in the interviews. In interview no. 10, it was discovered that the expert did not meet the inclusion criteria because of having less than one year of relevant experience, and the author decided to exclude this interview from the analysis. The analysis of nine interviews showed that a saturation (section 3.6.3) had been reached so that no additional interviews were scheduled.

Drone experts were mainly found in networks and through their media appearance. Due to the nascent nature of the topic, the community of drone experts seems relatively small. About 30 experts were contacted and finally nine interviewees were interviewed for the research. Participant 6 was not used as there was a mistake in the participant's consent form. Contacting the expert again was not possible so that the interview participant is listed as "withdrawn consent" and the interview was not used in the further analysis process.

3.6.3 Representativeness and sample size

Qualitative research has to confront the challenge of allowing for generalisation, which is predicated on representativeness (Helfferich, 2014). Representativeness in qualitative studies can nevertheless be reached through depth and the quality of the interviews (Mayring & Fenz, 2014). O'Reilly & Parker (2013) state that a pragmatic and flexible approach should be applied in sampling. If the data gathered in a qualitative-empirical interview study can serve as a basis for generalisation, it can be decided using the concept of theoretical or data saturation.

Theoretical saturation is defined as a stage in an interview study at which no new information is added by another interview (Bobbitt, 2004). Data saturation has been reached when no more new data can be added for a conceptual node or theme (Francis, Johnston, Robertson, & Glidewell, 2010; Guest & Johnson, 2006; O'Reilly & Parker, 2012). While the researcher cannot know during the first interviews when saturation is reached because of its intrinsically subjective character (Nilsson, 2005), theoretical saturation is a useful method of evaluating when a sufficient number of interviews has been conducted. Francis, Johnston, Robertson, & Glidewell (2010) consider data saturation in semi-structured interviews also to depend on the purpose of the study and its scope, which in the case of drones in automotive OEM logistics operations is very specific.

While other sources also specify between six and twelve interviews as adequate (Guest & Johnson, 2006), Saunders et al. (2016) suggest that about 12 interviews can be sufficient if the interviewee group is homogeneous, but tend to consider 25-30 interviews as adequate in the case of heterogeneous interviewees (Saunders et al., 2016). Each of the two groups of interviewees for this thesis can be considered to be homogeneous. In total, about 10 interviews were expected by the researcher as sufficient to reach the level of saturation needed for the research, which is in agreement with the estimates given by Saunders et al. (2016) and Guest & Johnson (2006).

Initially, the author aimed to reach a certain level of saturation within the nine interviews in each two sets. Indeed, additional interviews were not needed as no new codes were added after the sixth and, respectively, seventh interview. For the set of automotive experts, the flattening of the curve in Figure 3.1 shows that saturation was reached after the seventh interview as no new codes were generated.

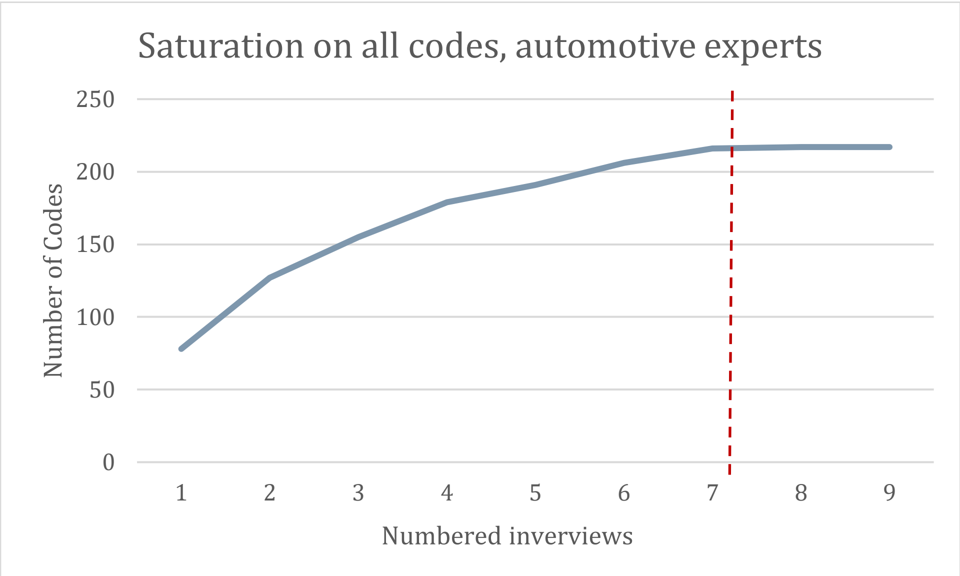


Figure 3.1 Saturation in automotive expert interviews, Source: The author

Likewise, the saturation within the set of drone expert interviews reached saturation after of the sixth interview, which can be seen in the following Figure 3.2.

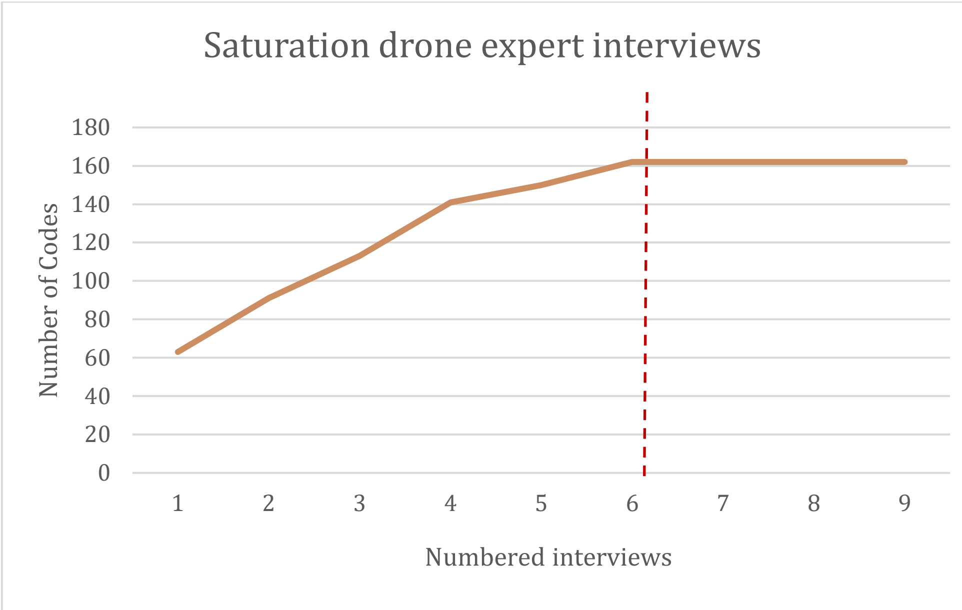


Figure 3.2 Saturation of all codes in drone expert interviews, Source: The author

3.6.4 Research ethics

The researcher considered all relevant ethics principles for research with human subjects following the policies of the University of Portsmouth (Kolstoe, 2020).

The approval process was twofold. A first application for ethical approval for the two sets of interviews was granted with a favourable opinion for the version of January 8th, 2018 (Appendix C). At the first contact with potential participants, all required information was given to them via email. This information included an invitation letter, a participant information sheet, a consent form as well as a preview of the interview topics with some guiding questions. After sending the email with the invitation and information sheets, the interviewees were contacted again via email or phone after an average of five business days. In this call, special emphasis was put on the absolute confidentiality of the interview data and a relatively light time effort (about one hour) for participants, who were offered that the researcher would travel to their region of residence or work. After the contacted individuals agreed to participate, a time and location for the interview were arranged.

The second step in the ethical approval process was the amendment to the ethical approval prior to the validation phase, which was given a favourable opinion for the version of June 10th, 2020 (Appendix D). Before the validation interviews, all relevant information was sent by mail to the experts, similar to the first two sets of interviews. Additionally, the interview results were sent out. A further change concerned the participation in the interview via an online-meeting due to the Corona pandemic.

3.6.5 Pilot studies

The empirical part of this research started with conducting pilot studies in both sets of interview questions. For both interview sets two different pilot interviews were conducted. At first, colleagues of the author volunteered for first pilots which led to some changes in the question design, especially to structuring of the questions and to changes in their order. The order of the question was changed to have a better structure following the process areas yet to reduce any potential bias. The restructuring allowed participants to focus on each process area individually. The second round of pilot interviews was conducted with drone and automotive experts who were not part of the research sample. The second round of pilots led to changes in the phrasing of individual questions. As a major result of the pilot studies, the final interview guide was generated (section 3.6.6; Appendix C).

Similar to the two sets of interviews also the validation interviews were piloted with peer students. Furthermore, a back translation was done by a peer to review the German translations of the interview questions.

The following section discusses the interview guide and its use in the interviews.

3.6.6 Interview guide

All interviews were held in a German automotive OEM environment. Interviews, coding and transcription was done in German, while the analysis was done in English, see Figure 3.3.

Two sets of expert interviews + one set of expert validation	German	English
Interviewing	x	
Transcription of the interviews (German)	x	
Coding of the interviews (German)	x	
Translation of main themes and quotations (German to English)	x	x
Analysis and Interpretation (English)		x

Figure 3.3 Language usage in data collection phase, Source: The author

Semi-structured interviews were conducted to gather primary data from key automotive and non-automotive experts. Semi-structured means, that the researcher follows a topic list or also called an interview guide, with partly formulated questions (Bryman & Bell, 2015). This affords a high degree of flexibility in the data-collection process, which is a particular strength of this type of interview (Bryman & Bell, 2015).

Stage 1, Semi-structured interviews

Each interview with an automotive or drone expert was anticipated to take about 60 minutes and to include the following questions.

All **automotive expert interviews** contained:

- Introduction with an open conversation, adding background, and ascertaining expert level
- Logistics operations from the interviewee's perspective. Questions are open in order to be able to follow up on answers
- Focus on the use of drones; questions regarding the interviewee's understanding of drones and if/how the interviewee has actively used drones
- Focus on the use of drones in the interviewee's process area and in logistics operations; questions about related performance measures
- Relevant future developments that may influence the implementation of drones

All **drone expert interviews** contained:

- Introduction with an open conversation, adding background and ascertaining their expert level
- Focus on expertise in existing classifications of drones
- Opinion on the DIALOOP drone classes
- Characteristics of, and possible main applications, for different drone types
- Future developments that influence the implementation of drones

The listed interview questions can be found in Appendix C.

In the automotive interviews, the author provided a 'communication support paper' (Appendix C), containing the drone classification (Table 2.5). This was presented after the interviewees had the chance to present their own understanding of drone classifications at the beginning of each interview. It then was used to get a perceived rating by the automotive experts to the conceptual drone classes (section 2.3.1). The perceived rating was used to support a further understanding of the suggested drone classes (section 5.5).

Stage 2, Validation interviews

Following the two sets of interviews, the analysis phase and the DIALOOP framework development, a validation process took place. The duration of the validating interviews was planned to be 30 min, with 15 minutes for the presentation of the results beforehand. The validating expert interviews predominantly address research objective 5.

All **validation interview** with automotive experts contained:

- Comments on the 4-step comprehensive DIALOOP approach
- Comments on the DIALOOP core elements containing logistics operations and performance measures which could be affected by drones

- Comments on major developments that can affect the implementation of drones.

Validation interview questions can be found in Appendix D.

3.6.7 Order of both sets of interviews

This section in the data collection phase relates to the order of both sets of interviews. Overall, there are three different possibilities. The author at first reflected on two possible alternatives in applying a sequence concluding towards the chosen third possibility of using no sequence.

A first option is to have the set of drone expert interviews first followed by the set of automotive expert interviews. This leads to a potential risk that drone experts could bias the rating and understanding of the automotive experts. A focus on drones instead of focus on process areas and logistic operations could further reduce the case-specific knowledge given by the automotive experts.

A second option is to conduct the set of automotive expert interviews prior to the set of drone expert interviews. An advantage would be, that the process-based requirements of the automotive experts could be used by drones experts to match these statements with drone characteristics. However, the fast-moving drone environment introduces the risk that a different perception of drones, as drones might have developed further between the sequenced set of interviews, led to incomparable results to possible capabilities in logistics.

In both cases of sequencing the sets of interviews, the triangulating character of the interviews was at risk. The drone classes in the second set might have changed to the drone classes in the first set due to publications or technology leaps. Also the comparison of the future developments and changes, as a separate topic as well as in case of triangulation, would not be possible.

In this thesis the third possibility was applied: both sets of semi-structured interviews were held independently from each other. There was no sequence of the sets and the interviews did not influence any of the questions in the data gathering phase. In the later data analysis stage single passages of the set of drone experts were used to triangulate the perceived rating to drones by the automotive experts. Similarly, the future developments questions were used in both sets of interviews and seen as comparable and triangulating in the analysis stage. The clear benefit to not connect the sets of interviews in a row was to have all interviews in the same time period. This seamed important in this nascent and fast-moving research topic with its cross-sectional nature.

3.7 DATA ANALYSIS

The following sections explain the processing and analysis of the qualitative data gathered through semi-structured expert interviews in this thesis.

3.7.1 Thematic analysis

Thematic analysis is a fundamental method for the analysis of qualitative data (Saunders et al., 2016). Edmondson & Mcmanus (2007, p. 1160) suggest a thematic content analysis for nascent theory after a data collection of a qualitative nature. Saunders et al. (2016) suggest a thematic analysis for both deductive and inductive approaches, and it appears plausible to assume that this also applies to the abductive approach employed in this thesis. They further state that a thematic analysis lends itself to the investigation of an understanding or attitude held by individuals or groups and their interpretation of phenomena, but also of factors (Saunders et al., 2016). In this case, thematic analysis allows the researcher to relate interview data on the current state of the art in logistics operations to existing theory as well as to derive new insights in the potentials of drone implementation. This twofold movement in thematic analysis of linking data to existing theories on the one hand and gaining new theoretical insights on the other is also described by Saunders et al. (2016). Bryman & Bell (2015) criticise that it is often not clear how themes are identified within thematic analysis and suggest that the frequency of appearance of a certain content may be a useful method of finding themes. However, within thematic analysis, patterns can also be found and used for interpretation without applying quantitative criteria such as counts, and this may result in a richer understanding of the data (Saunders et al., 2016). Accordingly, thematic analysis is applied in this thesis without a count of the appearances of content elements in the answers. This methodological choice is due to the nascent nature of the topic, which demands to take full account of all information contained in the interviews.

3.7.2 Data interpretation and analysis

The interviews with automotive experts took place from May 2019 to August 2019 and were conducted in the German language. Allthough the interviews were planned to have a longer duration, the slots for interviewing that the experts had scheduled were often only 60 minutes. The average duration is about 46 minutes in all interviews. Figure 3.4 summarises the duration and wordcount of the interviews and presents cumulative as well as average values.

Interview Respondent	[mm:ss]	Transcription [words]
A1	62:19	9998
A2	41:32	5604
A3	52:20	7677
A4	54:32	8510
A5	38:14	4996
A6	51:09	6241
A7	50:06	7749
A8	27:05	3740
A9	41:17	4672
Subtotal	**418:34**	59187
Average	**46:30**	**6576**

Interview Respondent	[mm:ss]	Transcription [words]
D1	49:41	6204
D2	60:34	7343
D3	30:02	4167
D4	42:23	5975
D5	30:22	3877
D7	41:35	5945
D8	33:34	4381
D9	55:47	7333
D10	51:04	7875
Subtotal	**420:45**	53100
Average	**46:45**	**5310**
Total	**839:19**	**112287**

Figure 3.4 Duration and word count of interviews, Source: The author

Figure 3.5 presents an overview of the experts' background as well as their years of experience and current position, automotive experts labelled A1 to A9 and drone experts labelled D1 to D10. All experts met the inclusion criteria. Among the automotive experts, the professional positions ranged widely from Process engineer to Senior manager of intralogistics or Innovation manager respectively. However, they all met the criteria (section 3.6.2). Also the drone experts interviewed occupied very different positions. The span ranged from academic employees to founders of drone companies and CIOs or CEOs of world-leading drone-related companies. In the automotive experts, the years of experience ranged from three to 33 years. In comparison, the drone experts had fewer years of experience, ranging from three and a half to 12 years. This may be attributed to the fact that drone technology is a recent phenomenon.

Automotive Experts			Drone Experts		
Experience of the interviewees	**[Years]**	**Position of the interviewees**	**Experience of the interviewees**	**[Years]**	**Position of the interviewees**
Automotive Participant A1	5	Process Engineer	Drone Participant D1	3,5	Sales and business development hardware and doftware
Automotive Participant A2	3	Technical teamleader for a central innovation project	Drone Participant D2	4	Strategic business development in EMEA-region
Automotive Participant A3	33	Head of transportation logistics	Drone Participant D3	6	CEO of a company providing solutions on drone basis
Automotive Participant A4	11	Workshopleader for nnovation in SCM	Drone Participant D4	6	Teamleader in the environment of identifications, localisation
Automotive Participant A5	7	Head of innovation and digitasation in intralogistics	Drone Participant D5	4	Founder and CEO of drone venture capital firm
Automotive Participant A6	23	Senior manager FTS strategy intralogistics	Drone Participant D7	12	CIO at drone incubator
Automotive Participant A7	6,5	Head of sequencing wagon team and FTS project lead	Drone Participant D8	4,5	Member of the board of the biggest producer of drones worldwide
Automotive Participant A8	3	Head of operative logistics line supply	Drone Participant D9	10	Academic employee in the field of aeronautical engineering and freelancing drone consultant/engineer
Automotive Participant A9	12	Innovations manager	Drone Participant D10	5	Founder and managing CEO of a drone consulting and market research firm

Figure 3.5 Overview over the experts' experience and professional background, Source: The author

All interviews were transcribed by the author from audio records. Transcription and coding of the interviews were done in German. The coding script (Appendix C) was also used for peer coding by a fellow student, who verified the structure and the coding areas identified by the author. The coding by the peer student was done by using colours for the highlighted question areas (A) to (K). It was identified that the peer reviewer clearly understood the questions. The coding was confirmed with no major changes following the discussion on major thematic content areas.

For the coding of all 18 interviews, the author applied a thematic coding approach and used NVIVO for a first clustering of the results. The coded quotations which were used for the analysis in chapter 4 were translated from German to English and are presented in the tables(Appendix G). Quotes were reviewed by a native English proof-reader. The validation process was similar to the first two sets of interviews. Validation interviews were also held in German and coded similarly as the first two sets of interviews.

Following the data collection phase, also the analysis of the data needs to be considered and planned (Havar-Simonovich, 2012). The author applies thematic analysis and it is to emphasise that “themes” are presented from coding results (Saldaña, 2013, p.14). First interviews were carefully read, coded in nodes following the research questions and the areas of interest. All interviews were read and coded according to the information that was needed or that emerged from them. Thus, new codes were introduced with every additional interview until no more new codes occurred and saturation was reached. Coding was thus done already between the first interviews as well as after the interview phase completion, for what reason later interviews might have been coded more precise. To mitigate that inhomogeneous coding, after all interviews had been coded, each interview was coded and analysed again with the updated list of categories and codes in NVIVO. This iterative coding ensured that relevant data on a topic that had been missed before was found and entered into the analysis and discussion phase. The initial coding was identified for the main categories derived from the literature review, i.e. processes and performance measures for automotive experts, and DIALOOP framework features as well as future developments, for drone experts. More precisely, the drone expert interviews concentrated on drone classes and the characteristics of different drone types as well as on future developments. Additionally, the initial coding was performed against the background of the research objectives. A similar coding model is given by Saldaña (2013) what is shown in the following *Figure 3.6*.

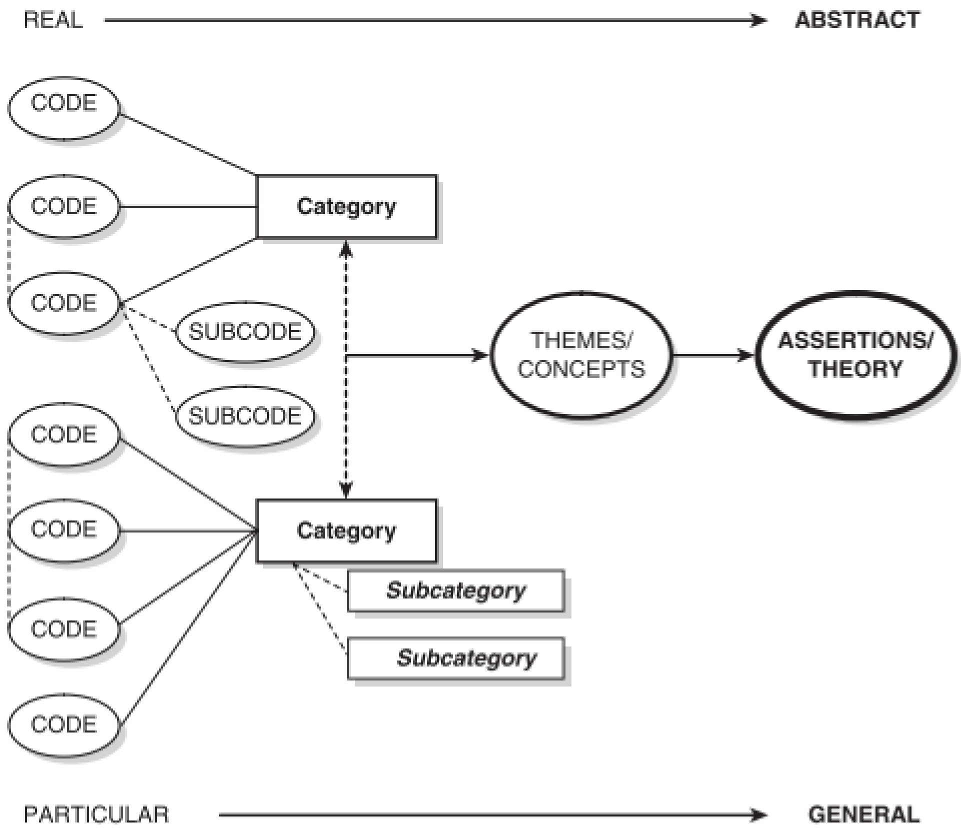


Figure 3.6 Code-To-Theory-Model, Source: Saldaña (2013, p. 13)

In a second step, another round of coding was conducted to ensure an unbiased assignments and clustering of codes. Hereby, again all categories were used which were formed by the initial codes. Finally, the identified themes were used to develop the framework. All codes are listed in Appendix C.

3.8 RESEARCH QUALITY

To assure the quality of this research, its reliability and validity need to be discussed (Bryman & Bell, 2015; Saunders et al., 2016, p. 202). Validity and reliability are also highlighted as key determinants of research quality by Quinlan et al. (2018, p. 265). The following sub-sections discuss both aspects of quality. However, some authors argue, that there is a difference regarding validity and reliability in the context of qualitative research (Golafshani, 2003) and further state that "*reliability and validity are conceptualized as trustworthiness, rigor and quality in qualitative paradigm""* (Golafshani, 2003, p.604). For this reason the author focusses on these elements as important aspects for this research. The following two definitions are hereby used.

Trustworthiness is "*the quality of a research is related to generalizability of the result and thereby to the testing and increasing the validity or trustworthiness of the research*" (Golafshani, 2003, p.603).

Rigor "*is understood by researchers to characterize the trustworthiness, credibility, and plausibility of research as judged by the use of theory, research design, data generation, and data analysis*" (Anderson, 2017, p.2). The author argues that rigor is strengthened by elements as "*reflexivity, methodological coherence, sampling and data access issues, member checking of data collected, discussion of transferability, and ethical issues*" (Anderson, 2017, p.6).

Morse (2015, p.1212) adds to trustworthiness in qualitative research, that researchers should use rigor, reliability, validity and generalisability.

An overall reflection about the *quality* of the research is given as a summary followed by the next two sections.

3.8.1 Validity

Validity concerns the interpretation of the observed (Silverman, 2016). This implies the question of whether or not the observation and its interpretation are appropriate to the phenomenon that was intended to be researched. In other words, *"validity is concerned with whether the findings are really about what they appear to be about"* (Saunders et al., 2009, p.167). To ensure that the relation between observations and their interpretation on the one hand and the investigated reality on the other can be traced so that validity can be judged, the results of a study need to be appropriately and accurately described and analysed because only this allows for their possible generalisation (Saunders et al., 2016). Only then can be evaluated how logical, truthful, robust, reasonable, meaningful and useful the results of a research are and, thus, what degree of validity it offers (Quinlan et al., 2018, p. 265). Yet, generalisability could be seen as a challenge in qualitative research (Georges, 2020).

There are different types of validity. Internal validity "*refers to ensuring consistency during a research project*" (Saunders et al., 2016, p. 202) Internal validity is normally very weak (Bryman & Bell, 2015), and it is mainly ensured in this research by corroboration through peer coding. This corroboration is part of a triangulation approach mentioned by Golfashani (2003). Additionally, the interview question development by four pilot interviews, the peer-coding of the interviews and the discussion of findings point to triangulation aspects, following Leung (2015, p. 325). All steps were carefully documented by making notes and reflecting on those later (Appendix C). The main learnings from the pilot interviews were that

- the structures of the questions was unclear, and some content was repeated
- the main questions need to be strictly followed to not getting into details that lead away or anticipate other questions to come later
- a communication support regarding drone classes could help in the perceived rating of drones in the process areas

The main interviews' analysis results were presented to and discussed with two academic peers for feedback. To provide proper documentation of the interview phase, the author added a literature search criteria section in the Appendix E.

Content validity (Saunders et al., 2016, p. 202) of the results has been strengthened in this thesis using an extra set of validation interviews after having developed the framework on the basis of initial interview data. For validation purposes, the so-called *participant validation* was used. Participant validation is discussed by Saunders et al. (2016, pp. 205-207) as a measure to improve study quality and is also described by Bryman & Bell (2015 p. 401), who use the term *respondent validation* or Anderson calling it member checking (Anderson, 2017, p.4-6). They emphasise that this technique improves the connection between the findings and the knowledge of the participants. Slettebø (2020) argue, that participant validation "*provides participants with an opportunity to reexamine validity*" (Slettebø, 2020, p. 3) and further state that it "*helps researchers assess their observations and interpretations of data to improve its trustworthiness*" (Slettebø, 2020, p. 3).

A major element of *triangulation*, what Flick (2004) defines as "*to refer to the observation of the research issue from (at least) two different points*" (Flick, 2004, p.178), are the partly-comparative two set of interviews. Both automotive and drone experts were asked to a perceived rating of drones in the research area, future changes as well as the drone classification. Although there are differences in experiences, this strengthens those elements of this research by adding a dual perspective.

Besides the peer review elements of piloting and the main interview, also the validation process incorporates for the above described triangulation argumentation. Findings of the interviews as well as the developed DIALOOP framework were presented with the aim to validate themes by experts who were recruited from the original group of interviewees. The validation contained a scenario-thinking approach, what led to a change in the interviewees' perspective. By talking themselves through scenarios a possibility was given to change perspective and add further reflection. This change from a pure interview to narrative validation compares to between-method triangulation (Flick, 2004, p.180). The choice of experts was made due to the expert knowledge of the interviewees and the importance of the framework validation on the basis of prior interview contribution. A validation is necessary because of the nascent nature of the research topic, which necessitates a highly interpretive approach to data analysis, which in turn increases the danger of distortions due to bias and subjective perceptions, for example from the author but also the negative experience of single experts with drones. Negative experience in prior drone test could have influences the interviewees' mindset on possible application of drones, also because of focussing on just one application case. Validation allowed for this risk to be minimised.

Generalisability is an aspect of external validity (Silverman, 2016, p.420). However the author is aware, that, especially in qualitative research, generalisability is hard to reach especially with small interview samples. Leung (2015, p. 326) discusses generalisability also by using parts of a validity-reasoning, for example triangulation, comparison and documentation. For this reason, this research aimed to include as many as possible relevant German automotive OEMs that apply a BTO strategy and especially to interview the most competent experts. Saunders et al. (2016) state that research in an emergent-theory area can improve its generalisability by comparing its results with existing knowledge. This approach was followed in this thesis by anchoring the DIALOOP framework in existing theory as far as possible and by discussing the developed framework with experts for validation purposes. A comparison to other frameworks is therefore given with the data being triangulated from different sources. Process area definition is done on a broad macro-level provides for adjustments in other application. The DIALOOP framework development structure is informed from literature, the interviews and the validation. This approach satisfies the view of Leung (2015, p. 326), the triangulation (aspect from peer and interviewee interaction), the comparison (with the literature) and sufficient documentation (that is maintained over the whole thesis).

Yet the research provides multiple aspects of triangulation, comparison and documentation towards transferability and therefore provides a certain level of validity.

3.8.2 Reliability

Quinlan et al. (2018, p. 265) consider reliability as a product of rigor in qualitative research. Accordingly, reliability can be assumed when the data gathering method and the analysis produce consistent findings (Saunders & Lewis, 2012), which implies that findings need to be replicable (Saunders et al., 2016). Because of their low degree of standardisation, semi-structured interviews can lead to concerns regarding reliability (Saunders et al., 2016). Given the nature of cross-sectional research, research findings may not be repeatable if they were reached in a fast-changing environment (Saunders et al., 2016), which is typical for the dynamic development of technological innovations and, thus, for the research topic at hand. However, the flexibility it offers in exploring newly emerged complex topics is one of the main strength of this kind of research (Saunders et al., 2016). As cross-sectional, qualitative research is therefore indispensable, the goal must therefore be to enhance concerns about reliability as far as possible.

Accordingly, there are three types of bias that need to be taken into account, namely those affecting the interviewer, especially if he or she is the only person doing the coding, the responses and the participating interviewees (M. Saunders et al., 2016, p. 203). To increase reliability, the author collaborated with peers to arrange for peer coding, chose different experts and tried to conduct all interviews within one month. All relevant steps to ensure reliability are documented in the methodology chapter, see data collection phase (section 3.6) or sections on data analysis (section 3.7) with added literature search logic in Appendix E or list of codes in Appendix C. This is following Quinlan et al. (2018, p. 265), who suggest to keep a diary-like documentation of the research, to “*outline, explain and justify the decisions the researcher made in relation to the research*” (Quinlan et al., 2018, p. 265).

This research provides triangulation influencing reliability in several ways. Following an argumentation of Lauri (2011, p. 13) data source triangulation can influence reliability in qualitative research. Triangulation aspects are described in the section to validity (section 3.8.1), especially the comparison of automotive and drone expert content. Additionally, the research is based on a literature review to both content areas what represents another form of data source triangulation as the findings from the analysis are concluded towards the literature. Existing drone classes, process areas as well as logistic operations or performance measure or even frameworks that were used at the beginning of the data gathering phase all relied on the literature review.

Additionally, peer reviews were applied as often as possible, either with participation in research conferences, or presenting progress or results to peer student in weekend learning sessions. Second, the pilot interviews and the main interview questions were reviewed and discussed with peer colleagues in all three sets of interviews. Additionally, after transcriptions were checked by a native speaker, a corroboration for coding was executed. As a third element the validation interviews with participants from the first set of interviews verified the research results. This actions match the thoughts of Leung (2015, p. 326), mentioning that triangulation enriches reliability issues as well by verification of data context and form.

An overall conclusion about the overall research quality is made with respect to trustworthiness, rigor and quality. Elements towards trustworthiness were presented with regard to this research. Multiple elements of triangulation were used in aspects of validity, reliability and also generalisability. According to Leung (2015, p. 326) or Morse (2015, p.1213) these three – validity, reliability and generalisability – can represent the quality of a qualitative research. The researcher' approach towards good rigor, following Anderson (2017, p.4-6), contains discussion to sample selection (section 3.6.1), data access procedures (data collection phase in 3.6 and literature search in Appendix E), sample size (section 3.6.3), member-checking, what is comparable to participant validation (validation, see also Appendix D), reflexivity (peer reviews and discussion), ethical considerations (section 3.6.4) and transferability (section 3.8.1).

3.9 SUMMARY

The philosophy underlying this research is constructionism and its critical-realist stance is appropriate for exploratory research in a nascent field, such as the field of drone implementation in intralogistics. An abductive approach was used to combine a deductive literature approach drawing mainly on automotive process-related sources with the inductive phase of analysis and interpretation of qualitative data gathered through semi-structured expert interviews. The results from two sets of interviews, one with automotive experts and one with drone experts, were integrated into a framework developed on a literature basis, which then was discussed in another round of interviews for validation purposes. Due to the fast-moving research field, the chosen time frame was cross-sectional. The semi-structured interviews offered the opportunity to add new knowledge in an exploratory approach and lay the groundwork for further research. The interviewed experts were contacted through the personal network and work environment of the researcher, while maintaining the inclusion criteria defined above. The planned number of interviews was not reached because one interviewee was found to fall short of meeting the inclusion criteria during the interview. However, saturation was reached well within the number of interviews conducted. During all data gathering activities, the ethics requirements of the University of Portsmouth were observed. Finally, it can be concluded that methodological justification has been outlined.

4 DATA ANALYSIS

The interview data analysis in this chapter serves to answer the research question and to achieve the research objectives. As explained in the previous chapter, the data were gathered in semi-structured expert interviews conducted with two sets of expert samples – one consisting of automotive experts and one comprised of drone experts. The results of the following analyses of these interview data were used to complete the DIALOOP framework, which then underwent participant validation in a separate round of interviews. The two sets of interviews were analysed separately on a thematic basis. The analysis of the data follows the analytical framework presented by Quinlan et al. (2018, p. 328), which contains four steps: *description, interpretation, drawing conclusions* and *theorizing*. In this chapter, the interview data is described using selected quotes. The interviews were conducted in German, but the quotes are in English. However, the corresponding original German text passages from the interview transcripts are given in the endnotes following the appendix. The analysis aims at reaching research objective 2 and 3 (section 1.3).

Figure 4.1 outlines the analysis process, graphically relating the sections of this chapter to analytical steps and research objectives. The results of the analysis are used for the further framework development in chapter 5.

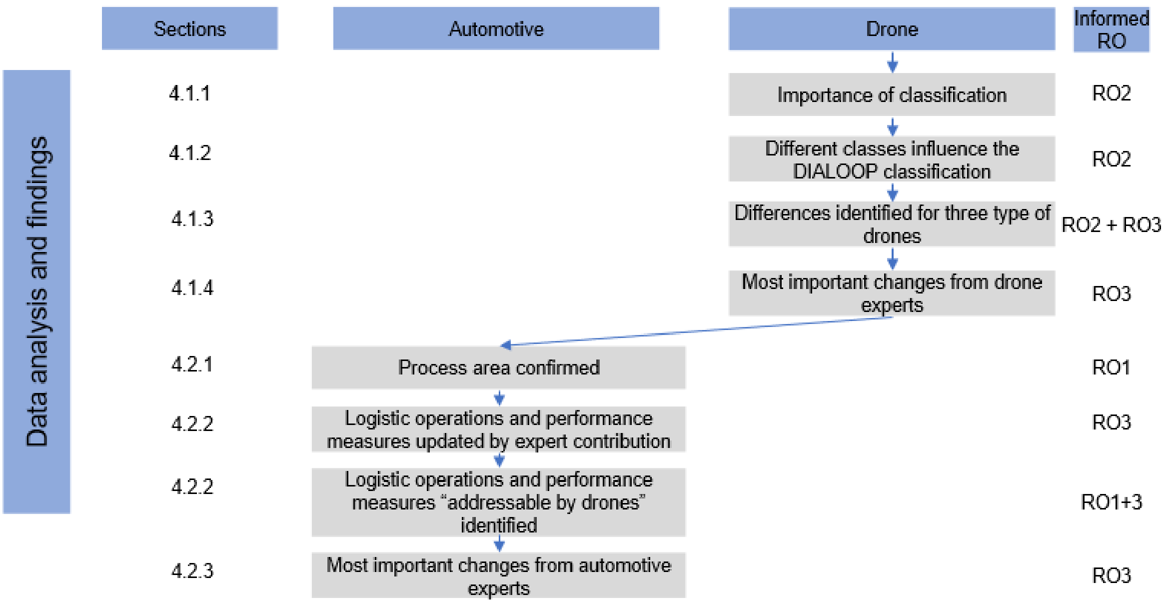


Figure 4.1 Overview of data analysis, Source: The author

4.1 RESULTS OF DRONE-EXPERT INTERVIEWS

The data from the drone expert interviews inform the drone knowledge in this research, in particular

- the classification, as being one of the objectives of this research,
- the findings by identifying advantages and disadvantages of drone types, as well as
- the performance measures possibly addressable by drones.

During the interviews, the participants were given the opportunity to name the classification of drones, with containing specific performance measures, which they would use and to explain how it may be used in the context of performance measures. The following analysis presents an overview of the factors that determine the usefulness of a classification according to the interviewed drone experts.

4.1.1 The importance of an aim of a classification

During the interviews with the drone experts, unexpected yet important statements were made. Interviewees repeatedly noted that

> *"the question is what the classification ultimately aims for"* [1] (D7).

Approaching a topic of technology integration is of importance for practitioners. The purpose of the mentioned frameworks varied from safety and quantity in interaction with workers to solving problems for the company or addressing its challenges. Throughout the interviews, the assumption that a clear purpose of the proposed framework is necessary was confirmed. It was also assumed that

> *"you end up with an x-part matrix and not just one criterion"* [2] (D4),

which was also mentioned by another expert with reference to an evaluation matrix. A case-based approach based on drone applications

> "*must inevitably result in a combination of different classifications"* [3] (D9).

Such a combination has already been suggested for the proposed framework in chapter 2, as drone type and the weight classes were included in the draft of the framework. Finally, one would

> "*not want to implement a drone to implement a drone, but simply because* [you] *want to solve a customer problem with it*" [4] (D4).

Drone expert statements suggest that a multi-step approach is necessary. Such an approach results from the necessity to define an aim for the framework and from combining different classification criteria in a matrix. Such a matrix is still missing. It has to be able to compare the classes to each other and match them with different use cases. Regarding the general use of a classification, the expert interviews suggested to focus on a problem or challenge in order to define first if drones can generally offer a solution. In addition, findings indicate the importance of considering influencing factors, such as the ones discussed below (4.1.4). On the other hand, there is a need to design the framework at hand in such a way that it is compatible with the given European Union's framework. This leads to using a matrix approach with different dimensions, as suggested by, among others, expert D9 stating that one

"*must inevitably result in a combination of different classifications*"[5] (D9).

Further quotations on the general usage of classifications against the background of a problem to be solved are presented in Table 4.1 in Appendix F.

4.1.2 Classes of the DIALOOP framework

This section summarises drone classifications derived from drone expert interviews. The aim is to identify useful classifications to be drawn on in designing the DIALOOP framework. This section also generates the main input for accomplishing research objective 2 (section 1.3).

4.1.2.1 Upcoming European Union classification

The European Union Aviation Safety Agency (EASA) has designed the main classification named by a majority of experts. One key statement was that this classification is

"all about the purpose and weight class, mainly"[6] (D1).

Weight was focused on also by many experts in the interviews (D3, D4, D8, D10). The experts further discerned a trend towards smaller classes. Presently, German law classifies drones according to upper weight limits 2.5 kilos, 5 kilos and 25 kilos (D4). In addition, speed is also considered in a law-based classification according the experts. Both weight and speed are strongly highlighted by the experts as part of the EASA classification. Weight seems overall more dominant a criterion than speed. However, the European Union classification is also met with criticism because

"*existing classifications are ultimately influenced by air law*"[7] (D9).

The interviews show that the EASA classification is highly relevant, although it went into law only shortly before the interviews occurred. Interviews clearly show that the drone experts are very well aware of the EASA classification. Yet, they do not use this regulation exclusively to classify drones. Instead, the regulation caused the experts to adjust their own classifications to enable a match or compatibility with the EASA classes. Some highlight a clear connection of the weight-based approach with the risk-based approach of the EASA. From an expert point of view, the DIALOOP framework should be able to be aligned with that of the EASA.

The quotations which relate to the European classification are presented in Table 4.2 in Appendix F.

4.1.2.2 Take-off weight

The interviews revealed weight to be a leading classifying criterion and are therefore considered in the DIALOOP framework. Take-off weight is a combination of drone weight and payload. The weight classification is strongly linked to a risk perspective, which points to the EASA classification discussed in the previous subsection. Weight is considered by interviewee D7 as a proxy for risk:

> *" If, for example, you get back to the question of soil risk, it may be that you should rather go for weight"*[8] (D7).

From this perspective, a strong link between the legal restrictions and the weight approach is plausible. A contrary statement is that the

> *"legislation that is now in the pipeline is very much oriented toward the risk that this drone poses for the environment, and there the weight will probably not play a big role anymore"*[9] (D10).

This indicates that weight is not suitable as a single classifying criterion. Furthermore, presumably about 90% of drones weigh between 2 to 10 kilos (D4). Apart from the pure weight, also the payload is of importance. One expert even states that

> *"finally, it's always about the payload"* (D5).

The final limits of the DDC classes (section 2.3.1) are comprised of take-off weights, specifically the weight of the drone and the payload combined. This is in alignment with the EASA classification, which also addresses take-off weight. Interviewee D1 observes that

> "t*he smaller and the lighter the drones are, the less regulated they are, the heavier they become, the more stringent the requirements will be*"[10] (D1).

The experts who did not attribute priority to the use of weight as a classification criterion focussed in their professional work rather on regulation, whereas the expert advocating a weight-oriented classification was, in their professional work, more concerned with questions of practical application. As a result of the interpretation, the interviews show that a majority of experts highlight the relevance of weight as a classifying criterion. Some single experts raise doubts about the relevance of weight as it may strongly vary. One stated that

> "*of course you can always argue about the weight*"[11] (D9).

The quotations, which relate to take-off weight, are shown in the following Table 4.3 in Appendix F.

4.1.2.3 Type

A second classification approach mentioned by a majority of interviewees uses the type of drone. Using type as a second criterion, in addition to weight, was also suggested in chapter 2 as a result of the literature review. As a foundation for drone type criteria, the interviewees mentioned the

> "*distinction between just fixed wing systems, the rotary and the hybrid systems*"[12] (D3).

Rotor-based drones were discussed in comparison to fixed-wing drones. Other distinctions concerned combustion versus electric (D2) or multiple hybrid solutions (D5, D9). For hybrid drones, there seem to be a larger range of distinctions. The classification by type is again strongly linked to the purpose of the drones. This is confirmed by D2, who mentioned the relation between the mission and the type of an operation, which informs the classification approach discussed below.

The interview data indicate that there is a common understanding of the main classes among the experts. Still, there is a lack of knowledge on hybrid drones and generally a lesser focus on fixed-wing and hybrid drones. However, a distinction between these two types could be valuable as the potential of hybrid drones has not yet been compared to that of rotor-based and fixed-wing drones. Another topic in need of further research is the junction between a type-based and a weight-based classification dimension. Finally, an exploration of drone types and their efficiency in OEM intralogistics or, more general, in industrial in-house logistics is still absent. However, as a type-based classification was mentioned by a majority of interviewees, it is also considered as a component of the DIALOOP framework in chapter 5.

The quotations which relate to a type classification are shown in the following Table 4.4 in Appendix F.

4.1.2.4 Purpose and mission

Drone experts also mentioned *purpose and mission*. The interviewees' recommendations stress the need to

> "*classify using the mission and the type of operation*"[13] (D2).

Possible missions are numerous and systematising them may initially be a challenge. Yet, some state that a classification can be done with regard to purpose (D8, D10) or proper use of a drone (D7), following individual drone strength. This clearly confirms the literature, for example if the focus is on distinctions between on

> *"sensor-carrying systems, […], then logistics and transport systems that transport any loads from A to B, and then at the upper end man-carrying systems"*[14] (D5).

The interviewees indicate a high relevance of this aspect to the research field as well. The literature review initially identified different missions such as information gathering and transporting operations (section 2.2.1), and it is one of the main purposes of the framework to link drone types to purposes, such as operations or missions. The interview answers further indicate that such correlations between drone types and purposes or missions have not been established yet so that there are no criteria for matching drone types with application scenarios or fields. The topic of purpose and mission is thus central to the purpose of the overall framework and may thus provide a preferable avenue toward classifying drones than other approaches (section 5.1), yet may not be applicable for classification purposes.

The quotations, which relate to a purpose and mission classification, are shown in Table 4.5.

4.1.2.5 Commercial versus private use

Although private use of drones is not in the focus of this research, several participants considered

> *"the distinction between commercial and private use"*[15] (D1, D3, D4, D8)

as a categorisation approach.

Expert D10 added a quantitative criterion for distinguishing between drones for private and drones for commercial use: if the price of a drone is

> *"set at about 10,000 euros, so everything that is north, we would count as pure professional equipment"*[16] (D10).

The distinction between commercial and private use was part of the findings of the interviews yet is not discussed any further. As automotive OEM in-house logistics operations are of a purely commercial nature, this classification is out of scope. In addition, private interests are overruled by the EASA regarding drone flight. Therefore, the commercial-private distinction is not discussed in in later chapters of this thesis.

The quotations that relate to a classification along the lines of commercial and private usage are shown in

Table *4.6* in Appendix F.

4.1.2.6 Indoor and outdoor

A classification between indoor and outdoor is mentioned by a few experts and therefore discussed. A single voice claimed that this is the

> "*most important distinction*"[17] (D3).

Another expert (D4), by contrast, pointed out the possibility that separate classifications for drones used indoors, and drones used outdoors exist. As in many cases, in-house processes are located both indoors and outdoors, drones might have to be able to be applied in both environments. As in the case of private use areas (section 4.1.2.5), the outdoor areas are for the most part regulated by the EASA classification and such drone usage may therefore be covered sufficiently. For this reason, this aspect is not discussed any further.

The quotations, which relate to an indoor or outdoor classification, are shown in Table 4.7 in Appendix F.

4.1.3 Characteristics of different types of drones

The following sections analyse the drone experts' view on different drone types and the interpretation of their characteristics with regard to this research. The interview questions were organised according to three types of drones, i.e. rotor-based drones, fixed-wing drones and hybrid drones. This division is based on dominant drone types identified in the literature review (section 2.2.2.2). The following sections emphasise interview data on drone types, highlighting their respective advantages and disadvantages. The findings are used to achieve research objective 3 (section 1.3) and are considered in the discussion in the next chapter.

4.1.3.1 Findings on rotor-based drones

Rotor-based drones are mainly suggested to be used for short-distance delivery, as described by D3. Only a few participants mentioned research-relevant uses of such drones, such as "*transport flights outdoors, of urgent parts, of spare parts"*[18] (D4).

Also indoor transportation was mentioned (D5). Apart from transportation, also information gathering is an important scenario for the usage of rotor-based drones. Advantages of the rotor-based drones can be summarized as flight characteristics, construction infrastructure and their manoeuvrability, which makes them suitable for many environments. A major purpose of such drones could be urgent delivery of single parts. Taking the shortest route demands flexibility of drones as they may have to fly around certain structures or even avoid other drones.

"Especially multi-rotor systems will prevail because of their flexibility"[19] (D1).

A certain speed in combination with the ability to take the most direct route affords significant advantages in reducing reaction and delivery times. Controllability is also named as very important; this could be summarised in the fact of

"very precise flying, with flying on the spot"[20] (D4).

Precise flying or vertical take-off and landing are needed especially indoors (D4). Given the ability of drones to use three-dimensional space very freely and land wherever needed, they can relieve the factory environment, i.e. the

"infrastructure on the ground can be kept relatively slim"[21] (D7).

The combination of flexibility, speed and a certain precision have developed well over time and amount to a unique advantage of rotor-based drones. Likewise, due to their longstanding development process and mass production, these drones are cost-effective in acquisition and over their lifecycle (D10).

Disadvantages of rotor-based drones are distinguished according to flight characteristics, infrastructure and construction statements. Regarding flight characteristics, the lift is created by the propellers directly and is therefore not wing-based. Thus, the energy efficiency of rotor-based drones is poor. In comparison, rotor-based drones have a boost and weight ratio that is about five times worse than that of fixed-wing drones (D9), which mainly results from their need to stabilise themselves at low speed. The energy used for lift can then not be used to traverse flight distance or for carrying a higher payload weight. The disadvantages mentioned most in the interviews concerning the construction were size and weight, which lead to

"the eternal trade-off, which one must face there"[22] (D10).

The trade-off is that higher payloads can only be reached by increasing the weight of the drone as such, which leads to limitations.

It can be said that, according the drone experts, rotor-based drones are very suitable for deployment in the research area investigated here. Nevertheless, no potential drone applications were named that were pertinent to the operations in the focus of this thesis, with the exception of urgent part delivery. However, specific areas or operations for their use were not explored in further detail.

A step necessary to draw conclusions is to outline in which areas or operations the advantages of a drone type overcome its disadvantages. Presumably, the advantages of vertical take-off and landing seem to be of special manoeuvrability value in narrow indoor environments. In contrast, rotor-based drones are, according to the drone experts, less usable in long-range operations. However, progress in the field of energy density may broaden the applicability of such drones in the future and result in their increased use because the advantages of these manoeuvrable drones can be used at lesser trade-off costs. Further conclusions are drawn in chapter 5.

The quotations on use scenarios are shown in Table 4.8, quotations on advantages in Table 4.9 and quotations on disadvantages in Table 4.10 in Appendix F.

4.1.3.2 Findings on fixed-wing drones

According to the drone experts, fixed-wing drones will play a less significant role in the process areas focussed on in this research. Fixed-wing technology could be used for

> *"increasing the efficiency of the platform so that they fly longer and faster or both"*[23] (D10).

Fixed wing drones are primarily considered for long-distance flight in suburban areas. This application focusses on deliveries in evenly spread locations, such as facilities with distributed infrastructure or appearance. Only one participant mentioned using fixed-wing drones for inspection purposes in warehouses, where they could

> *"actually somehow fly along high shelves, scanning barcodes"*[24] (D1).

Accordingly, the interviews outline clear advantage of fixed wings in long-distance flights. In this usage scenario, the energy efficiency of fixed-wing drones is of the essence (D7) and, compared to other drone types, fixed-wing drones are faster. Regarding construction, fixed-wing drones are

> *"also quite reliable and also quite [...] cheap in terms of maintenance"*[25] (D2).

The disadvantages of fixed-wing drones are headed by concerns regarding needed infrastructure, especially the facilities needed for

> *"take-off and landing"*[26] (D1).

If significant infrastructure is needed for landing, 46% of flight time might be lost (D10), which is a considerable disadvantage. Moreover, the inflexibility of such drones resulting from a lack of manoeuvrability (D8, D9) also leads to disadvantages regarding automation in the factory environment.

In summary, fixed-wing drones appear to offer fewer use scenarios than rotor-based drones and, thus, attract less attention in the expert community if thinking about this research area. The current application scenarios as well as the difficulties mentioned indicate that fixed-wing drones are generally not suitable for meeting the requirements of the process areas in the focus of this thesis. In addition, the need for infrastructure may prevent a pervasive application in a factory environment. Nevertheless, the advantages of efficiency and fitness for long-distance travel lead to the assumption that there can be cases lending themselves to the application of fixed-wing drones. In these cases, long-range applicability should be required, and the focus may not lie on selected process areas, but, rather, on the whole logistical supply process or extensive parts of it. In particular, early sub-processes in the supply process could be a plausible usage scenario as they can involve long-range operations, such as the area of goods receipt, or take place in large spaces, such as storage in yards, especially when fast delivery is needed. However, the findings point out that fixed-wing drones are generally seen as surveillance and information gathering drones, with a clear emphasis on information gathering. A usage in in-house logistics was not suggested.

The quotations on application scenarios are presented in Table 4.11, quotations on advantages in Table 4.12 and quotations on disadvantages in Table 4.13 in Appendix F.

4.1.3.3 Findings on hybrid drones

The findings allow for a comprehensive overview of different applications of hybrid drones, with tilt-wing drones being the most significant drone type.

> *“A tilt-wing multiple device can start vertically, then goes into gliding flight and then can land vertically again”*[27] *(D5)*.

Other applications, such as a combination of flying and rolling (D4, D6), swimming or driving or even tethered drones and lighter-than-air applications were only known and considered by few interviewees. The experts often mention that hybrids have to be

> “*designed specifically for a particular task*”[28] (D1).

The main advantages of hybrid drones can, in the opinion of the experts, be summarised as *speed* and *flexibility*. Speed aspects are of significant interest in logistics (D10) because

> *“distances are covered faster”*[29] (D7)

as the drones can fly up to 200 km/h. In comparison, hybrid drones demand a potentially

> "*lower energy input than* [drones] *with multi-rotors"*[30] (D8)

in long-distance flights. Thus, they provide a higher range than rotor-based drones, while also offering a high degree of *flexibility regarding obstacles* or infrastructure.

Disadvantages predominantly result from the *construction* of hybrid drones. A majority of experts stated that their *complexity* is higher than that of other drone types. This leads to a larger size and a higher weight. Complexity also results in *higher costs.* The second disadvantage is their flight energy consumption. This is significant because the change from flying to hovering consumes much energy and, contrary to the beliefs of many drone users, is not possible very often (D10), due to that energy consumption. Additionally, an indoor application might face a very long transition phase (D4) from horizontal to vertical flying and the in-flight stability may be insufficient (D1).

The findings show that the drone experts were rather sceptical regarding the usability of hybrid drones given the present state of the technology. The interviews point at a more plausible use scenario in the transportation sector. While the prices are said to decrease, the complexity of the drones is currently a weighty disadvantage and it is expected that hybrid drones only are useful in very specific areas or highly narrow use cases. While hybrid drones combine advantages of fixed-wing and rotor-based drones, their significant drawbacks have to be considered. The advantages resulting from these drones' combination of fast long-range coverage with precise hovering are cancelled out by energy inefficiency, cost and complexity, which limits their applicability to very specific needs and settings. More conclusions are drawn later in chapter 5 by including automotive-expert knowledge and process requirements in the discussion.

The quotations on possible applications can be found in Table 4.14, on advantages in Table 4.15 and on disadvantages in Table 4.16 in Appendix F.

4.1.4 Drone experts on future developments

Another part of the research addresses the questions of the most relevant future developments with a significant influence on the implementation of drones. This section serves as a basis to achieve research objective 3 (section 1.3) which aims at identifying the preconditions for drone implementation in automotive OEM logistics operations.

4.1.4.1 Infrastructure

The first theme identified by the drone experts was infrastructure. It may be possible to decrease investments into ground infrastructure by using drones, while adding flexibility (D7). One drone expert stated that companies

> "*must create larger areas where you can fly off and work*"[31] (D1).

A specific feature of an infrastructure appropriate for drone usage could be the provision of corridors, which would be a plausible result of following the EASA classification (section 4.1.2.1). In contrast, the concern was raised that complexity may increase, yet could be handled by

> *"taking into account appropriate safety requirements"*[32] (D8)

or by using drones only for special purposes and, then, as additional elements, as in the delivery of

> *"for example special parts"* (D8).

Instead of taking cars out of the production sequencing, drones could be utilised to carry parts their point of usage at a high speed and without negative effects. Infrastructural benefits may be one of the most significant developments in this research. Advice from drone experts, may prove very valuable for the implementation of drones in the researched area. The possibility to reduce complexity through drone deployment, cost-reduction potentials, which are highly valuable in in-house logistics, and the necessity of a dedicated airspace for drones are further considered in the discussion in chapter 5.

Quotations on infrastructure considerations are presented in Table 4.17 in Appendix F.

4.1.4.2 Network control system

Another finding from the interviews with drone experts concerns the integration of drones with other managed assets in an overarching technological structure. Findings point at a common network thinking amongst the drone experts. One expert stated that there have to be

> "*also ways in which drones can interact with other drones or a kind of centralized system to manage drone airspace*"[33] (D2).

All drone experts, despite slight differences in expertise and work focus, considered drone management to be relevant. Some experts articulated a more comprehensive vision of network communication. This comprehensive vision should inform the later framework. The integration of drones with other assets can help to find a more efficient and possibly even safer way to perform logistics operations. Drones should only be used if the advantages inherent in their flight ability are needed. Nevertheless, some experts mention the need for central control facilities, which is not in agreement with the above-mentioned focus on a self-organising, spread network. The initial aim of the network is to bring together as many players as possible. Additionally, in both cases a high automation could be an aim. A final conclusion is drawn later regarding network thinking, see in chapter 5.

Quotations on network thinking are gathered in Table 4.18 in Appendix F.

4.1.4.3 Drone-platform thinking

The drone-expert interviews also pointed at a platform implementation as a possible development similar to a network. However, the results derived from the interviews are divergent. Drone experts clearly highlight the need to think of drones as a platform, stating that

> "*here is such a research platform that flies and has interfaces, do what you want with it*"[34] (D1).

This indicates a need for drones with a general utility for many purposes. By contrast, some experts state that

> "*there are many who take the approach of developing a drone for, or adapting it to, to a very specific problem*"[35] (D1).

Findings clearly indicate that there are two different streams in the views on drone development in the context of platform thinking. Thus, there is the recommendation that a platform should match specific purposes, but there are also statements that indicate that the platform needs to be far more flexible and led itself to numerous, as yet unknown purposes. This former opinion clearly leads to a preference for special developments geared toward the needs of customers and application cases.

Quotations on drone platforms are presented in Table 4.19 in Appendix F.

4.1.4.4 Autonomy

From the perspective of drone experts, autonomy leads to a diminished need for changes in infrastructure built for drone technology. Thus, a higher level of autonomy is needed

> *"if environments become more complex and the problem has to be solved"*[36] (D1).

Autonomy results in lower a lower need for manpower, or, as one expert put it,

”I do not buy a drone so that a man then somehow loads the thing and another controls it, instead the part can be carried directly from A to B” [37] (D10).

Complexity can be mastered by solving navigation problems, increasing computing power or developing smaller electronics. Overall, the systems have to become more powerful and intelligent. The level of automation to be aimed for is not specified by the experts. This can result from different understandings of the experts as well as differences in their professional focus. Some experts focus on automated navigation whereas others relate automation to process topics, maintenance or battery replacement. Automation and intelligence also influence other developments, in particular network structures, efficiency or even the acceptance of drones by stakeholders.

Quotations regarding autonomy are compiled in Table 4.20 in Appendix F.

4.1.4.5 Efficiency

Interview findings show that efficiency has multiple aspects. Battery ability, energy efficiency as well as cost orientation are mentioned. Most statements address battery ability. Furthermore, the interviews showed how battery density can affect performance, with a potential to increase current performance by the factor five to 10 (D9). It would be especially helpful

“if we now achieved factor ten with an energy storage device with electrical or electrochemical [...] storage of electrical energy with batteries“ [38] (D9).

Otherwise,

“the game starts all over again, how many batteries can you carry, and what is the trade-off” [39] (D10).

Hybrid drones were addressed very often, probably because they may be affected the most by such developments. Overall, energy efficiency is of high priority in the future as a precondition for increasing drone implementation. The most important finding is that, according to the drone experts, the density of the energy combined with the energy efficiency of the drone are the determining factors regarding the drone implementation. Any developments regarding efficiency can influence multiple other fields of development, such as complexity or costs, and, therefore, efficiency is of very high importance for drawing further conclusions.

Quotations on efficiency are illustrated in Table 4.21 in Appendix F.

4.1.4.6 Acceptance

The findings from the interviews with drone experts also highlight acceptance. Drone experts recommend an extensive and frequent use of pilot projects. Examples of successful drone implementations can change minds or, in more specific cases, could persuade employees and work councils, especially if the examples promote the public good, such as blood delivery or emergency help. At first,

"people have to get used to the drones in the sky"[40] (D2)

by witnessing

"more pilot projects"[41] (D3).

Thus, drone experts emphasise a specific sequence in the implementation process: Acceptance is to be established first, as it is a foundation for advances in automation and therefore of the development of meaningful and efficient use cases. Acceptance is, however, a chicken-and-egg dilemma. If acceptance is low, pilot projects are less likely; yet without more pilot projects, acceptance cannot increase. For this reason, pilot projects have to be prepared by and accompanied by other measures to promote drone implementation.

Quotations on the topic acceptance are collected in Table 4.22 in Appendix F.

4.1.4.7 Regulation guidelines

Finally, findings from drone-expert interviews highlight that guidelines are needed to influence common acceptance. A key solution for higher acceptance can be

"uniform and simple regulatory conditions"[42] (D5)

because

"it can be assumed that in the present legal situation a small drone is often granted approval faster if critical infrastructures are involved"[43] (D7).

The regulations from the European lawmakers seem to be an appropriate start in this direction. The development and use of regulation guidelines is caught up in the same dilemma as acceptance. Without the contribution of experts, no useful guideline can be developed. Although there are some guidelines such as the EASA classification for drones, further investigations are needed to arrive at regulatory frameworks that are useful in practice.

Quotations on regulation guidelines are presented in Table 4.23 in Appendix F.

4.1.5 Summary of the results of drone-expert interviews

Regarding future drone implementation, one statement highlights the significance of this technology:

"the future of drones will be like today's cell phones or smartphones"[44] (D2).

The drone-expert interviews informed the DIALOOP framework in a threefold way. Their first valuable input consists in the confirmation of the classification, which underpins the conclusions derived from the literature review and, thus, contributes to achieving research objective 2: 'Classify drones for automotive OEM logistics operations'. The classification is used further to systematise the automotive experts' opinion on the use of drones in diverse logistics operations in the following section.

In addition, the findings show that

- the EASA classification,
- take-off weight and
- type-differentiation classifications

are of foremost importance for a classification and are used to develop the final DIALOOP framework. The other classifications – i.e. 'commercial and private' or 'indoor and outdoor' are not used for further conclusions and theorising.

Secondly, the drone-expert interviews contributed significantly to an understanding of the three drone types

- rotor-based drones,
- fixed-wing drones and
- hybrid drones.

The input from the interviewees on current applications as well as on the advantages and disadvantages offered a foundation for achieving research objective 3. Drones show different qualities, which are discussed with regard to single process areas later in this thesis (section 5.2). Hybrid drones may only be applied in few cases as of high costs and complexity. Fixed-wing drones confront infrastructural limitations regarding starting and landing and their low manoeuvrability in the narrow spaces of automotive OEM factories cause concern. Rotor-based drones are most suitable for in-house applications because of their flexibility and manoeuvrability. These insights are also used to draw further conclusions later in this thesis by synthesizing the results of the drone-expert interviews with those of the automotive-expert interviews.

In this sections, major developments are listed and interpreted with regard to the research topic. According to the interviewees, infrastructure, central control systems, a platform approach, efficiency, acceptance and regulatory guidelines demarcate the areas of development with the greatest influence on the future of drone technology and usage. These results relate to research objective 3 and are further discussed in chapter 5.

4.2 Results of automotive-expert interviews

The automotive experts were interviewed to gain data mainly on the process areas in automotive OEM logistics operations. Findings also show which performance measures are of interest in the process areas, but also in drone implementation. These results mainly serve to achieve research objective 1 (section 1.3). Furthermore, the interview results in this section move the analysis towards the use of drones in individual process areas and towards logistics operations. As was the case with the drone experts, the automotive experts were asked to identify future developments that may influence drone implementation. All these results are used to achieve research objective 3, i.e. to explore the preconditions under which drones can meet current requirements.

4.2.1 Drones in process areas

In the following sections, the investigated process areas are viewed with regard to their suitability for drone implementation. The first subsection targets process areas; subsequently, main performance measures in the current process-area landscape are addressed. Finally, the following subsections investigate the potential for drones in each process area with explicit focus on logistics operations and performance measures. The section structure uniforms in that the following steps are executed:

1. logistic operations added by experts
2. logistic operations where drones can be used
3. performance measures, added by experts
4. performance measures which can be addressed by drones

All results are finally drawn on in chapter 5 to finalise the framework.

4.2.1.1 Definition of process areas

In a first part of the automotive interviews, the interviews explored which process areas are commonly used and to define a process clustering suitable for the later framework. Automotive experts named ‘goods receipt’, ‘storing’, ‘picking and sequencing’ and ‘delivery to line’ and ‘empties processing’ as the most relevant areas for the proposed framework. In the following, quotes defining every process area are cited and discussed.

The starting process of intralogistics is *goods receipt*, with A1 stating that

> *"intralogistics begins [...] with goods receipt"*[45] (A1).

Another synonymous term is *"classic goods receipt"*[46] (A2). Goods receipt is the starting process in this research.

The subsequent process area of *storing* is mentioned in several versions, probably because companies

> *"have different storage structures"*[47] (A2).

A differentiation clearly focusses on the distinction between large loads for normal warehouses and small loads, which are handled in highly automated and specialised warehouses (A4), possibly to be distributed to supermarkets (A5), as special picking areas are called in an automotive context, which also count as warehouses.

As the next process area, *picking and sequencing* was identified by a majority of automotive experts. On the one hand, there are

> *„picking zones, where corresponding shopping carts are picked*" (A1)

or brought into a sequence (A4). Distinctions were made between big carriers (GLT), small carriers (KLT) and automatic small parts storage (AKL) (A7). The second part of this process area is sequencing, which often takes place during picking or subsequent to it.

The final relevant process area is *delivery to line*, which was also mentioned by a majority of experts. In this process, the goods are delivered to the value-adding point of use (A2). This process can take place in two forms,

> *„either the material is brought to the lines unmixed or [parts are mixed, but put] in a sequence"*[48] (A10).

The process thus comprises the delivery to the point of use and ends with the material arriving there (A3). This process is the final step considered in this down-stream-oriented research.

One additional area was mentioned by experts: the *empties return*, in which empty transport containers are sent back to their point of origin higher up in the supply stream. This process is expected to be at the end of all in-house processes (A3). One interviewee explained with reference to the German automotive group that he works for that

> *"we steer empties back to the nearest supplier who needs the [container] part in the [automotive] group*"[49] (A3),

which clearly shows that the overall process landscape is only partly comparable between the different automotive experts' employers.

Quotations on process landscape are presented in Table 4.24.

4.2.1.2 Automotive experts' view on performance measures

The automotive interviews also addressed briefly the performance measures applied by the experts in their everyday business. The experts confirmed

- **quality,**
- **time** and
- **costs** besides
- **security of supply** and
- **throughput**

as the major measures. Differences in quality were made regarding process quality (A4) or sequencing mistakes (A4) as well as delivery quality (A9). A time differentiation was made regarding employee times (A7) or additional time for rework (A8) and time for certain transportation (A5). Costs seem to be perceived in a uniform way by all interviewees, minor differentiations were made in logistics costs (A7) or procurement costs (A3), which results from a process perspective. Even more emphasis was put on the measure of supply security, which is determined by a delicate balance between stock and days in inventory (A7). Finally, throughput is a major measurement, especially with regard to the ratio of input to output (A5), which can be measured daily or weekly (A7)

Being asked about the applicability of efficiency, effectiveness and differentiation in the researched area, the experts opened up varying perspectives. In regard to efficiency, experts highlighted a tight connection to cost considerations (A2, A10) and stated that investing only for efficiency reasons and without the prospect of return on investment is not viable (A8). With regard to effectiveness, a common understanding was that it is mostly measured by comparing different plants on a management level (A7, A9), and might be not applicable for a more operational level of drone application. There was agreement on common measures to be used if certain innovation processes were applied (A9) or certain quality aspects were optimised (A10). The third measure, differentiation, was understood very differently by the automotive experts. Some concretised differentiation as transparency (A1, A5), gamification (A1), flexibility (A2), culture (A10), innovativeness (A2), mutability (A2) or perfection (A5, A7, A9) and digitisation (A5), yet an overarching collective perspective was absent.

Overall, efficiency, effectiveness and differentiation were not very present in the responses of the automotive experts. In contrast, the measures addressing time, cost and quality seem to be very applicable.

4.2.1.3 Potentials of drones in 'goods receipt'

Four identified logistics operations

Findings from the interviews showed four main logistics operations in the process area of 'goods receipt', which are *receiving of the goods*, *administrative booking*, *checking* and finally *unloading of goods as well as labelling*. Yet, that the process of goods receipt can also be understood with respect to risks:

> "*receiving is actually […] only a passage of risk*" [50] (A3).

Besides different checks and administrative processing of documents, the main task is

> "*unloading a truck and placing the goods at some checkpoints*" [51] (A4).

Implementation of drones

In the interviews, three possible logistics operations were identified, in which drones could potentially be implemented, i.e. *transportation*, *booking of goods receipt* and *checking of the goods*. Regarding the transportation, the drones can conceivably render routing support for incoming truck (A10). A more extensive implementation of drones in transportation was met with scepticism, which was rooted in the assumption that the payload capacity of drones would be too low or that parts are simply too heavy. Some interviewees could imagine that drones could handle the receiving of goods. Others thought that

> "*the weight of the carriers* [is] *simply* […] *far too high*" [52] (A4).

From another perspective, drones were considered as possible scanning tools for containers. These interviewees considered an implementation of drones in this process area as advantageous. Yet, it can be argued that such a use of drones results from prior inefficiencies:

> "*if I imagine that I should take a drone in 2019 or in the year 2020 to determine where the truck is or where my load is, then I have actually prior to this another problem that I have not solved*" [53] (A6).

Therefore, the interviewee added, the focus should rather be on the processes instead of drone technology. Yet, the DIALOOP framework can help to identify some supportive processes for drone implementation.

Common performance measures

The main common performance measures in goods receipt were identified as *quality issues*, *performance*, *punctuality* and *duration*. *Quality issues* may be of a varying kind, such as faulty documentation, transportation damages, delivery quality and completeness, the latter requiring that

"*what has been delivered [needs to be] checked for completeness*" [54] (A2).

As a second performance measure, *performance* itself was identified. According to some experts (A4, A7), performance is often not measured or only reported with a significant time lag, i.e. after the fact, what results in a significant time gap till performance increases. As a third set of performance measures, *delivery date and time* were mentioned. It should be checked how punctual the vehicles and, accordingly,

"how punctual […] the goods" [55] (A10) are.

Performance measures influenced by drones

Both *speed* and *quality* can be influenced by drones in this process area. Determinants of speed mentioned in the interviews were *parallelising* of processes and *reduction of manual processes*. Another theme concerned a potential increase in *quality* because of gains in accuracy effected through machines as opposed to human employees (A2). Depending on a possible reduction of workers, *having less manpower* also results in *less cost* and potentially also in higher quality, due to reduction of human mistakes. However, some experts (A1, A9) did not know any performance measures that could be changed by drones or, respectively, did not believe that drones could produce a change in performance measures.

The findings highlight that drones show potential for implementation in both transportation-based and information-based logistics operations in the process area of goods receipt. Potential tasks to be discharged by drones were, to a limited degree, transportation or booking and checking. While drones can be a valuable support in scanning, some interviewees questioned their ability to deliver goods because of their limited transportation capacity. Quality and speed in the scanning and booking process may be increased through drones. A reduction in the manpower needed for these tasks may lead to cost reductions.

Quotations on logistics operations are gathered in Table 4.25, quotations on possible drone implementations in Table 4.26, on common performance measures in Table 4.27 and on potentially improved performance measures in Table 4.28 in Appendix F.

4.2.1.4 Potentials of drones in ‘storing’

<u>Three identified logistics operations</u>

The findings identify the logistics operation of *storing, buffering*, *transportation* and *releasing from stock* as sub-processes of the process area ‘storing’. The majority of experts highlighted *storing* as the most significant logistics operation. The process area of ‘*storing’* is also compared to buffering (A3, A6, A9). Nevertheless, within the process area of ‘storing’, *transportation* was named as of the logistics operations pertaining to it, with using the term

> “*transport in the broadest sense of course, too*” [56] (A2).

The final logistics operation mentioned is *releasing from stock* , which involves goods being fetched from the storing place as they are demanded. A range of other operations, such as measuring of parking situation (A1) or repacking or relabelling, could also be placed within ‘storing’. However, these tasks could also pertain to the process area ‘goods receipt’ according to other interviewees (A4, A6).

<u>Implementation of drones</u>

The findings show that logistics operations for drones in *storing* are significantly information-based; transportation was not considered to be a potential application of drone technology. A majority of the experts viewed information-based operations, such as *inventory taking*, as possible applications of drones, for which operation in the vicinity of humans can be avoided if

> “*the drone flies through the hall again late at night or during non-operating times*”[57] (A5).

Another possibility, the

> *“optimization of parking-space allocations through the detection of vacant parking spaces”*[58] (A2),

is suitable for this process area and could increase performance. Certain *checks for completeness of stock* or *warehouse structures* could also be performed by drones, and also different scanning processes, e.g. processes aiming at measuring the current level of storing capacity used, could also, if carried out by drones, increase performance. Special operations in intralogistics are *searches for lost loads* or *box finding*, which drones may perform efficiently. Finally, there are *surveillance* operations. While the transportation of whole automobiles is not in the focus of this research, there are information-gathering operations in this process area that drones could discharge. The main purpose would be to ascertain lot-filling levels, and the ability of drones *"to hover above the vehicles"*[59] (A9)

would be a strength.

In contrast, many interviewee denied that logistics operations in *storing* lend themselves to drone operations and argued that there might be *no opportunities for drone implementation* at all (A5, A6, A7, A9, A10). One interviewee stated that one

> "*should […] focus more on my process so that I know how to position myself, and on making the process robust; then, I do not need to fly through a corridor afterwards"*[60] (A6).

<u>Common performance measures</u>

The interview results show the essential performance measures to be *quality*, followed by *performance*. Categories of *quality* are *damages*, *wrong storage*, *wrong label* or *delivery*. Leading categories of the second measure, *performance*, are *utilisation* or *storage filling level*, which refers to the degree of the physical utilisation of available storage space. Days of inventory (A6) pertain to the *utilisation* and are a measure for the turnover of stock. To decrease days of inventory and to raise utilisation, goods need to be processed as fast as possible, i.e. it is

> *"of course [...]important that we have low, shorter lead times"*[61] (A1)

This would result in keeping

> *"as low a stock as possible*"[62] (A1),

which in turn would lead to a low capital commitment (A10).

<u>Performance measures influenced by drones</u>

The findings on performance measures that can potentially be affected by the implementation of drones point to *quality* and *performance*. The majority of the performance measures that are sub-ordinate to these main, composite measures are performance-oriented measures. These include *stock transparency* and *error-based KPIs*. Especially the latter may potentially be improved considerable by using drones. Transparency can reduce inventory and related capital commitment by helping to increase the

> *"utilisation of the storing structure"*[63] (A2) .

Additionally, the *speed of the storing itself* could be increased through automation. This is mentioned by a majority of experts, who state that transport can be

> *"faster with a drone vs. the classic transport units"*[64] (A3).

Increased speed would finally lead to

“an increase in efficiency”[65] (A7)

in the opinion of other experts. Furthermore, *delivery quality* was mentioned by experts in the interviews. Drones could ensure the *security of supply*, even if there were less inventory but a better use of the space available. This may compensate for, or solve, the problems posed by increases in product variety, in the number of sets built caused by customer demands.

Findings show that also in the process area of ‘storing’ drone implementation can unlock potentials. While the logistics operations with a transportation character show a low likelihood of successful drone integration, information-based operations can, according to the experts, profit from drone deployment. The information gathered by drones could be used to effect improvements in performance measures such as quality or performance itself. Also mentioned as candidates for drone-based improvement were the performance measures *days in inventory* and *filling level*. However, drones require free space in order to be able to discharge their tasks efficiently, which reduces the range of successful applications. Additionally, increases in available space can raise the speed at which drones operate and may make their deployment for sorting and transportation more plausible.

Quotations on logistic operations are presented in Table 4.29, quotations to on drone implementations in Table 4.30, on common performance measures in Table 4.31 and on potentially affected performance measures in Table 4.32 in Appendix F.

4.2.1.5 Potentials of drones in ‘picking and sequencing’

Three identified logistics operations

The findings from the interviews led to the identification of three logistics operations as part of the process area ‘picking and sequencing’, which are *delivery to the picking line*, the *actual picking* and, partly, *delivery*. *Delivery to the picking line* comprises the transportation of parts from storing facilities to the picking place or to the supermarket, where parts are picked in sequence. In the course of the actual picking operations, so-called shopping carts and sets are created, which also constitutes

“the pure picking process”[66] (A7).

Whereas some experts only focus on transport others consider sorting or, respectively, the sequencing of goods as relevant logistics operations. The delivery to the point of use can be considered to be the final logistics operation in this process area.

Implementation of drones

The findings show a twofold potential for the implementation of drones in picking and sequencing as information-based and transportation-related applications appear possible, with the latter being more dominant. For information-related applications, *data collection* methods are lacking for purposes such as measuring temperature, air moisture or dust exposure (A4). Also, the *operation picking and delivering* is of importance. Drones could function as tools for *lifting* parts, albeit this appears feasible only for small parts. A possible application is to bring parts to the line in a post-delivery emergency process, which also affects the next process area in this analysis. By contrast, some experts do not consider any drone applications in these logistics operations to be possible. One reason can be unmatching processes or parts, that

> *„the parts I want to sequence are either stored on shelves or distributed at ground level"*[67] (A4).

Parts can be too heavy or to large, or the existing space is simply not suitable for drones.

<u>Common performance measures</u>

The findings on common performance measures focus on mostly *error-based*, but also *speed-related* ones. Categories of error-based measures are *sequencing errors*, *missing parts* and *wrong pickings*. Errors occur because there is

> *"no 100% control"*[68] (A10).

In addition, *speed* was identified as an important factor for performance in the interviews. A category pertaining to *speed* is *manual tasks reduction*. A reduction in manual tasks would presumably result from a higher degree of automation reached by drones. A second factor relevant for speed is that a

> *„parallelization of the processes is possible"*[69] (A2),

which could lead to a higher capacity. Speed was mentioned as a relevant performance measure alongside a reduction of F-times, i.e. assigned worker time units.

<u>Performance measures influenced by drone implementation</u>

The interview results highlight three main performance measures that can potentially be influenced by the implementation of drones, which are *timeliness, delivery quality* and *throughput*. *Timeliness* measures

> *"how much time do you need to complete a certain process"*[70] (A3).

Time needed may be influenced by the ability of drones to take direct routes and to travel at high speeds. Regarding *delivery quality*, drones could improve this measure by *checking parts quality and location*. Drones can also help with

> *"avoiding misallocated components"*[71] (A9).

Improvements in both measures can result in an increase of throughput; however, some experts consider drones as not suitable for operating these processes, but only as a support of

> *"accompanying processes of this activity"*[72] (A2).

As with most other process areas, some experts believe that there are not performance measures for 'picking and sequencing' that could be affected by drone implementation (A4, A5, A6). Single suggestions were made about redesigning the entire process so that drones could be implemented in it on a large scale. However, this would require changes in the following delivery-to-line process.

The findings show that the 'picking and sequencing' process area encompasses both transportation and information logistics operations. Scanning of parts in the line process is of similar importance as transporting the parts to the picking stations or delivering them further in the process. There is thus a high potential in refining the delivery process by controlling it on an informational basis – visually or by other sensors; also, an expeditious emergency delivery can improve performance. The process area 'picking and sequencing' also involves transportation over relatively long distances in the in-house logistics of automotive OEMs. Thus, the upstream storing locations may be far away from the production line and may also be widespread. However, this also depends on how 'picking and sequencing' is marked off from the upstream 'storing' and the downstream 'delivery to line'. However, emergency delivery can offer extra value, especially if long distances have to be traversed. However, an exclusive use of drones to fulfil this function may not be possible because of the space requirements for free flight and the sheer number of drones needed – since a high number of parts would require a mixed process or the usage of drones as an additional support for the existing process. The conditions of drone implementation are clearly different, depending on whether drones are integrated into existing structures or applied in a green field setting. This also has implications for the return on investment from drone implementation.

Quotations on logistic operations are gathered in Table 4.33, on possible drone implementations in Table 4.34, on common performance measures in Table 4.35, and on potentially affected performance measures in Table 4.36 in Appendix F.

4.2.1.6 Potentials of drones in ‘delivery to line’

Two identified logistic operations

Two different logistic operations were identified using the interview data. The first is *pure transportation* and the second is *allocation at the line*. The delivery to the point of use has a

> *“really great potential”*[73] (A6).

The process can start

> *„out of our staging areas with our tugger trains and forklifts, um, transport systems, up to the spot”*[74] (A8).

Furthermore, logistics centres may be located in another hall or location so that the transportation route is still long enough for using a truck. However, the goods are primarily transported to, and located at, the point of use, which could match the feeding process mentioned above. ‘Delivery to line’ can thus be defined as

> *„traveling the distance, from the warehouse, from the point of origin to the place of demand“*[75] (A10).

Implementation of drones

The sub-processes identified as potentially suitable for the implementation of drones are *urgent delivery*, *long distance* delivery and *non-series material (synonymous to non-production material)* delivery. The main category here is an urgent delivery of re-supplies, i.e.

> *“an express delivery or a special delivery in case material should have gone out”*[76] (A5),

but also included are

> *“post-delivery processes when errors occur”*[77] (A4).

By contrast, *serial delivery* was not mentioned by the experts as a potential candidate for drone implementation, although drones can be used for delivery over long distances, using corridors or lanes. Whether this is possible may depend on the parts to be delivered as well as on the overall organisation of supply and storage. A second potential for implementing drones was found to be in delivery of non-series material. It is, however, very doubtful that these types of supplies, which may include items such as gloves or shoes, need to be delivered using a highly innovative technology because they are typically not critical. Some concerns raised in the interviews highlighted the weight of the drones versus their capacity:

„the goods to be transported […] are too heavy to be carried with the technical possibilities of a drone”[78] (A4, A8).

The pre-assembly of goods in automotive OEM production leads to an increase of weight along the line and the resulting problem that the compound parts may become too heavy for transportation by drone.

Common performance measures

The interviews revealed the main performance measures to be *delivery date*, *timeliness*, *costs* and *inventory handling*. The first category is *on-time delivery*, which either means being

“at the right time in the right place”[79] (A2)

or

“that [the part] *arrives on time, so in this case not the duration* [matters]*, but the time window, in which it is provided”*[80] *(*A8).

A major factor regarding timeliness is the handling of the traffic. In this process area, traffic intensity is a major challenge.

“Topics such as transport load [or] *transport frequencies”*[81] (A10),

which were raised by some experts, influence *supply security* and are of high importance here. Additionally, minimal *inventory* at the line could lead to reduced costs, yet entails a higher risk regarding supply.

Performance measures influenced by drones

The findings show *speed* to be the performance measure often mentioned with regard to the implementation of drones, as speed is an important factor in both urgent and long-distance delivery. The process

“happens faster, because I can use drones and unload transport units faster, so to speak”[82] (A2).

A faster resupply can result in more flexibility close to the delivery date, which, in turn, allows for a longer window for changes in the order. In summary, drone usage results in timeliness, speed and automation.

Other categories, in addition to *speed*, are *utilization of the transport route* and the *use of space*:

“*also imagine that the third dimension simply relieves the infrastructure*”[83] (A10).

Some experts talked about alternative storage, where drones could be useful. However, the transport volume may increase if drones are implemented. Especially in a brown-field setting, i.e. in the case of an already existing plant structure, the use of the space available is of high importance.

Data show that the logistics operations in the 'delivery-to-line' process area have a good potential for implementing drones. Nowadays especially, traffic density influences delivery on time to a significant extent. Limiting drone application only to express delivery tasks may leave important potentials unused. However, transporting non-series materials may not warrant the costly application drones in the absence of any time pressure. Especially compound performance measures such as flexibility, speed and timeliness harbour opportunities for drone implementation in this process area. Especially rotor-based drones show a high potential for use in a 'delivery-to-line' setting, which is highlighted by the automotive experts' ratings.

Quotations on logistics operations can be found in Table 4.37, on possible drone implementations in Table 4.38, on common performance measures in Table 4.39 and on potentially affected performance measures in Table 4.40 in Appendix F.

4.2.2 Automotive experts on future changes

Similar to the drone experts, the automotive experts were also asked about possible future developments which may influence the implementation of drones. Here, too, the interview data gained by way of this question are used to achieve research objective 3. The following sub-sections summarise the results of the data analysis and offer first interpretations.

4.2.2.1 Infrastructure

According to the automotive experts, infrastructural requirements that need to be fulfilled before implementing drones can be distinguished in a *corridor solution* – either designated aerial zones or zones specifically designated for air cargo use – and completely *free flight* at a higher altitude, where the factory space is not divided by walls or other obstacles. Free flight can be beneficial as it allows drones to exploit their full potential of flexibility and, unbound by grids or walls, to take the shortest route (A6). It would be preferable to use existing space, which would help reduce cost and lessen the competition for roads and intersections, which is confirmed by A6 and A7:

> „*I want to be able to get up and down [with my flying drone], I do not want to have to make holes in my ceiling tomorrow. I want a flexible factory*"[84] (A6).

Again, either corridors can be used as an appropriate solution, or the upper space can be left open for drones to fly over storage and production areas (A4). Additionally, findings show a high relevance of accessibility for drones and of needed carrier adjustments (for example to ensure better hold by the carrying drones). It is necessary

> "*to change many details in the processes so that, for example, accessibility for the drone is created*"[85] (A2)

Other concerns were raised regarding data protection because most drones use cameras for navigation; this problem could also be solved by using separate corridors for drone traffic. This shows that, from an automotive expert's understanding, a separation of drones and human workers is indispensable. While both solutions, i.e. separate corridors and free flight, appear feasible, separate corridors may be more applicable in brown-field environments and free flying areas more suitable for green-field settings, in which the building and the infrastructure can be planned accordingly.

Quotations to infrastructure are illustrated in Table 4.41 in Appendix F.

4.2.2.2 Drone management system

The automotive experts' focus was on the creation of flow in a supply chain. Therefore, it was considered important to be able to

> *„ map the entire supply chain"*[86] *(A1).*

The regulation or management of in-house traffic in a factory was also in the focus of the automotive experts. Many technologies have to intersect in a complex logistics environment. Thus, a drone management system alone may be insufficient because drone operations have to interact with other automated operations. Instead, a central vehicle management system is needed, which is able to handle multiple cycles in different variants in order

> "*to perform not just this one process, but we have to implement a combination of many processes*"[87] (A7).

A central vehicle management system may promote drone implementation by enabling the logistics infrastructure to supply the mass of diverse parts needed in today's production of richly varied cars.

Quotations on the drone management system can be found in Table 4.42 in Appendix F.

4.2.2.3 Autonomy

The interview data also point at a connection between a high level of automation and autonomy. Automation, or autonomy, may result in *"the reproducibility of the entered flight path"*[88] (A8).

Automotive experts would

„relate [autonomy] *more to the use case, i.e. the task and not the size"*[89] (A2).

Additionally, if using drones for handling activities, the drones need to have at least

"a secure fit with the carried load"[90] (A6).

This secure fit from drones to loads also needs to be considered if automation is the aim.

Findings show that automotive experts are not aware of the maturity level of autonomy research, and that they also do not see a need for fully autonomous drones. Instead, they focus more on security and on reproducing flight paths. Thus, they consider automation, rather than autonomy, and the reproducibility of operational processes as essential for drone application.

Quotations on automation and autonomy are listed in Table 4.43 in Appendix F.

4.2.2.4 Efficiency

Efficiency strongly depends on loading cycles and numbers as well as the ability of the drone battery itself. Automotive experts emphasise battery endurance:

" if I [have to] put the drone on the battery-loading dock three to four times per shift, that would never work"[91] (A4).

In addition, the experts highlight

"the pure performance, i.e. what a drone can lift"[92] (A2).

Efficiency is thus not only influenced by battery endurance, battery performance or density, but is also contingent on the relation between payload and process cycles. If drones cannot meet the required specifications, then, alternatively, the processes or the payloads themselves would have to be changed.

In summary, automotive experts are generally willing to implement drones, yet are also concerned about their fulfilling process requirements.

Quotations on efficiency can be found in Table 4.44 in Appendix F.

4.2.2.5 Acceptance

The success of a new technology also depends on its acceptance, and, judging by the interview results gained from the automotive experts, as with the drone experts, an implementation of drone technology would most likely require a change of mindset to be met with approval. After all, processes and the entire environmental setting would be altered by drone implementation. In the automotive sector, work councils are frequently adverse to changes. One expert emphasised that

> „*the technology has to be present for the people [= the people must have a concrete idea of the technology] and they have to see what is possible with it*“[93] (A1).

Acceptance by the employees seems to be a significant hurdle given the prospective changes in the working environment. For example, the noise level of transport drones may negatively affect the working environment and would have to be managed. Acceptance is also clearly linked with addressing topics such as infrastructure and as a part of the working environment (section 4.2.2.1), which, in the case of drones with cameras and other sensors, may also affect workers' privacy. In sum, mindset, and with-it acceptance, is of high importance.

Quotations on changing the mindset are collected in Table 4.45 in Appendix F.

4.2.2.6 Regulation guidelines

Findings from automotive expert interviews also highlight safety and security concerns. Especially safety concerns about drones flying inside the factory building can influence the implementation of drones. Interviewees stress the importance of

> "*finding a technical solution so that I can work under the hovering load*"[94] (A6)

or of wearing helmets, when other solutions are not available. A second major concern regarding safety was the noise, whose reduction was highly recommended by the interviewees. Both concerns have major implications for drone usage and are closely related to the previously discussed role of acceptance (section 4.2.2.5). Furthermore, safety concerns could also massively influence the development of legal regulations in this area, which was also mentioned by the interviewees.

Quotations on safety and security are shown in *Table 4.46* in appendix F.Legal Framework

Findings regarding social changes emphasise the development of a more precise legal framework. A key quote is that a

> "*great enabler for the topic drone is really still the legal framework*"[95] (A2).

The interviews have shown that there are massive concerns about using the new technology, which are also a result of a lack of legal frameworks. Developments in this area can therefore lead to significant advances in acceptance levels with a far-reaching influence on implementation prospects.

Quotations on legal aspects are presented in Table 4.47 in Appendix F.

4.2.3 Summary of the results of automotive expert interviews

The section on automotive experts' interviews confirmed the identification of process areas in the literature review. This implies that the structure of the research topic developed in chapter 2 can be maintained. The process areas are *goods receipt*, *storing*, *picking and sequencing* and *delivery*.

For each main process area the interview results provided the logistics operations pertaining to it as well as the relevant performance measures. In addition, the experts elaborated on how, and if, drones could be implemented in each process area and which performance measures would be affected by an implementation. Overall, there are potential applications for drones in every process area.

In a second part of the interviews, the automotive experts were asked about changes necessary to apply drones in a factory setting. They mentioned changes in infrastructure, drone management, automation, efficiency, mindset, safety and security and in the legal framework as important drivers for an implementation of drones.

These results are drawn on in developing the DIALOOP framework in chapter 5.

4.3 SUMMARY OF DATA ANALYSIS

Interview data from both drone experts and automotive experts were analysed. Drone-expert interviews yielded data on drone classifications, on the characteristics of different drone types and on future developments and changes. Interviews with automotive interviewees addressed processes, logistics operations and performance measures as well as potential drone-application scenarios.

The drone expert interviews confirmed the drone classification outlined in section 2.3.1. The basic classification by types – rotor-based, fixed-wing and hybrid– was supplemented by three weight classes, namely small, medium and large. Other classification criteria were also discussed, but only the two above-mentioned classification criteria are taken into further consideration in finalising the classification system and its application. The data on the characteristics of different drone types and their suitability for specific environments and tasks resulted in clear overview of their potential for application and their case-specific deployment. Although this research focuses on in-house use on company ground, the DIALOOP classification can also serve as an amendment to the classification presented by the EASA.

The data from the automotive-expert interviews (section 4.2) helped structure the OEM intralogistics investigated in this thesis into process areas and, further, into sub-processes pertaining to each process area. In addition, performance measures for each process area were identified through the interviews and, if applicable, were further divided into subordinate performance measures. The experts discussed potential implementation scenarios for drones and the performance measures affected by a potential application of drones. Some experts viewed drones as a possible solution to the structural problem of current intralogistics, while others were more sceptical about their efficacious use in the identified process areas.

Both drone experts and automotive experts were asked about future changes necessary to promote drone implementation in logistical in-house process areas of automotive OEMs. The challenges mentioned by the experts included infrastructural adjustments, drone and vehicle management systems, the needed level of autonomy or automation, efficiency, the mindset of stakeholders, including their acceptance of drone technology in the workplace, as well as the necessity of a sufficiently detailed legal framework. Additionally, safety and security concerns were highlighted, especially by the automotive experts. Drone experts seemed more optimistic about the capabilities of drones, stating that

> *"we are technically at a level with the drones which would enable much more than what we currently do"*[96] *(D7).*

By virtue of their respective backgrounds, drone experts put their focus on the drones themselves, whereas automotive experts concentrated on processes. Chapter 4 has provided the findings needed to develop the DIALOOP framework outlined in chapter 2.3.1 further and in more detail. The chapter has thus also created the basis for the discussions in the following chapter 5, which aims to synthesise both aspects of drone technology and requirements of the intralogistics setting them into a matrix that can be used to decide upon, and guide, drone implementation.

5 DRONES-IN-AUTOMOTIVE-LOGISTIC-OPERATIONS-FRAMEWORK (DIALOOP)

This chapter further examines the data gained through interviews and the state of research to finalise the development of the DIALOOP framework as a major result of this research. In this chapter, the results are brought together and synthesised to flesh out and refine the structural framework created in section 2.3.1. Literature, interview-based findings and interpretations are used to map, and execute, a comprehensive approach to a framework, finalise the drone classification system and integrate process areas as well needed changes in the framework. Finally, the results of the participant validation of the thus created DIALOOP framework structure and its content are presented.

5.1 COMPREHENSIVE APPROACH TO USING THE DIALOOP FRAMEWORK

At the beginning, the literature review identified different structural influences on the to-be-designed framework. If only drone classes were distinguished, the user of the framework would not be able to address challenges, logistics operations suitable for drone implementation, or the prospective change in performance measures effected by drone integration. On the basis of the literature discussed and used to form the preliminary step-wise draft of a framework (section 2.3.2), the following section discusses this four-step approach in the way the framework can be used. Figure 5.1 outlines the conceptual structural design of such a framework along with the elements of the research process used to fill the framework outline with content.

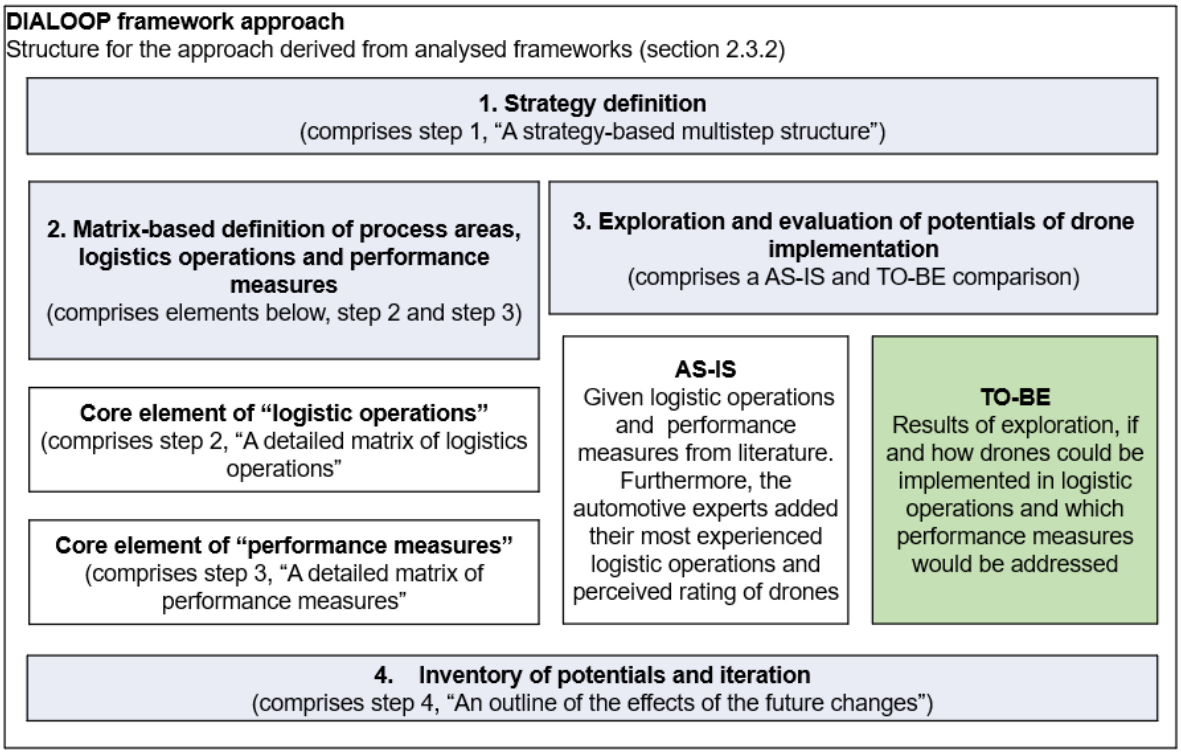


Figure 5.1 Outline of the DIALOOP framework as a structure for the research process, Source: The author

In the following, the four steps are discussed in detail, analysing the interview data against the background of extant literature and determining the implications thereof for the framework.

1. Strategy definition

Applying the DIALOOP framework should start with *defining the vision or strategy*. A vision and mission definition (Ghalayini & Noble, 1996; Trienekens et al., 2008) or taking account of environmental factors (Mentzer et al., 2004) is considered to be an essential step in the literature (section 2.3.2). Automotive experts did not mention the topic of vision or mission. However, they did stress the need for a strategic understanding as a first step of applying the framework. Similarly, drone experts emphasised the importance of a clearly defined purpose of a framework (section 4.1.1). Additionally a drone classification according to purpose and mission was discussed and this shaped the overall approach (section 4.1.2.4). The results thus lead to the conclusion that a 'strategic mission approach' is advisable. The entire literature highlights the importance of a defined purpose or mission (section 2.2.1), but does not identify or establish relations between missions and specific drone classes. This gap is closed by the DIALOOP framework. The integration of *aim and mission* into a framework can put the specific application scenario of drone technology into focus and, thus, highlight possible problems along with solutions suggested by many experts. In contradistinction to this, the DIALOOP framework's aim-based approach is similar to the one taken in the framework for logistics operations in distribution centers developed by Vidal Vieira et al. (2017) or the goal-oriented alignment with business strategies in the multistep-approach outlined by Marchesini & Alcântara (2016). Thus, the emphasis placed by interviewees on clarifying the requirements to be fulfilled before drones can be implemented is comparable to the first step recommended by Marchesini & Alcântara (2016), i.e. a *strategic evaluation of technology*. Most comparable to the aim of the DIALOOP framework though are the concepts of purpose and usability (Dörnhöfer et al., 2016). Establishing a clearly defined strategy (i.e. purpose) and ensuring the usability of a framework lead to a better understanding of drone implementation. Creating an understanding corresponds to analysing the as-is state as a step recommended by Gladysz & Santarek (2015) and Klingebiel (2006). Findings from the interviews about the need of a comprehensive, purpose-driven approach thus confirm, and align with, the literature that required a strategy-based multistep structure (section 2.3.2).

2. <u>Matrix-based definition of process areas, logistics operations and performance measures</u>

The comprehensive approach is implemented in the DIALOOP framework partly by distinguishing several process areas and the logistics operations pertaining to them. Overall, this step summarises step 2 and step 3 of the suggested framework approach (section 2.3.2). The process areas that were clustered roughly by the author, also due to the nascent nature of the research topic. This second step addresses the definition of current logistics operations and performance measures, which amounts to a general, not firm-specific as-is inspection (Gladysz & Santarek, 2015) or a current state analysis (Klingebiel, 2006). The definition of logistics operations and performance measures also corresponds to the selection of appropriate processes, activities and measures recommended in the literature (Marchesini & Alcântara, 2016; Vidal Vieira et al., 2017). The logistics operations identified by the experts were divergent to some extent, yet only in minor process discussion to area boundary.

Users of the DIALOOP framework should therefore compare the process areas and the respective logistics operations with the AS-IS structure of intralogistics in their company on a matrix basis and, if necessary, adjust the framework. In a similar approach, the researcher asked the interviewees about their process landscape (section 4.2.1.1) despite there being well-defined process areas in the literature. In this case, all process areas in the framework were confirmed. The DIALOOP framework draft can be seen as a guideline, but may not be applicable in every single case. The core structure of the DIALOOP framework, which can be used for the above-mentioned comparison purpose, is presented in the following section 5.2. Apart from the definition of process areas, logistics operations and performance measures as an important step in applying the DIALOOP framework, the related performance measures (section 4.2.1) need to be considered to evaluate the implementation of drone types as specified in the framework's drone classification. This step is detailed below.

3. Exploration and evaluation of potentials of drone implementation

The DIALOOP framework's core can serve as a guide to a step-by-step exploration of the process landscape with regard to every individual logistics operation's potential for drone integration. The framework distinguishes two steps. First, the DIALOOP framework can be used to identify the current operations with a potential for drone implementation, the performance measures that would be affected by such an implementation, and the drone classes suitable for usage in these operations. In a second step, the DIALOOP framework helps identify the future challenges to drone implementation and the changes necessary to overcome or circumvent these challenges (section 5.3). This phase of the approach is similar to a definition of the to-be process (Gladysz & Santarek, 2015) or a field of action (Klingebiel, 2006) and allows for a comparison between actual and target processes and solutions. Overall, this third step combines the matrix-based approach from step 2 with the AS-IS comparison part, that then adds drone knowledge to the matrix. (section 2.3.2).

4. Inventory of potentials and iteration

The framework is meant to be applied in an iterative way so that additional findings as well as changes in the framework's input parameters can be taken into account. In a first step in this phase, an inventory of process areas and logistics operations should be established and matched with pertaining performance measures (Dörnhöfer et al., 2016) with a special focus on the integration of drone applications. This step also serves to keep the framework updated in order to provide for a template for other process areas or to other participants in the supply chain. Thus, new potential application scenarios for drones should be added to the DIALOOP framework in each iteration. Also, future research could change or amend the framework and, should this happen, iterations could proceed with the altered framework.

The four-step approach outlined above and derived from the literature review (section 2.3.2) was considered applicable by both groups of experts. Furthermore, the experts emphasised the importance of a coherent and comprehensive approach. The following Figure 5.2 summarises the four steps graphically.

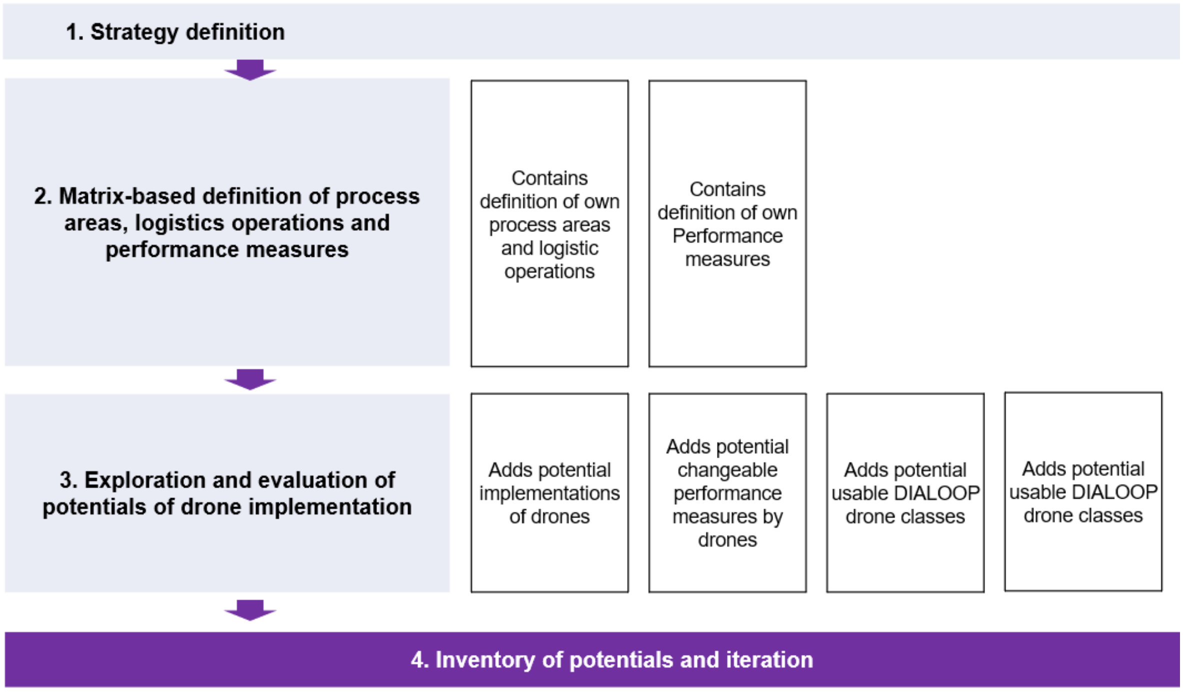


Figure 5.2 Strategic challenge-oriented use of the DIALOOP framework, Source: The author

The following section further addresses the steps at the core of the comprehensive approach that follow the definition of a strategy or purpose, namely the process areas, logistics operations and performance measures influenced by drones (section 5.2), future challenges and necessary changes to address them (section 5.3) and drone classification (section 5.4).

5.2 DIALOOP CORE STRUCTURE: PROCESS AREAS, LOGISTIC OPERATIONS AND PERFORMANCE MEASURES INFLUENCED BY DRONES

The core of the DIALOOP framework aims to follow a matrix approach to analyse the potentials of implementing drones in a general way. The structure is designed to guide the user to conclusions about which process area, and its respective logistics operations, is suitable for drone implementation. Additionally, this section discusses the performance measures that would be affected by drone usage and the drone classification. Dörnhöfer (2016) as a recent and prolific contributor to this field of study has used a matrix approach as well, with a focus on 'downstream in-house logistics', which is also pursued by Boysen et al. (2015).

The following sections present a detail-oriented discussion and graphical outline of the process areas *goods receipt, storing, picking* and *sequencing* and *delivery to line*.

5.2.1 Process area: goods receipt

The research empirically checked the logistics operations in goods receipt, which were identified in the literature (section 2.1.2), for applicability in the OEM intralogistics environment. These were *register, unload, scan and book* (Boysen et al., 2015) or *checking, packing labelling* and *put-away* (Vidal Vieira et al., 2017). Predominantly, the logistic operations in Boysen et al. (2015) were confirmed by the automotive interview participants (section 4.2.1.1). The main logistics operations that emerged from the interview data were *receiving of the goods*, *checking*, *administrative booking* and, finally, *unloading of goods.* Drones were assumed by the interviewees to be able to discharge the tasks of *scanning, checking, booking, unloading, transportation controlling* and *relabelling*. These findings lead to the conclusion that drones could be used in any logistic operation of the process area of goods receipt and, for this reason, a high potential can be attributed to them with regard to this process area. It is, more specifically, predominantly information-based tasks that show a high potential for drone usage, in particular the operations *booking* and *checking* of the goods. This adds to current theory.

Relevant performance measures pertaining to this process area are, according to the interview data, *quality*, *performance* and *delivery time and duration*, among others (section 4.2.1.1), while the literature identifies a by far larger number of performance measures (section 2.1.3). The interview results align with the literature regarding *quality* and *delivery time* (Bhatnagar & Teo, 2009; Hedler Staudt et al., 2015; Klingenberg & Boksma, 2010; Mentzer et al., 2004; Rafele, 2004; Gregory N. Stock et al., 2000). As part of the performance measure *performance*, *throughput* is, according to the interviews, of importance, but there is no equivalent of *throughput* among the performance measures mentioned in the literature. The performance measure *perfection* is only mentioned by Dörnhöfer et al. (2016) what implies the performance measure *quality*, which was identified as important by the interviewed automotive experts. A majority of interviewees also identified *throughput*, in addition to *quality*, as a major performance measure. *Throughput* is partly related to *delivery time* (Bhatnagar & Teo, 2009; Hedler Staudt et al., 2015; Klingenberg & Boksma, 2010; Mentzer et al., 2004; Rafele, 2004; Stock et al., 2000). The experts viewed drones as capable of affecting the main logistical performance measures, in particular *throughput*, *quality* and *costs* (as a measure subordinate to the performance measure *performance*).

The results are fed into the core-elements of the framework. *Table 5.1* shows the logistic operations collated from the literature (Table 5.1,left white column) as well as the interview-contributed logistic operations where drones can potentially be implemented (Table 5.1,left green column). In the same way, performance measures taken from the literature and confirmed by interviews are listed in the right white column, and performance measures that were believed to be affected by drones are listed in the right green column.

Table 5.1 DIALOOP framework elements for 'goods receipt', Source: The author

DIALOOP framework element for 'goods receipt'

Common logistic operations	**Potential for implementing drones** from Interviews	Common performance measures	**Adressable performance measures by drones** from Interviews
Receiving of goods		Time	**Time**
Scanning	**Scanning**	Quality	**Quality**
Checking	**Checking**	Costs	**Costs**
Booking	**Booking**	Flexibility	
Unloading	**Unloading**	Inventory	
	Transportation conrol	Reliability	**Reliability**
Relabeling	**Relabeling**	Modularity	
Reorganisation internal		Asset managment	
		Utilisation	
		Scalability	
		Changeability	
		Reconfigurability	
		Safety	
		Controllability	
	No potentials*		**No adressable measures***

* = some experts didn't give any answer

Automotive experts would emphasise that *speed* and *throughput* as well as *quality* aspects can be addressed by drones. The automotive experts' preference for rotor-based drones as particularly able to influence speed, quality and costs is supported by insights from the drone-expert interviews (section 4.1.3.1). Rotor-based drones are able to fly a direct path, to land in a precise spot and to navigate with great flexibility and stability. They combine speed with controllability and reliability. By contrast, hybrid drones – although combining fast flying and precise landing – have a high energy consumption and high purchase and operating costs. By using rotor-based drones in this process area only for checking and scanning, but not for transportation, the contribution that drone technology can make is less marked. Goods receipt thus shows a mixed potential for implementing drones as possible fields of application are of a mostly information-based nature. As far as transport goes, goods often arrive in large boxes and are numerous, which limits the efficacious use of drones for transport services in the 'goods receipt' area.

Both sets of interviews highlight that mainly rotor-based drones have a potential of being implemented in 'goods receipt'. With their mostly information-oriented support of logistics operations, drones would affect the performance measures *quality* as well as *speed* and *throughput*.

5.2.2 Process area: storing

The process area of storing is widely discussed in literature. With a division of the process areas such as the one applied in this research, storing comprises only a few logistics operations. The literature review identified *put-away*, *storing* and *locations assignment*. Automotive experts named *storing*, *buffering* as well as *releasing from stock* as operations (section 4.2.1.4). Additionally, they added *transportation*, which the literature generally appears assign to another area, e.g. delivery to line. Interviewees therefore mainly confirmed the reviewed literature, see 4.2.1.4. Two main modules were the *location assignment* (Vidal Vieira et al., 2017) and the *put-away* (Paião, 2014), which were also addressed in the interviews. Overall the experts confirmed the existing literature and emphasised the numerous variants of storing, which may allow for many different scenarios of drone use.

As with goods receipt, many drone implementation potentials were identified in the interviews for *storing* (section 4.2.1.4). Surprisingly to the author, these logistics operations were information-based, although the process area also should include a considerable part of transportation. In contrast to the literature review (section 4.2.1.4), no scenarios of pure transportation operations were seen as suitable for drones in the interviews. Additionally, all potential drone uses identified were of a supportive character, e.g. search for lost loads, what only affects single pieces out of many. The potentials for implementing drones thus appear fewer than anticipated. Nowadays, storing facilities are highly automated. If automotive OEMs do not use a high-rack warehouse, then mostly the reason is that the goods are too big or too heavy. Such goods would also be too large or heavy for aerial in-house drones. Furthermore, many automotive experts saw no implementation possibilities for drones at all. This may also result from the fact that the identified logistic operations were mostly transportation and storing itself, whereas possible drone implementations were mostly of an information-based nature. As instances of possible information-oriented, supportive functions that drones could fulfil, the storing-specific logistics operations of *checks for completeness*, *search for lost loads* and *box finding* can be considered. If checks for completeness are a suitable drone-implementation scenario in storing, then inventory activities can also be counted among the suitable scenarios.

With regard to storing, multiple performance measures were found in the literature as this process area is present in almost every industry. The *flexibility* required in storing (Paião, 2014), which may be afforded by drones rather than by ground-based technology, can be less enhanced by an information-based, supportive use of drones. With regard to *efficiency* (Manzini et al., 2015; Paião, 2014), there may already exist technology that enables a high-capacity handling of parts while using existing spaces in an optimal manner. As already implied above, it can be assumed that mostly smaller parts are handled in high-rack warehouses. However, the automotive experts did mention *utilisation* and *storage-filling level* as possible performance measures that can be affected by a drone implementation. The experts' choices of these two measures, both related to a demand of stock reduction, confirm the findings of Caridade et al. (2017). Essential performance measures regarding *quality* that the interviewees identified were *damages*, *wrong storage* or *labelling* (section 4.2.1.4). An equivalent in the literature is the performance measure *perfection* discussed by Dörnhöfer et al. (2016). The experts' view of *quality* appears to be strongly linked to *costs* and *efficiency*, and this link can also be found in the literature (Manzini et al., 2015). The performance measures affected by drones, which are mostly *speed*, *utilisation* and *quality*, are also strongly related to *transparency,* which is information focussed and thus dependent on information-gathering logistics operations, whose potential for drone implementation has already been confirmed. For this reason, drones could be implemented in the logistics operations pertaining to 'storing', yet their potential may be limited. The cumulated results can be seen in the core-elements of the framework in Table 5.2.

Table 5.2 DIALOOP framework elements for 'Storing', Source: The author

DIALOOP framework element for 'Storing'			
Common logistic operations	**Potential for implementing drones** from Interviews	Common performance measures	**Adressable performance measures by drones** from Interviews
Put-away		Efficiency	
Relabeling		Cost-efficiency	**Cost-efficiency**
Storing		Stock reduction	
			Stock transparency
Location assignment		Lead time	**Time**
	Inventory tacking	Speed	**Speed**
Replenishment		Area utilisation/filling level	**Utilisation**
Buffering		Delivery reliability	
Transportation		Flexibility	
Releasing from stock	**Delivery of parts (releasing)**	Accuracy	
	Emergency delivery process	Quality	
Parking space measuring			**Error-based measures**
	Optimisation of parking space	Perfection	
	Checks for completeness	Performance	**Performance**
	Checks of warehouse structure		
	Searches for lost loads		
	Box finding		
	Surveillance		
	No potentials*		**No adressable measures***

* = some experts didn't give any answer

Given the automotive experts' assessment of the potential of drones in 'storing' (section 4.2.1.4), a high likelihood of implementing smaller rotor-based drones is seen, but a single interviewee's answers also pointed at a potential use of hybrid drones. This appraisal is in agreement with the findings on space limitations in a storage setting and supports the assumption that mostly information-based applications lend themselves to drone usage, as they only require the adjustment of certain sensors, for example heat or humidity sensors.

Against the background of the characteristics of rotor-based drones, this assessment is plausible, and rotor-based drones would be the preferred choice because of the advantages they offer in difficult-to-navigate environments due to their precision, controllability and stability in flight. Their capability of vertical take-off and landing make them especially usable in small areas. They are thus the drone type most suitable for addressing the identified performance measures *utilization* and *flexibility*. In very special cases, fixed-wing drones or hybrid drones may also show potential of being implemented. Yet, the limited manoeuvrability of fixed-wing drones (section 4.1.3.2) and the high costs of hybrid drones (section 4.1.3.3) should make these cases very rare.

Overall, drones have a proven potential before being implemented in the process area of 'storing', where they would discharge mostly information-based, supportive operational tasks. The preferred drone type would be small rotor-based drones as they are best suited for enhancing *performance and* quality in the logistics operations pertaining to the process area 'storing'.

5.2.3 Process area: picking and sequencing

The 'picking and sequencing' process area comprises putting parts into an order and the *delivery to picking-line* (Boysen et al., 2015) as well as *layout optimisation* (Glock & Grosse, 2012) or, summing up, *picking, auditing, packing and handling* (Vidal Vieira et al., 2017). These elements, which initially were derived in section 2.1.2, were mainly confirmed by the interviews (section 4.2.1.5). *Auditing* and *packing* are also comparable to *sequencing* inasmuch as the parts are sorted and packed in the right sequence. However, the logistics operation of *handling* may rather be allocated to 'delivery to line' according to Vidal Vieira et al. (2017), whom this thesis follows in this question only partly. The majority of the interviewees identify potential use scenarios for drones in the operation *handling*. Especially emergency processes were highlighted, which have to be carried out when mistakes occur. Only one interviewee mentioned a data-collection operation. Although several interviewees by contrast discerned no potentials, the overall picture emerging form the interviews suggests that drones can be usefully deployed in *handling* activities, especially in sequencing and picking operations.

The literature identifies numerous performance measures in this process area (section 2.1.3), such as *orders-picked*, *equipment utilisation*, *picking accuracy*, *order picking cycle time* or *picking documentation* (Paião, 2014). *Layout optimisation* to improve time and efficiency is also mentioned in the literature (Glock & Grosse, 2012), but is met with obstacles resulting from the increase of complexity driven by more product variants. Also *flexibility* (Paião, 2014) is mentioned, which aims at both stock reduction and costumer orientation

(Caridade et al., 2017). The proliferation of variants of parts is a crucial problem in this process area. The main performance measures are identified in section 4.2.1.5 and relate to *throughput*, which is comparable to picking rate and linked to sequencing errors. Additionally, *utilisation* and *costs* are highlighted. These measures address *efficiency* and stock-piling. Performance measures that can be affected by drones pertain to *quality* and *throughput* as well as *time* aspects (section 4.2.1.5). The cumulated results can be seen in the core-elements of the framework in Table 5.3.

Table 5.3 DIALOOP framework elements for 'Picking & Sequencing', Source: The author

DIALOOP framework element for 'Picking&Sequencing'			
Common logistic operations	**Potential for implementing drones**	Common performance measures	**Adressable performance measures by drones**
	from Interviews		from Interviews
Delivery to picking line		Equipment utilisation	
Picking	**Picking**	Picking accuracy	
Handling	**Handling**	Order picked	**Throughput**
Auditing		Cycle time	
Packing		Picking rate	
Sequencing		Picking documentation	
Delivery			**Number of empties movement**
	Parts emergency process	Timeliness	**Time**
	Data collection	Cost-efficiency	
		Quality and perfection	**Quality**
		Damages and lean	
		Scan&labeling quote	
		Layout optimisation	
		Sequecing errors	
	No potential*		**No adressable measures***

* = some experts didn't give any answer

Looking at drone classes regarding their potential for implementation in this process area (section 4.2.1.5), automotive experts highly emphasis rotor-based drones of all size classes so that they could match with diverse part sizes in this area. Findings show that currently mostly bigger drones would be needed, which reduces the potential of drones for being implemented. However, with regard to smaller parts, drones seem to have a high potential to be used here. The findings from the interviews with drone experts confirm this result (section 4.1.3). The latter emphasised that rotor-based drones offer high controllability and precise flying while not requiring any significant changes in the infrastructure. Their precision, was also mentioned to be a major advantage over fixed-wing drones. Hybrid drones, while offering advantages of both other drone types, i.e. vertical take-off and landing and high speed, could be useful depending on the location of the picking and sequencing area. The location would need more space and justify enough distance for not only using rotor-based drones.

Overall, drones show potential of being implemented in the process area of ‘picking & sequencing’. Interestingly, the results for this area, in contrast to those gained for the areas of goods receipt and storing, identify a major potential of drones for transporting goods.

5.2.4 Process area: delivery to line

For the process area of ‘delivery to line’, the logistics operations of *identification of parts* and *scheduling peaks* (Golz et al., 2012) as well as *scheduling of vehicles* (Emde & Gendreau, 2017) and *feeding process* (Kern et al., 2017) were identified as constituent tasks (section 2.1.2). The automotive interviews highlighted *pure transportation* and *allocation at the line*, both transporting operations, as important processes (section 4.2.1.6).

Logistics operations suitable for drone implementation are, according to the automotive interview data, *urgent delivery of supply*, *resupply or post-delivery* after errors occurred (section 4.2.1.6). Thus, the interviews suggest that drones can be implemented in *delivery to line* in a transportation capacity.

With regard to this process area Dörnhöfer et al. (2016) discuss the compound performance measure *perfection*, which comprises the subordinate performance measures *time and location* as well as *part, quality* and *packaging*. However, commonly-known performance measures are equally usable (section 2.1.2). The interview data gathered from automotive experts identifies the main performance measures to be *speed* and *on-time delivery* (section 4.2.1.6). Speed, as an advantage of drones, along with, and resulting from, the utilisation of three-dimensional *space*, is also discussed in the literature, with the time aspect being of particular importance according to Mentzer et al. (2004). Both performance measures, *speed* and *on-time delivery*, were equally identified by some experts. Thus, performance measures potentially influenced by drones are *speed* as well as the *utilisation* of transport routes by using the existing space. This is in agreement with pure transportation operations and urgent delivery, both also discussed in the previous section. The cumulated results can be seen in the core-elements of the framework in Table 5.4.Table *5.4Table 5.4 DIALOOP framework element for 'delivery to line', Source: The author*

DIALOOP framework element for 'Delivery to line'

Common logistic operations	Potential for implementing drones	Common performance measures	Adressable performance measures by drones
	from Interviews		from Interviews
Sheer transportation		On-time delivery	
	Urgent delivery of supply	Time	
	Error post-delivery	Speed	Speed
	Urgent resupply	Costs	
	Long distance delivery	Inventory	
	Non-series material delivery	Security of supply	
Line allocation process		Efficiency	
Scheduling shuttle demands		Quality-based	
Parts identification			Degree of automation
			Utilisation of transport route
			Use of existing space
			Flexiblity
	No potentials*		No adressable measures*

* = some experts didn't give any answer

The automotive experts' preference for rotor-based drones, and in some cases the acknowledged potential also of hybrid drones (section 4.2.1.6) is confirmed by the drone experts' statements. Delivery to line demands speed, and a flexible utilisation of existing space. The drone experts emphasised the delivery speed of rotor-based drones as well as their good controllability, which amounts to efficiency (Marchesini & Alcântara, 2016) and reliability (Apics, 2017). Speed is also offered by fixed-wing drones and hybrids, yet space limitations and a lack of manoeuvrability can impede the application of the fixed-wing type. Hybrid-drone application may depend on the length of the delivery path and the time gains afforded by hybrids compared to those offered by rotor-based drones. Given the demand for speed, flexibility and precision highlighted by the automotive experts, the interview data collected from drone experts also point at a better applicability of rotor-based drones. As the opinions of both expert groups are in agreement, drones are suggested to have a high potential for being implemented in the process area 'delivery to line'.

Summarizing section 5.2 discussing the part of the DIALOOP framework that relates to the process areas, the following three conclusions can be drawn. Firstly, the above processes were updated and can now be compared, or used as a basis for detailing, to company processes of DIALOOP framework users and their future processes. The framework also supports an iterative approach, which was recommended in section 5.1. Secondly, the inclusion of performance measures in the framework enables a mediation between the strategic or mission level and the operational level so that strategic measures can be squared with operational possibilities to a certain extent. Thirdly, DIALOOP core enables an alignment of drone capabilities with the requirements of process areas. In all process areas, the research identified potentials for the implementation of drones.

5.3 RELEVANT FUTURE CHANGES INFLUENCING THE IMPLEMENTATION OF DRONES

Both automotive and drone experts were asked about future developments that may influence the implementation of drones in automotive OEM intralogistics. Future developments were perceived in similar ways (section 4.2.2). The empirical results partly confirm, and partly revise the literature. This section summarises the main themes that emerge from the interview data. The areas are discussed in detail in the following paragraphs.

New infrastructure as basis of flexible complexity handling

A first finding on developments from the interviews is a clear focus on infrastructural development needs. Both automotive experts (section 4.2.2.1) and drone experts (section 4.1.4.1) similarly see a need for infrastructural development as a precondition for the use of drones. Simple corridor design may lead to a reduction of complexity and, at the same time, allow for more flexibility. Improvements in infrastructure design could result in higher drone application and more use cases. The advantages of using direct flight paths would shorten delivery times and at the same time reduce infrastructural challenges that presently account for *"limitations of AGVs"* (Olivares et al., 2015). Although the most important aspect of drone usage is presently the absence of a need for a special infrastructure, drone experts point at key advantages of providing of large areas for drones and airspace structures, e.g. nets or walls. Infrastructural changes can also affect known challenges (section see 2.2.4) such as safety and security (Clothier et al., 2015; Rao et al., 2016). Overall, large spaces can help avoid collisions (Khosiawan & Nielsen, 2016) and obstacles (Trujillo et al., 2015) and also allay noise concerns (Kunze, 2016). Overcoming these challenges may likewise help meet the acceptance criteria discussed in the literature (Arroyo et al., 2014; Vincenzi et al., 2015; G. Zhang et al., 2015). Nevertheless, the drone experts confirmed the automotive experts' requirement of infrastructure adjustments, so that infrastructure can be considered as a confirmed major factor to be included in the framework.

Drone and vehicle management system

A second finding from both interview groups is the need for a drone and vehicle management system. This supporting system has the aim to overview the supply chain and manage drones and other vehicles within the plant for traffic reduction. Implementing such a system is challenging, but a precondition for process efficiency. Whereas the automotive experts (section 4.2.2.2) focussed on a more generic vehicle management system, the drone experts (section 4.1.4.2) highlighted the need for a central drone management system with interfaces to other systems. While this second solution may be preferable in a brown-field setting, yet an overarching vehicle management could lead to a deeper implementation and a better flow of goods and information, which is equally required. A drone management system can still address some of the challenges raised in the literature such as economic concerns (Boysen et al., 2015; Olivares & Cordova, 2016) because of better path planning, which again lowers costs (D'Andrea, 2014) or can be the solution for battery ability restrictions (Hassanalian & Abdelkefi, 2017). A central drone and vehicle management system needs to be established and would clearly have manage only drones at first, but increasingly also manage parallel and linked processes as well as human-machine interaction.

Higher level of autonomy

Another major theme identified in the findings is the development of a higher level of automation as a step towards autonomy. Automotive experts focussed on flight path reproduction as well as the automated gripping of goods (section 4.2.2.3). By contrast, drone experts focussed on navigation as well as sensor development (section 4.1.4.4). Progress in navigation could also promote the development of flight-path optimisation. Interview results confirm the requirements for implementing drones discussed in the literature (Idries et al., 2015). Logistical advantages may ensue if drones fly automatically. Even though automation can be defined as a machine's capability *"of carrying out functions normally performed by a human"* (Vincenzi et al., 2015), autonomy is by definition the highest level of interaction (Vincenzi et al., 2015), yet there are voices claiming that there are no autonomous drones. The problem of different levels of autonomy has given rise to different approaches in literature, such as a five-level classification (Custers, 2016) or a three-level classification (Gupta et al., 2013). Against the background of the results of both interview groups, a significant potential can be seen in a further development of autonomy. In any case, the level of automation needs to be adjusted to the use case at hand.

Efficiency enhancement

Further findings from the interviews concerned the development of more efficiency. Automotive experts clearly focussed on the lifting capacity of drones (section 4.2.2.4). Also, the capability of drones in terms of workload and number of flights performed was discussed, which partly overlaps the above-mentioned payload (lifting weight), but also with a process view of drone usage. Both concerns are similarly highlighted by the drone experts (section 4.1.4.5). The latter were even more focussed on battery ability energy efficiency as fields that may harbour important developments influencing the applicability of drones. A higher energy storage capacity without an increased battery mass would enable drones to perform a high number of flights, as required in an automotive logistics operations environment. The potential of such a development is also highlighted in the literature (Hassanalian & Abdelkefi, 2017; Murray & Chu, 2015; Olivares et al., 2015), which also emphasises drone swarm abilities. The drone experts confirmed the automotive experts' concerns that efficiency and its future development is a key influence and needs to be integrated in the framework.

Required social mindset change and acceptance

Both sets of interviews highlighted the need for a change in mindset. Automotive experts' consider the utilisation of drones to depend on the employees' openness to this new technology (section 4.2.2.5). After all, new job profiles will have to be created and head counts may have to be reduced as a consequence of drone implementation. The drone experts confirmed this result (section 4.1.4.6) and deduced a need for a larger number of pilot projects in the field of drone implementation, but also surmised that a higher visibility of drones in everyday life would support companies' efforts to embark on the use of drone technology. Pilot projects and a higher visibility of drones could massively reduce the fears and concerns on the part of stakeholders, especially workers, and them get used to this new technology. The literature highlights the need to secure acceptance (section 2.2.4), but there are no publications proposing or investigating solutions to the problem of drone acceptance in the automotive industry. Yet, intensified drone-application pilot projects, as suggested by the drone experts, could lead to more acceptance and also accelerate the creation of new job profiles. The research at hand hopes to promote acceptance by supplying a practice-oriented framework. The level of acceptance reached will also depend on the framework's ability to bring drone usage into agreement with government regulations.

Regulation guidelines concerns

Safety and security concerns and their vicissitudes in future developments were uttered by the automotive experts (4.2.2.6), but were the only concern not also shared explicitly by the drone experts. From their perspective, progress in drone autonomy would eventually lead to fewer safety requirements. Thus, the danger of drone crashes, collisions, losses of payload in mid-air or noise pollution did not figure prominently in in the drone experts' thinking. This may mean that there are already solutions to the potential problems mentioned by the automotive experts. The literature, in contrast to the drone experts, raised many concerns, such as safety, security, privacy and missing regulation (Luppicini & So, 2016; Rao et al., 2016). On the whole, this interpretation of the empirical findings aligns rather with the literature. The reason is that safety and security can clearly be considered as preconditions of the required mindset changes as they influence the acceptance of drones. Therefore, employees' safety and security should be included in the framework.

Legal framework and regulating guidelines

Further findings from the interviews relate to the need for a legal framework or regulating guidelines. Automotive experts considered a legal framework to be mandatory (section 0), which is also confirmed by the drone experts, who stressed the importance of regulating guidelines (section 4.1.4.7). Developing a legal framework seems to be a task caught in a vicious circle as the currently very complex and varied landscape of drone laws results in widespread scepticism and very limited acceptance of drones, which, in turn, makes it unlikely that significant law-making efforts will take place and result in successful legislation. Yet, the scepticism will not diminish without laws and regulations. This research hopes to systematise questions of drone implications and, thereby, contribute to the formation of a conceptual basis that may help legal authorities to address the required changes.

Platform thinking

One major development was mentioned only by drone experts, namely platform thinking. Experts highlighted the need to think of a drone as a multi-purpose tool that can be used for a range of tasks. From their point of view, the drone is part of the platform able to support numerous applications and to serve as a vantage point for the development of novel applications. Current tendencies, however, would instead lead to purpose-specific drone applications.

Summary of future developments and changes

In summary, this section has shown that almost every development or change is likewise perceived by the automotive and the drone experts. The changes identified as necessary can be condensed in the following categories:

- Establishing a new infrastructure
- Establishing a drone management system and expanding it into a vehicle management system
- Integration of drones into new security concepts
- Striving for a high level of autonomy in drones
- Increasing efficiency
- Working towards acceptance of drones and a mindset change
- Developing usable legal frameworks and regulating guidelines

Although the respective priorities are slightly different, both expert groups in essence share the same viewpoints.Table 5.5 outlines a summary of the findings.

Table 5.5 Comparison of future changes, Source: The author

	Automotive experts on future changes	Drone experts on future changes
Changes	**Categories (* = interviewees)**	**Categories (* = interviewees)**
Infrastructure	Infrastructure adjustments	Use of existing infrastructure
	Air corridors	Air space
	Zoning	Air space regulation
	Grids	
	Traffic reduction	Process complexity
	Carrier adaption	
	Accessability	
		Process costs
Drone Management	Delivery concept	Central Drone Management
	Vehicle management	Communikation
		Linkage
	Change of flow	
		Support-system connection
Automation	Autonomy	Automation
		Navigation
	Actuating elements	Sensors and Computing
Efficiency	Battery performance	Battery performance
	Loading cycles	Energy efficiency
	Payload	
		Complexity
		Costs
		Standardisation
Acceptance	Mindset	
		Use Cases
	Job profile change	
		Board decisions
	Employee reduction	
Legal Action	Regulation	Regulation
	Legal framework	
		Legal setup
Safety and Security	Noise emission	
	Safety	Safety for working in parallel
	Data protection	
	Downwinds	Controllability by redundancy
Platform development		Drone as a platform
		Special developments

The developments and changes identified here can function as signposts for framework users to work with. Figure 5.2 shows the integration of future developments and changes into the framework's comprehensive approach.

The topic of changes and developments is integrated into the framework on a general level, i.e. it is not assigned to specific process areas or logistic operations. The reason is that developments and changes may influence every aspect of the framework and, therefore, should always be taken into consideration rather than being blanked out by concentration on a single aspect.

5.4 DRONE CLASSES OF THE DIALOOP CLASSIFICATION

In light of the interview data, the classification outlined on a literature basis (section 2.3.1) requires minor revisions. Drone experts explicitly confirmed the segmentation in section 4.1.2. Two leading classification schemata were defined: drone type and take-off weight. These schemata are in agreement with the EASA classification entered into European law. These revisions are discussed in the following paragraphs.

Consolidation of types for the DIALOOP Classification

In a first classification attempt, drone types were distinguished into ‘rotor-based drones’, ‘fixed-wing drones’ and ‘hybrid drones’. The suggested drone classes, developed in the literature review in section 2.2.2.2, were commonly confirmed throughout the research in both interview sets. Drone experts confirmed the researcher’s distinction of drones according to three classes (section 4.1.3) shown in Table 5.6:

Table 5.6 Determined drone classes by type after the analysis, Source: The author

Rotor-based drones	**Fixed-wing drones**	**Hybrid drones**

Furthermore, the drone experts also validated the use of these classes as a rating instrument for the automotive experts, who had to rank drone types for specific purposes in the interviews (section 4.2.1). The automotive experts appeared to have a good understanding of the drone classes, but were also given a handout with drone types during the interviews. Some mentioned that they were not aware of hybrid drones and many of the automotive experts knew only the rotor-based drone type prior to the interviews. However, with the help of the handout, the classification was quickly understood and easily applied.

Consolidation of weight for the DIALOOP Classification

As proposed in section 2.3.1, weight differentiation used three ranges: *small* with ‘up to 2kg’, *medium* with ‘2kg to 10kg’ and *large* with ‘10kg to 25 kg’. The weight-based approach can be related to the risk-based approach of the EASA framework as

“it's all about the purpose and weight class, mainly”[97] (D1).

The classification according to purpose, an important aspect of the DIALOOP framework, is discussed in section 4.1.1 and the classification according to weight in section 4.1.2.2. Furthermore, some interviewees (D9) advised to adjust the weight limits further following the EASA classification, although most of them verified the boundaries. The EASA framework was used as a model particularly in the area of weight (EASA, 2018b), which is why the following decisions were made on the basis of the interview findings:

- the DIALOOP class 1 '*small*' is adjusted to 0-4 kg instead of 0-2 kg. The newly created DIALOOP Class 1 comprises the classes C0, D1 and C2 from the EASA classification.
- the upper boundary of DIALOOP class 2 *'medium*' of <10 kg stays as proposed as the EASA initially does not differentiate within the weight range between 4 kg and 25 kg. The DIALOOP Class 3 further could granulize the EASA C3 and C4 differentiations into more detail, thereby offering a higher informational value to users of this classification.
- the upper limit of the open category remains the same as proposed in section 2.3.1, i.e. 25 kg.

Conceptual classification

Rotor-based	Fixed-Wing	Hybrid	Max. Takeoff-weight
DC* 1-R	DC 1-F	DC 1-HT	small [<2kg]
DC 2-R	DC 2-F	DC 2-HT	medium [<10kg]
DC 3-R	DC 3-F	DC 3-HT	large [<25kg]

*DC = DIALOOP Class

EASA Framework

Max. Takeoff-weight	Classes	Operation. Subcategory
<250g	C0	A1: fly over people
<900g		
<4kg		A2: fly close to people
<25kg	C3	A3: fly far from people
	C4	

Resulting DIALOOP drone classification after analysis

Rotor-based	Fixed-Wing	Hybrid	Max. Takeoff-weight
DC* 1-R	DC 1-F	DC 1-HT	small <4kg
DC 2-R	DC 2-F	DC 2-HT	medium <10kg
DC 3-R	DC 3-F	DC 3-HT	large <25kg

Figure 5.3 Revised DIALOOP Classification, Source: The author partly adopted from EASA (2018)

On the one hand, speed was preferred to weight as a classification marker by one expert (D10), which would confirm the kinetic energy theory (Novaro Mascarello & Quagliotti, 2017). This risk-based approach is also discussed in the literature, yet has been developed with the help of manufacturers and users into a *"concept of operations"* (Pauner et al., 2015). In recent publications, the classes "open-specific and certified" are used, yet without details about their categories (Novaro Mascarello & Quagliotti, 2017).

In parallel, Hassanalian & Abdelkefi (2017) used a range from two to five kilos. Within the drone-expert community, many different opinions occurred regarding classification limits within and outside of the 25-kilogram range. Furthermore, there is a lack of discussions about classes in between. The middle class on the other hand could follow other literature, in particular Bernard et al. (2011), by using 15 kilo as the upper limit, or Weibel & Hansman (2004) with a range from 0,5 to 20 kilo. Using the interview findings, this research sets the dividing line between medium class and large class at ten kilogram. This approach helps lessen the gap between smaller drones from two to four kilogram and drones at the upper limit of 25 kilogram.

Except for the minor adjustment from two kilogram to four kilogram, the DIALOOP classification is very similar to the EASA classification. This allows for a more detailed differentiation of classes than offered by C3 and C4 in the EASA classification. Although the EASA classification was passed during the interview phase, the similarity between it and the classification developed on a literature basis in this research show that there was a need to develop such a categorisation system. The DIALOOP classification can be seen as an extension of the EASA classification with the purpose of offering a more detailed approach to drone classification specifically for automotive OEM logistics operations. A more precise categorisation of drones could possibly lead to higher acceptance levels. Following a comprehensive approach again, Figure 5.2, presented at the beginning of this chapter shows the position of the drone classification in the DIALOOP framework.

With the classification, research objective 2 is achieved, which aimed at a drone classification suitable for automotive OEM logistics operation. By adjusting the weight boundary of the drone class the author furthermore aims to higher the acceptance of the classification in later usage.

5.5 CONTEMPORARY PERSPECTIVE ON DRONE POTENTIALS USING THE DIALOOP FRAMEWORK PROCESS STRUCTURE AND THE DIALOOP DRONE CLASSIFICATION

As presented in the above sections, the DIALOOP framework was initially developed as a highly abstract structure and, thus, unaffected by transitory factors. However, the interviews yielded insights into topical factors relevant for the DIALOOP drone classes and the entire framework, which are discussed in the following section. During the interviews, the automotive experts were asked to give a perceived rating of the proposed DIALOOP drone classes as a basis for suitability in the process area. The rating is based on the classification of drones in section 2.3.1 in types – rotor-based, fixed-wing and hybrid – and size classes– small, medium and large. It can be stated that overall the automotive experts showed good acceptance of the DIALOOP drone classes applied in combination with the process areas.

DIALOOP drone classes in ‘goods receipt’

With regard to the process area of ‘goods receipt’ (section 5.2.1), the tasks of transporting, booking and checking were outlined. Overall both drone experts and automotive experts attributed rotor-based drones the highest potential in this area, while they saw for fixed-wing drones no likely application and for hybrid drones only a very low suitability of being applied. Against this background, a high suitability for rotor-based drone implementation can be assumed. Only single statements attributed a medium suitability of application to medium and large rotor-based drones. The highest suitability can be seen for small rotor-based drones. Other drone classes are not seen as likely candidates for implementation. The preference is clearly for

> *“rather smaller solutions because it is indoor”* [98] (A1).

Fixed-wing drones show no suitability for implementation at all. There is even a complete negation of any chance of applying fixed wing drones in ‘goods receipt’ in a statement uttered by A5:

> *“with these fixed-wings, with those I can actually do nothing from an intralogistics perspective”* [99] (A5).

Only one expert saw a high suitability in the use of hybrid drones. One expert did not subscribe to the existence of the process area of ‘goods receipt’ in general. One automotive expert, A10, abstained from an assessment regarding hybrid drones, stating a lack of knowledge as a reason.

<u>DIALOOP drone classes in ‘storing’</u>

Summarising the potentials of drones in the process of *‘storing’* has to start with the observation that the experts exlusively identified information-based tasks as possible application scenarios for drones. This finding is surprising as logistics operations are typically tranportation-oriented, such as buffering, pure transportation and releasing goods from stock. Performance measures generally addressed delivery and product quality, followed by perfomance. As in ‘goods receipt’, for the tasks considered suitable for drones, rotor-based drones were clearly preferred. This is partly due to requirements of an indoor application and to the fact that they

> *“can turn on the spot,* […] [they] *do not have to fly a big turn somewhere”* [100] (A1).

Similarly, a higher suitability for small rotor-based drones was ascertained and also a slight tendency toward using hybrids could be seen. Especially one expert (A2) expressed a high suitability for the implementation of hybrids besides rotor-based drones and rated the use of smaller drones even as very likely. Regarding fixed-wing drones, air space limitations would prevent them from flying at high speeds in storage facilities. However, some experts ranked large fixed-wing drones as very likely to be used in the process area of storing. However, automotive experts in general attributed a high likelihood of application to small rotor-based drones.

DIALOOP drone classes in ‘picking and sequencing’

In the process area of ‘*picking and Sequencing’*, it was particularly rotor-based drones that matched the requirements and were considered to be able to influence efficiency and quality of the logistics operations, especially in data-gathering but also in parts-transportation functions. All rotor-based drone classes were considered have an at least good suitability for application. Findings from automotive expert interviews show that rotor-based drones are considered to be more likely to be implemented, yet drone size had a lesser influence on the perceived ratings. All experts stated that for fixed-wing classes usage is not likely at all. Regarding fixed-wing drones, a statement made by A10 expresses the general scepticism:

> *“on factory grounds I would not even consider the fixed-wings here”* [101] (A10).

Findings regarding hybrid drones show that only two experts assumed a slight suitability. Contrary to their statements, drones may not make sense in this process area.

> *“Regardless of the technology carrier, it is very unlikely that a drone would be used there”* [102] (A4).

This statement represents the opinion of the majority of experts, who see no application for drones of any kind in this process area. Other more suitable technology may be preferable. Again, one expert (A10) declined to answer this question with regard to hybrids based on a lack of knowledge.

DIALOOP drone classes in ‘delivery to line’

A clear tendency to rotor-based drones is found in the process area ‘*delivery to line*’, as in all other areas. Yet, there was not much differentiation in the ratings regarding the size of rotor-based drones. By contrast, some experts did not see any suitability of drones being applied. All experts agreed on a lesser likelihood of application for fixed-wing drones and only a few mentioned hybrid drones as possible candidates for implementation.

The drone ratings of the automotive experts showed a strong tendency to a suitability of implementing rotor-based drones, and about half of the experts attribute to hybrid drones at least a low suitability. Mostly no differences were made with respect to size, even though smaller drones were recommended, e.g. by A10 with regard to drones in factory halls:

> *“the smaller the better”* [103] (A10).

A major emphasis was put on transported weight, with one expert assuming that

> *“with small and light parts perhaps also small and medium [drones] are adequate”* [104] (A1).

However, one expert only considered rotor-based drones fit for indoor use (A1). Others, addressing the indoor setting, stated that fixed-wing drones were not suitable at all. Fixed-wing drones need free space (A4) and may be more

> *"suitable to travel longer distances, so I would not have a need for them here in the factory"*[105] (A10).

This statement is underpinned by another expert, stating that for

> *"regular delivery of load carriers, I see everywhere a five, that does not work"*[106] (A4).

On the other hand, a clear selling point of hybrids could be that they could offer a more efficient solution than other drone types if the distance between storage location and line is large (A1).

In summary, the following results were reached. It was shown in the above paragraphs that the DIALOOP classification was recognised as very useful by the automotive experts, who used it in draft form for their ratings. These opinions along with the results of the drone expert interviews (section 4.1.3) make it likely that the ratings are valid and that the application of a drone classification as a basic framework leads to solid results. The ranking of the perceived application rating of drone classes can vary according to application cases. However, the results show that

- there is a clear focus on rotor-based DIALOOP drone classes. In all process areas, rotor-based classes were attributed a good or even very good suitability of being applied. The tendency toward a higher application suitability of rotor-based drones increases for smaller versions of this drone class. In three process areas – 'goods receipt', 'storing' and 'picking and sequencing' – smaller rotor-based drones were preferred, whereas in the 'delivery to line' process area the size apparently did not matter. Furthermore,
- for fixed-wing DIALOOP drone classes there appears to be almost no suitability of application in automotive OEM intralogistics. Finally,
- there is some, albeit limited, interest in hybrid DIALOOP drone classes. Hybrid drones show a medium suitability of being applied in the opinion of a few automotive experts.

Some automotive experts stated that there is little or even no reason to apply drones in these process areas. This can result from a lack of knowledge about drones or it can indeed indicate that these process areas are not suitable for drone implementation. However, applying a basic form of the DIALOOP framework and the DIALOOP classification showed that automotive experts find the DIALOOP drone classification very applicable. With these tools, they accomplished almost the same results for automotive OEM in-house logistics as drone experts experienced in other, non-automotive areas had predicted for the area under investigation here.

All quotations are presented in Table 5.6, Table 5.49, Table 5.50, Table 5.51 in Appendix F.

5.6 VALIDATION OF THE DIALOOP FRAMEWORK

Due to the inductive nature of the empirical part of this research (section 3.1), a validation of the DIALOOP framework was conducted. The framework was validated using a further round of interviews. As described in the methodology chapter, experts from a single automotive company were drawn on for participation in the validation interviews, and all of them had already served as respondents in the initial round of expert interviews conducted with automotive experts.

The validation interviews contained questions

- about the developed four-step approach structure (section 5.1)
- about the DIALOOP core structure for every process area (section 5.2)
- about the future developments and changes (section 5.3).

All questions focussed on the applicability of the elements. The researcher also asked the validation respondents if they wanted to change or add anything. For this reason, the preliminary results were presented to the validating experts prior to the validation interviews. The following section summarises the validation interview results.

Validation of the comprehensive DIALOOP structural approach

Regarding the overall structure of the comprehensive DIALOOP approach, all experts confirmed that the approach matched their perception,

"*the structure already fits and is a procedure that you can choose*"[107] (V2).

The framework structure even helps to avoid the common mistake in current drone applications

"*that you start with a solution and then try to find a problem*"[108] (V3).

This means that drones are often used because of their innovative character without first analysing the challenges or process needs beforehand and considering other, non-drone-based solutions.

The applicability of the framework was further supported by statements comparing the developed framework with other frameworks. It was emphasised that the approach was similar to those for other technologies, which is in agreement with this research process of deriving the framework from the literature (section 2.3.2), using knowledge also from neighbouring fields. The structured, yet flexible application afforded by the DIALOOP framework was recognised by the experts as conducive to integrating strategic thinking; one expert mentioned that he would

> "*especially find it to be an interesting approach to start with strategy*"[109] (V3)

and further emphasised that the approach, due to practical orientation and transparency, was suitable for logistics departments. It was further highlighted that companies

> "[...] *proceed in a similar way with AGV processes*"[110] (V1)

and that other, not drone-related projects would be approached in a similar way (V3). These points of contact with other approaches in other areas facilitate the integration of the framework in automotive OEM logistics departments because at any stage of the DIALOOP framework users could decide against drones and choose another solution instead. Besides confirmation of the DIALOOP framework structure as a whole, some more detail-oriented observations were offered by the validating experts.

The general applicability of the framework for other technologies as well as its unbiased approach to the question whether or not drones should be used also implies, according to V2, that for every process area and logistics operation, for which drone implementation is considered possible, a list of alternative technological solutions could be included, this would add additional value to the framework application.
As several hundred different logistics operations may be dealt with in the framework, these comparisons must be practicable. A comparison of technologies on a numerical basis, e.g. with tow trains, points to future research opportunities. An illustration of this potential application of the framework is presented in the following Figure 5.4.

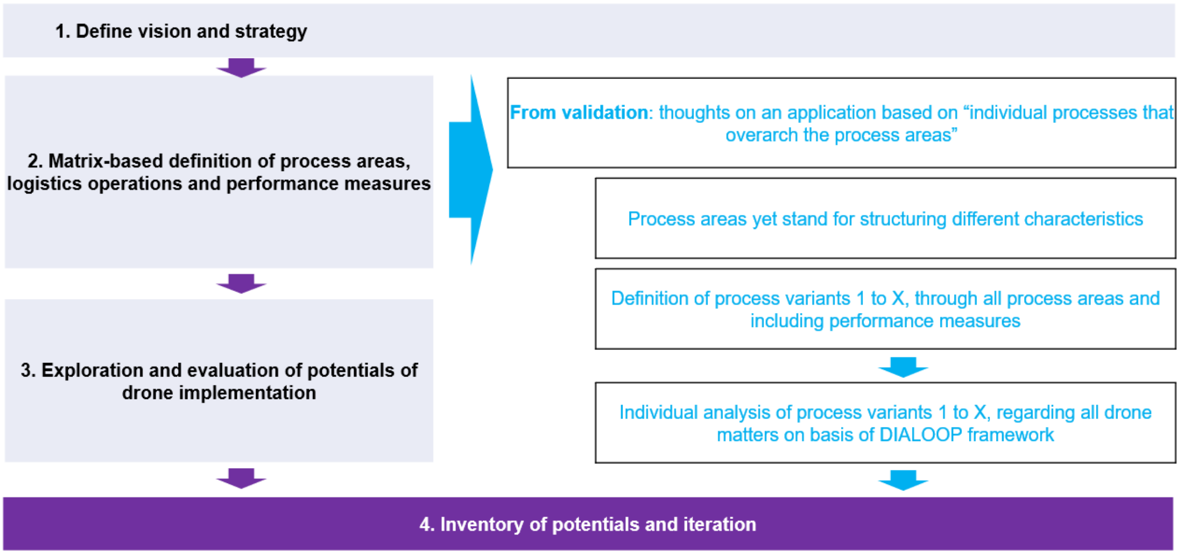


Figure 5.4 Definition of "individual process-based" future application of core area, Source: The author

Finally, the validation process yielded suggestions for applying the comprehensive DIALOOP framework on the basis of a computer tool. It was recommended to feed all parameters for drone implementation into a programme. These parameters should be logically connected and ranked. The current tools would result in a yes or no decision. However, a software-based instrument with its necessarily quantitative output and its either-or results was not the aim of this research, as it was not in scope. The DIALOOP framework has taken first steps towards structured approach to decisions about drone implementation and, thus, offers a basis for further research that may eventually lead to a digital tool.

Validation of the DIALOOP core structure and contents

The draft of the DIALOOP framework given to the respondents matched their expectations with regard to structure:

> "*it fits very well in terms of the approach, i.e. the methodological approach. That's very fine with what you were doing*"[111] (V2).

From a less structure-oriented and more content-oriented perspective, the framework's basic logistics performance measures of time, costs and quality were highlighted as suitable

> "*because logistics are always the right part in the right place at the right time*"[112] (V2).

As in the initial set of interviews, performance measures discussed in very recent logistics theory were not mentioned.

From a process perspective, long-distance deliveries were discussed as

> "*you actually want the process away from the factory premises because it takes up space without end*"[113] (V1).

By contrast, another statement pointed out that

> "*there are many factors because such a process has so many premises. Of course, any number of combinations of these premises can ensure that it suddenly becomes relevant*"[114] (V1).

This clearly implies that there is a plethora of factors to be considered. Thus, long-distance delivery may enable a better use of factory premises, but may result in a trade-off with on-time delivery. If, however, this trade-off can be avoided, a reliable long-distance delivery would be

> „*for example a very big thing in* [terms *of*] *quality*"[115] (V2).

Overall, the validation interviews confirmed initial findings from the interviews identifying *time* and *quality* as essential measures and highlighting *emergency processes* as well as *long-distance delivery* as suitable implementation scenarios for drones. This also points at application areas which were out of scope of this thesis. However, regarding the proposed DIALOOP framework structures, the experts offered a number of comments, which are described in the following paragraphs.

One comment focussed on the integration of process variants (V1) in a very detailed way (not clustered in process areas but looking at one process at a time), especially of existing processes. This would mean skipping the process areas in favour of comprehensive, continuous process views. However, the process areas are not expendable, even if process variants are introduced. The reason is that the process areas would still be necessary for systematising the individual elements and processes that constitute a process variant. It was also mentioned that it could take years to integrate hundreds of processes. The comment led to a slight change in the presentation of the framework, which is outlined in the following section 6.1.5.

Another advantage of a continuous process view could be the fulfilment towards specially mentioned process variants such as "sequencing at the supplier and then deliver", which may lead to a change of the core structure in the future. The focus on continuous processes could further facilitate a consistent differentiation between information-oriented and transportation-oriented (V3) drone implementation. This was not achieved in the previous differentiation by process areas. However, if elements of the process areas are transferred into multiple different continuous processes, all performance measures would have to be researched individually for all process variants.

Another criticism pointed out that the core structure of the DIALOOP framework – separated in process areas - may lead the user to assume that performance measures identified for one process area but are not applicable for the others. This false impression may result from the fact that the interviewees answered the same iterative questions for every process area. This would suggest a separation into process areas to be confusing.

Validation of future developments and changes

As a third part of the validation interviews, the future developments and changes were discussed, resulting in statements such as

> "*I think that's good, I understand that too, it's okay, yes*"[116] (V2).

It was striking that the experts highlighted a hierarchy of legal regulation, safety and security and acceptance and considered changes in these elements to be interdependent. Thus, it was observed that,

> "*above all, acceptance and safety and security are, of course, very close together*"[117] (V3),

which highlights the above-mentioned interdependence.

Such interconnections between developments and changes were not in the focus of either the initial interviews or of the validation interviews. Yet, with respect to such interconnections, it was also highlighted that

> "*the current legislation makes economic application extremely difficult*"[118] (V3).

This observation linked economic efficiency to the legislative situation, at least in cases in which drones are partly applied in public air space.

Additionally, the experts were asked about future developments not considered in the framework. This question led to the identification of environmental protection as a relevant development with increasing effective force (especially against the background of the Diesel-Gate scandal in Germany). It is added to the framework.

Efficiency, automation, traffic avoidance and job-profile changes as facets of the changes and developments discussed in section 5.5, were also confirmed. Apart from the addition of environmental protection as a development and the observation that developments and changes may interact with each other in a hierarchical structure or within a sequence of influence, no further unanticipated results ensued form the validation interviews. The validation interviews regarding developments and changes thus showed the results to be valid.

Scenario-based validation of the DIALOOP framework

As a last step in the validation, the experts were offered scenarios as a vantage point for working through the DIALOOP framework. Two scenarios were introduced. The first scenario demanded the implementation of a strategy aiming at "*being more competitive, using more modular approaches or technologies*". The second scenario was a demand to implement the strategy to "*use drones*" with a focus on future developments and changes.

First scenario: "Start with the framework at the strategy stage"

The experts were asked to walk the researcher through the DIALOOP framework, and the observations made in this process confirmed the framework's applicability and, especially, its suitability for an iterative approach. Experts stated that jumps or backsteps would make the DIALOOP framework very interesting for multiple applications and that

> "*that would fit. You'd probably feel like driving a bit parallel [= taking several trains of thought into consideration at once]*"[119] (V1)

Or, in the case of multiple perspectives or process variants,

> "*I jump back again. You would explain that with your loop, if it came to bear there*"[120] (V1).

Especially when using the DIALOOP framework as a tool in a workshop, iterative loops could be employed until sufficient results are reached or

> "*until I somehow say I'm done […], then somehow the potentials have been unlocked*"[121] (V2).

The scenario-based interviews also led to considerations regarding the graphical representation of the framework. While the researcher elaborated on *the framework's iterative nature*, the validation process showed that the iterative process structure needed to be further highlighted in the framework's illustration. This suggestion is implemented in the following section 6.1.5. Regarding the application of the framework, a slight *difference in the application in brown-field and green-field* settings emerged, which is currently not reflected in the framework. A differentiation between existing plants and emerging facilities was not planned from the beginning, but could be addressed by further research taking this thesis as a vantage point.

It was also commented that the DIALOOP framework could help to gain a fresh perspective as it guides the user to

> "*maybe take a look at where the drone actually offers the chance to distance myself a little bit from the existing process world*"[122] (V3).

Although the DIALOOP framework addresses existing process landscapes, it is certainly also possible that its usage in practice leads to new ideas and new application possibilities.

This could help experts to

> "*also ask the question where in the existing world might I possibly have revolutionary approaches to processes simply through these advantages that the drone offers*"[123] (V3)

While this may be most relevant in green-field settings, in the case of existing brown-field processes, the framework can help find

> "*premises that make it necessary that different processes are required for different components*"[124] (V1).

Second scenario: "Drone usage as predefined strategy"

The second scenario, in which drone application was set as a strategy, was characterised by one expert as a kind of pilot or test approach, especially given the immaturity of the technology, which requires that

> "*one would test a proof of concept under the heading Pilot or Enabler [...]*"[125] (V1).

Regarding the application of the framework, the expert stated that he

> "*would then use the thing again in the end – so make a loop and then determine the numbers that you will need in the future*"[126] (V1).

These thoughts reverberated in the comments of a second expert, who highlighted a use-case approach and stated that

> "*then you have to think specifically about where I want to go*"[127] (V2),

but acknowledges that the DIALOOP framework is applicable overall even if drone usage is determined in the first step of defining a strategy.

On the other hand, a third expert admonished the bias inherent in a process starting out from a decision about a solution instead of leading up to such a decision:

> "*I think it's incredibly wrong, […] to start with a solution and look for a problem*"[128] (V3).

He added that once the decision to use drones was predetermined, the DIALOOP framework's steps would lose their purpose. In addition, a strategy-prioritised approach would have the effect that “*performance measures would no longer have the meaning they currently have*”[129] (V3).

Furthermore, the expert commented that there

“*would then probably be much more in focus than potential and costs and key performance indicators*”[130] (V3),

i.e. future changes, process areas and logistic operations.

It is shown that the scenario of “setting drones as predefined strategy” highlights the importance if the DIALOOP framework in the opinion of the author.

Summary of the validation of the DIALOOP framework

Summarising the validation interviews, it can be stated that the DIALOOP framework matches the expectations of the experts. With the validation, research objective 5 was achieved; this objective was to have the framework validated by automotive experts. The applicability of the DIALOOP framework was tested by executing its steps in a scenario-based approach. Both scenarios employed confirmed that the DIALOOP framework meets the requirements of the experts. On the whole, validation neither led to significant changes in the framework’s structure or steps nor to the addition of core elements. A few suggestions were made by the experts, such as digitising the DIALOOP framework in order to create a software-based tool. The suggestions are partly be revisited in the section on recommendations for further research (section 7.3).

A table of the validation question is given in Appendix D.

6 CONTRIBUTION TO THEORY AND PRACTICE

Automotive OEM logistic operations, aerial drones and their possible interplay are the principal subjects in this research, whose central research question is:

> **“Can drones be implemented in automotive original equipment manufacturers (OEM) logistics operations and how can this be achieved?”**

To answer this twofold question comprehensively, the following research objectives were identified (section 1.3):

- **Research objective 1:** Define automotive OEM logistics operations and performance measures
- **Research objective 2:** Classify drones to facilitate their application in automotive OEM logistics operations
- **Research objective 3:** Explore the preconditions under which drones can meet current requirements of automotive OEM in-house logistics operations and identify related performance measures
- **Research objective 4:** Establish a framework for the implementation of drones in automotive OEM logistics operations
- **Research objective 5:** Validate the framework including the contemporary core content within automotive OEMs

All research objectives had the aim to structure the separate subjects of logistic operations, drones, framework development and validation without blocking a comprehensive vision of the framework. On the basis of a literature review, the overall structure and contents of the research objectives were confirmed (section 1.3).

6.1 CONTRIBUTION TO THEORY

The following section shows the thesis’s contribution to theory. To this end, the subsections below discusses the results pertaining to each research objective in respective.

6.1.1 Updated automotive OEM logistics operations and applicable performance measures

The literature review on logistics operations and performance measures in section 2.1 identified basic process areas and measures, which influenced the DIALOOP framework drafted section 2.3. The expert interviews were conducted using the process areas as a structural guide (section 4.2.1). The automotive experts were asked about their perception of those areas and confirmed the literature-based selection and definition of the areas (section 4.2.1.1). Likewise, performance measures identified in the literature were compared to the performance measures identified by interviewees. The DIALOOP framework and its usage were then developed at a detailed level and under consideration of the interview results in section 5.2.

The key findings summarised and discussed in this section are twofold. Firstly there are the findings to processes and secondly there are the findings to performance measures.

Key results on process-areas

While process areas and logistics operations were not in the main focus of this research, it was necessary to establish a common understanding of them with the experts to create a detailed overview over the process landscape as an orientation for the later discussion of drone implementation with the experts. The process areas relevant for the scope of this thesis and identified in the literature were

- ***goods receipt,***
- ***storing,***
- ***picking & sequencing* and**
- ***delivery to line*.**

They broadly matched those identified by the experts. The literature-based selection and definition of process areas (section 2.1.2) were thus confirmed by the automotive experts (section 4.2.1.1). The process areas as well as their pertaining logistics operations were finally used to form the core structure of the DIALOOP framework (section 5.2). Single statements from experts regarding supplier integration in the early supply chain as well as empties processing, both out of scope, indicate fields of further research regarding a supply-chain or strategic perspective of drone implementation and have been taken into account in the recommendations for further research (section 7.3). In this research, however, these topics were not pursued because of its downstream process-oriented, implementation-based in-house focus (section 2.1.1). While future research investigating supplier integration would have a strategic focus, research on empties processing would not deal with a topic related to downstream logistics and, thus, be in a wider fit with this research.

Key Results on performance measures

The second aspect of research objective 1 was performance measurements. The literature review (section 2.1.3) identified multiple perspectives with a supply-chain focus, a manufacturing focus, a logistics focus and an automotive logistics focus. Throughout the interviews, the automotive experts highlight performance measures which were partly identified in the literature on manufacturing and logistics. Figure 6.1 presents the results graphically.

Performance Measures from Literature	Supply Chain - based	Manufacturing - based	Logistic - based	Confirmation/contribution from automotive expert interviews
Efficiency	x	x		
Effectivness	x			
Differentiation	x			
Throughput		x		x
Time		x	x	x
Quality		x	x	x
Costs			x	x
Realiabiliy		x	x	
Security of supply				x
Modularity		x	x	
Predictivness		x		
Flexibility		x		
Responsivness		x		
Automation		x		
Inventory			x	
Asset management			x	
Changeability			x	
Scalability			x	
Safety			x	
Reconfigurability			x	
Decentral controllabiliy			x	

Figure 6.1 Performance measures foregrounded in the expert interviews (automotive), Source: The author

The basic measures emphasised in the interviews, such as *throughput, time, quality, costs* and *security of supply* have matches particularly in logistics literature. While some experts took a supply-chain perspective on drone application, they did not propose to use the measures *efficiency*, *effectiveness* and *differentiation*, which are typically highlighted in supply-chain literature. Similarly, the logistics experts among the interviewees did not mention any newly developed performance measures, which differ from existing basic logistics measures, although the current research is driven by multiple nascent theories and influences (section 2.1.1). While basic logistic performance measures as such were not in the focus of this research, it was necessary to gain an understanding of the experts' knowledge and application of performance measures as a basis for assessing the potential of drone applications.

Although it was anticipated at the beginning of this research that supply-chain-based views or recent developments in logistics would influence the choice of measures and definition of process areas by the experts, the results showed that automotive OEM logistics experts confirmed both existing process areas as well as basic performance measures despite the novelty of the present topic. This clearly establishes a common view on the research topic.

6.1.2 Logistics operations suitable for, and performance measures affected by, drone application in automotive OEMs logistics operations

The thesis's contributions regarding logistics operations potentially discharged by drones and performance measures affected by drone implementation mostly relate to research objective 3 (section 1.3). This investigation of potential drone-application scenarios and of the performance measures affected by these scenarios was based on the distinction and definition of process areas, of the logistics operations pertaining to them and the performance measures commonly identified (see previous section 6.1.1).

The findings from the automotive expert interviews on drone potentials are presented in section 4.2.1, and then in section 5.2 with a particular focus on the DIALOOP framework. Furthermore, the consideration of drone implementation must take future developments and changes into account that may influence the implementation in significant ways. Potentially influential future developments and changes were at first identified in the review of the literature that discussed already-known challenges of drone implementation (section 2.2.4); yet, these did not include challenges specific to drone utilisation in an automotive OEM logistics environment. Therefore, both drone experts (section 4.1.4) and automotive experts (section 4.2.2) were asked to comment on developments and changes. An analytical perspective on such influences synthesising both drone experts' and automotive experts' views was presented in section 5.3 within the framework-creation chapter. The following paragraphs summarise all major contributions of this section.

Key contributions of the thesis regarding potential logistics operations for drones

After section 6.1.1 outlined the research contributions necessary to lay a structural groundwork for the further progress of this research – in particular, identifying, defining, and confirming a common understanding of process areas, logistics operations and performance measures –, the contributions gained from the interviews with experts in both logistics operations and performance measures are highlighted in the following.

Because of the nascent character of this research topic, the relations established between drone application on the one hand and logistics operations and performance measures on the other are original contributions geared at filling a research gap in the existing literature.

The implementation of drones in different process areas was identified to be of either a transportation-oriented or an information-oriented character. It was not ascertained if the transportation or the informational character of drone application dominates. The reason is that there are, as already discussed, hundreds of different processes, which would all have to be investigated to arrive at this determination. This, however, would exceed the scope of this thesis, whose aim it was to create a first tool, the DIALOOP framework, which can adequately address drone implementation for all processes. An investigation of every single process is not necessary to reach this goal.

The research contributions relate to all process areas, with both a view to logistics operations as well as to performance measures. Regarding the process area 'goods receipt', see Table 5.1, most of the potential drone-based operations align with operations from literature, yet are not specifically discussed in the literature as potential settings for drone applications. Performance measures adressed by drones correspond to the basic measures used in logistics, i.e. time, quality, costs and reliability.

The key contribution of the thesis regarding drones in the process area 'storing' (Table 5.2) is the finding that logistics operations potentially executed by drones are predominantly information based, yet also delivery of parts and emergency part delivery were identified as potential application scenarios for drones in this process area. The findings on logistics operations that can potentially be carried out by drones as well as the findings on performance measures affected by drone implementation in the process area 'storing' are original contributions to research.

Major contributions on logistics operations and performance measures in the subsequent process area 'picking and sequencing" are outlined (Table 5.3). The findings show that logistic operations suitable for drone implementation are predominantly of a transportation character (picking, handling, parts emergency process), but data collection, an information-oriented process, is also included. The potentially addressable performance measures again are basic logistics measures, with the addition of numbers of empties which could be handled by drones.

The findings relating to the final process area, 'delivery to line', are presented (Table *5.4*). They, too, add new insights to the research field. The results show a clear focus on urgent or error post-deliveries with a potential to improve performance measures relating to speed, automation and the utilisation of limited space.

Figure 6.2 presents this thesis's contribution on performance measures potentially affected by drones. These performance measures can be distinguished in three groups. The first group comprises basic logistics performance measures, such as *throughput, time, quality* and *cost*. The second group encompasses manufacturing-based performance measures, in particular *flexibility, automation* and *inventory*. The third group relates to logistics *performance* and was not discussed frequently in the literature. These performance measures are *stock transparency*, *space utilisation*, *space availability* and *performance* (as part of an overarching measure *performance*).

A major contribution to research is the finding that automotive experts do not assess their processes using newly-developed performance measures. The limitation to basic logistics performance measures leads to the assumption that drone application as a novel technology may not be evaluated appropriately without newer measures. Therefore, it is highly recommended to update performance measures in automotive OEM logistics operations, also in order to apply the DIALOOP framework as advised in this research.

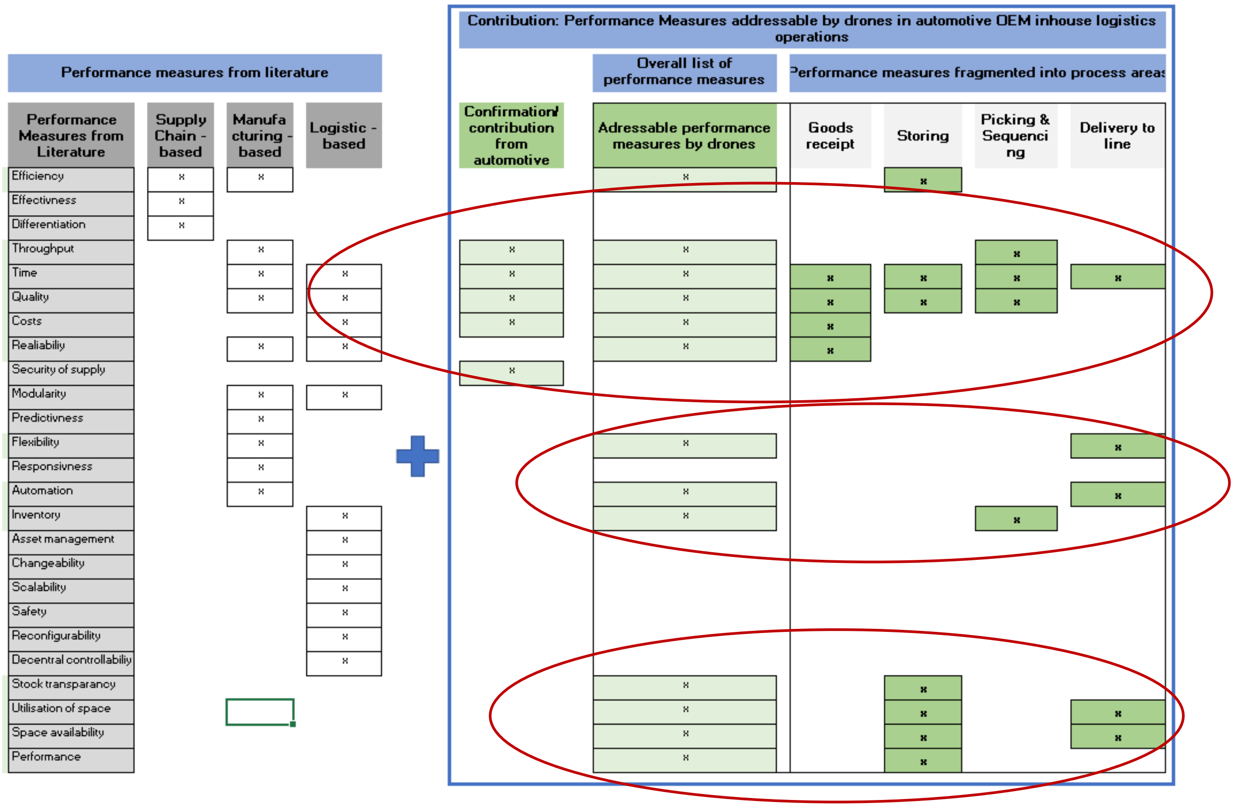


Figure 6.2 Grouping of performance measures addressed by drones, Source: The author

A final contribution regarding the implementation of drones is the inclusion of the expertise of drones experts with regard to the application of drones in the process areas. Drone experts' evaluation of drone capabilities were matched with logistics operations and performance measures.

A contribution can be seen in the finding that rotor-based drones offer the best fit to OEM intralogistics processes and performance measures. This was also evident in the automotive experts' application of the DIALOOP drone classification. The second-best fit is offered by hybrid drones. Yet, there are multiple difficulties to overcome for a successful use of hybrid drones, such as their considerable complexity and high costs. Also fixed-wing drones show many disadvantages. Especially the extensive starting and landing spaces required for their use can hardly be provided in an automotive OEM intralogistics setting. The only applications of fixed-wing drones that can be taken into consideration are situated in the context of supplier integration, where these drones could carry parts over long distances, or of large car-storage facilities, where they could be used for information-based processes in an environment characterised by open spaces and long distances. Both application scenarios are, however, out of the scope of this thesis. Concerns regarding fixed-wing drones are strongly confirmed by the automotive experts. It can be concluded that only rotor-based drones and, in some cases, hybrid drones of a suitable type can find application within OEM intralogistics covered by the DIALOOP framework.

To summarise all the contributions claimed in this section, the research has distinguished process areas for automotive OEM logistics, identified logistics operations and performance measures pertaining to these process areas and, on this basis, has identified logistics processes suitable for drone implementation and performance measures potentially affected by such an implementation. With these results research objective 3 was achieved.

On the whole, it has been shown so far that drones can be implemented in automotive OEM logistics operations and can affect performance measures based on the perceptions of the interviewees. This and the previously mentioned findings constitute novel contributions to research and fill gaps in the as-of-yet under-researched field of drone application in automotive OEM intralogistics.

An additional, also novel contribution, which was only mentioned in passing in this section, consists in an assessment of the suitability of drone types as this is still not developed in current literature. This is the focus of the following section.

6.1.3 DIALOOP drone classification for the use in automotive OEM logistic operations

The research steps toward research objective 2, regarding a drone classification for the DIALOOP framework, started with a literature review (section 2.2.2), which included literature on current applications of drones (section 2.2.1) and benefits and challenges of drone application (section 2.2.3 and 2.2.4) and led to a summary of the proposed DIALOOP classification (section 2.3.1). The literature review on existing drone classes at first identified multiple drone classes, which were applicable in other application areas. However, the overall field of drone classification proved to be characterised by a multitude of classifications using different drone classes and terminology. None of the existing classes was suitable for application in automotive OEM logistics operations.

The suggested conceptual DIALOOP classification took account of the most significant wing types as well as weight as classification categories. A weight range of up to 25 kg was identified as appropriate for the researched area. Within this range, further differentiations established a weight class of up to 4 kg and one of up to 10 kg. These weight classes can be used to match drones with specific use cases, such as transportation on the one hand (for heavier drones) and for information-gathering operations (for lighter drones).

On the basis of this conceptual classification, the drone expert interviews were held. At first, drone experts were given the opportunity to communicate their own perception of classifications (section 4.1.2), then the experts were asked for their opinion on the conceptual DIALOOP classes (section 4.1.3). In parallel, the conceptual DIALOOP drone classification was also presented to the automotive experts (section 4.2.1). All results were summarised and used to form a final DIALOOP drone classification (section 0) and to collect data from the automotive experts regarding the application of the classes (section 5.5). During the interview phase, the European Aviation Commission published the EASA classification, which largely matched the classification drafted in this thesis. This match can be viewed as a confirmation of the thesis's classification. The accuracy and usability of the DIALOOP classification was also confirmed by drone experts in the interviews. Additionally, automotive experts used the classification to discuss possible drone implementations in the process areas. Thus, the applicability of the classification was discussed, and tested, by a number of experts. Rotor-based drones with lower weight were considered as most likely to be used in an automotive OEM intralogistics setting. However, the other drone classes were considered to offer specific implementation potentials.

Compared to most of the existing classifications in literature, the DIALOOP framework clearly separates the three types of drones, i.e. rotor-based, fixed-wing and hybrid versions. Beyond this, the DIALOOP classification combines common classification criteria from both the literature and the European Commission. Multiple authors classified especially smaller drones in the rotor-based segment. Some distinguished weight classes of drones with cut-off limits at 2 kg maximum for the lowest weight class and 15 or 20 kg upper limit. The research suggested 2 kg as upper limit for the lowest weight class, but revised this limit to 4 kg mainly following comments from the interviews also for better acceptance besides the EASA classification. The DIALOOP classification now offers a practice-oriented boundary in the small-drone area of automotive intralogistics. The thesis initially also proposed to set another boundary for drones with extra payload, adding another 4-5 kg to the drone. This led to the boundary of 10 kg as upper limit of the medium class and lower limit of the large class.

Interestingly, the EASA classification includes two classes above the 4 kg limit. The 10 kg boundary of the DIALOOP classification is strongly recommended to be used to differentiate the EASA classes C3 and C4. The DIALOOP framework can be applied to arrive at more practice-oriented and more granulated classifications than offered by the EASA framework without cutting across the latter's classifications. Thus, the DIALOOP classification does not compete with the EASA framework and is thus safe to use also from a legal point of view. Figure 6.3 shows the DIALOOP drone classes in comparison to classes identified in the literature, thereby highlighting the thesis's contribution to research in the field of classification.

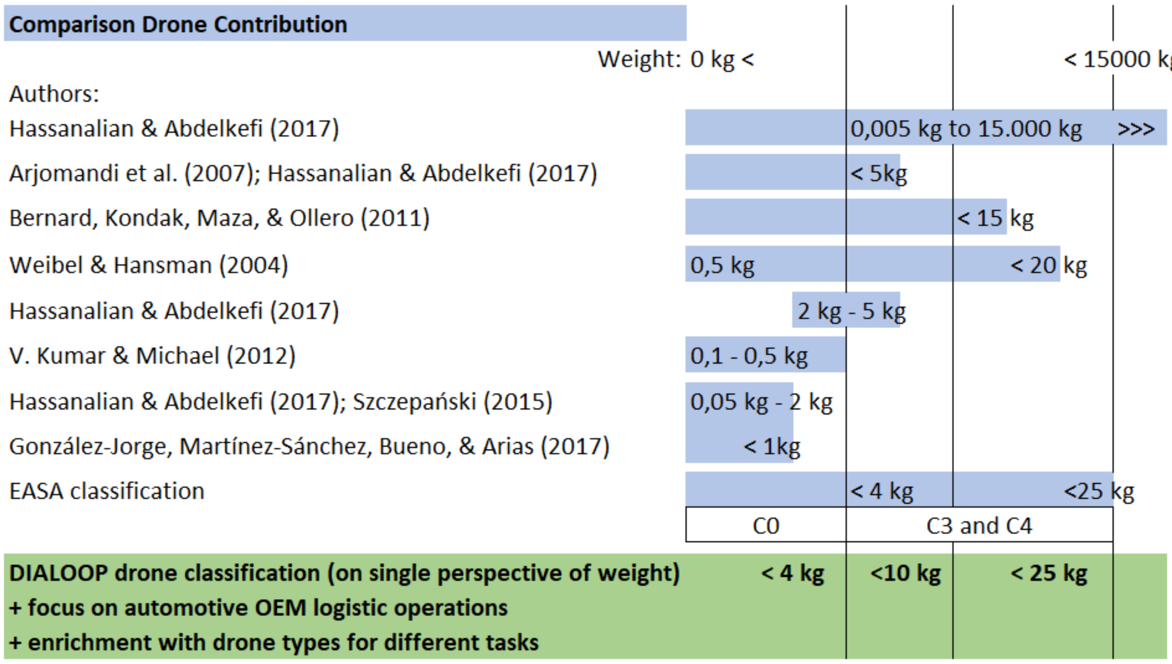


Figure 6.3 Drone classification in current literature compared to DIALOOP classification, Source: The author

A perspective of the DIALOOP drone classes from the standpoint of practitioners intimately familiar with current conditions in automotive OEM logistics was added as another viewpoint (section 5.5). The automotive experts applied the suggested DIALOOP classes during the interviews and discussed which drones could match current requirements of the intralogistics setting on basis of a perceived rating. It was apparent that the application of the framework structure offered the automotive experts useful guidance in thinking about existing processes, operations, measures and the application of drones. While using the classification, the automotive experts changed their opinion of certain drone classes in the process areas. A final overview of the exploration of the final DIALOOP drone classes is given in the following *Figure 6.4*:

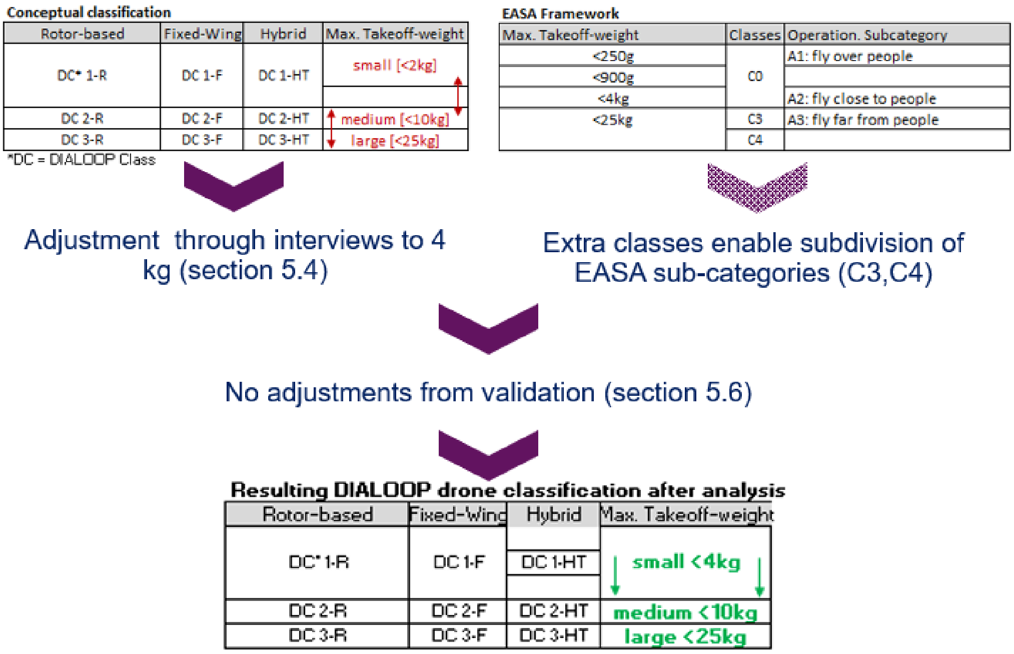


Figure 6.4 Exploration of the DIALOOP classification in the thesis, Source: the author

In summary, research objective 2 was achieved with the development of the DIALOOP drone classification. As a contribution to research, the application of drones in automotive OEM logistics operations was elucidated against a theoretical background and resulted in a classification system that helps bridge the gap between a finely granulated, practice-oriented classification suitable to automotive intralogistics on the one hand and the legally-binding EASA framework on the other.

6.1.4 Contributions regarding future developments and changes

In addition to logistics operations, performance measures and drone classification, the research investigated influential development and future changes with a potential impact on drone implementation. Overall, the developments and changes identified are similar to those that the literature review found in other areas of technology application. Accordingly, drone experts and automotive experts highlighted similar developments and changes and also weighted them, similarly, as shown in section 5.3. A summary of the main contribution of each change cluster is given in the following.

The contribution of this thesis with regard to developments and changes is twofold. On the one hand, developments and changes were identified and experts' main statements were summarised in *Table 5.5*. On the other hand, the participant validation identified a possible need for a hierarchically differentiated chain of effects which shows the causal interrelations between developments and changes. A ranking of the changes and developments or an analysis of their interdependencies was, however, not an aim of this research, but is included among the recommendations for future research in section 7.3. In addition, the interview data showed a clear basic accord across both sets of experts, i.e. drone as well as automotive experts, that the legal restrictions interfere with successful commercial drone implementation and innovative projects, and that legal changes may be instrumental in enabling other developments conducive to drone applications.

6.1.5 DIALOOP framework for the implementation of drones in automotive OEM logistics operations

The research finally culminated in the DIALOOP framework based on both literature-review and interview-analysis results. The framework, conceptually drafted in section 2.3 on a literature basis, revised in section 5.1 using empirical data and validated in section 5.6, are presented in its finalised form in the following section. With the finalised DIALOOP framework, research objective 4 is achieved, which aimed at the development of a framework that combined insights on automotive OEM logistics operations with the nascent theory of an application of areal drones in these operations. The literature review found about 45 frameworks in the literature and drew on six for the first draft of the DIALOOP framework. The development phases of the DIALOOP framework are at first graphically given in the following *Figure 6.5*, also highlighting key characteristics identified in all stages.

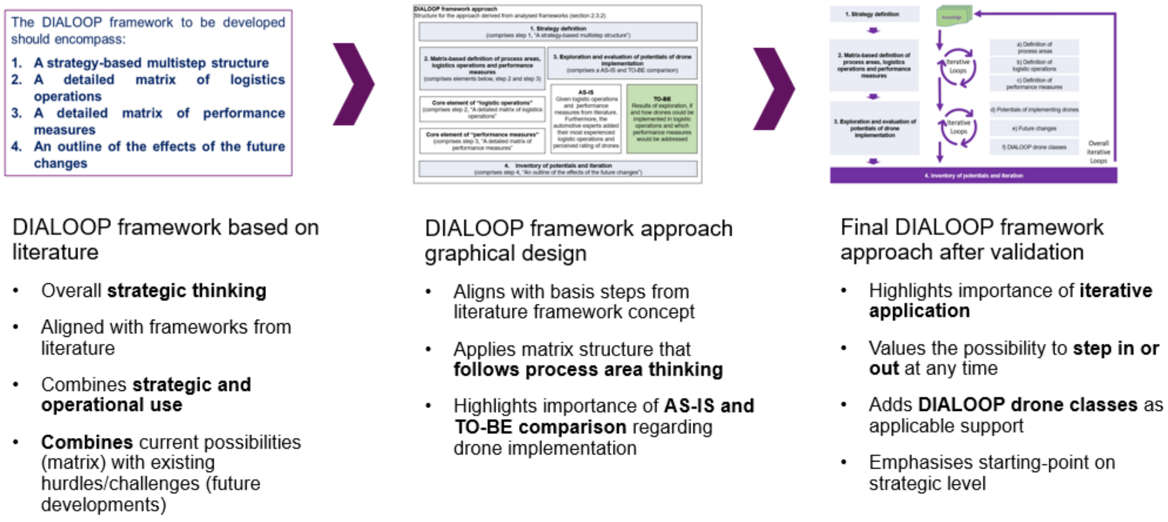


Figure 6.5 Exploration stages of the DIALOOP framework, Source: the author

The large number of frameworks showed that a comprehensive approach to both framework development and framework application was needed. This approach is outlined in section 5.1.

The DIALOOP approach encompasses:

1. **Strategy definition**
2. **Matrix-based definition of process areas, logistics operations and performance measures** (under guidance of the DIALOOP framework)
3. **Exploration and evaluation of potentials of drone implementation** (under guidance of the DIALOOP framework)
4. **Inventory of potentials and iteration** (under guidance of the DIALOOP framework), **which includes the integration of major developments and changes that may influence the potentials of implementation**

Having defined the overall steps, the DIALOOP core structure was derived. In order to establish this core structure, the process areas and the logistics operations and the performance measures pertaining to each process area were listed (section 6.1.2). The basis for this step was provided by both the literature review and the interviews. The potential drone application in logistics operation was added as a step. This core structure allows the framework to be used to compare the as-is state to a potential to-be state.

The third part of the DIALOOP framework is the DIALOOP drone classification. The classes were developed on a literature basis and then validated in the expert interviews. Small adjustments led to the classification now included in the finalised DIALOOP framework (section 6.1.3). The classification supplements, but does not contradict, the EASA classification and can thus be considered as a useful amendment to the existing and legally binding regulation. The distinction of drones in different classes aids the user of the DIALOOP framework in selecting a drone type suitable to the logistics operation and environment under scrutiny.

As a fourth element of the DIALOOP framework, relevant future developments and changes were identified. Initially identified in the literature review (section 2.2.4), they were also pointed out by drone or automotive experts as having a potentially significant influence on the implementation of drones. The experts also identified the most significant challenges to be addressed with respect to the discussed changes and developments.

The DIALOOP framework then underwent a validation process with automotive experts. This step appeared particularly important because of the nascent nature of the research topic and the resulting need to reduce bias, subjective distortions and blind spots in the qualitative approach taken here. Overall, the experts confirmed all results – the comprehensive

DIALOOP framework approach, the core structure including content and the future changes – as useful to them and did not add any further insights to the already discussed results.

A final graphical version of the DIALOOP framework is given in Figure 6.6:

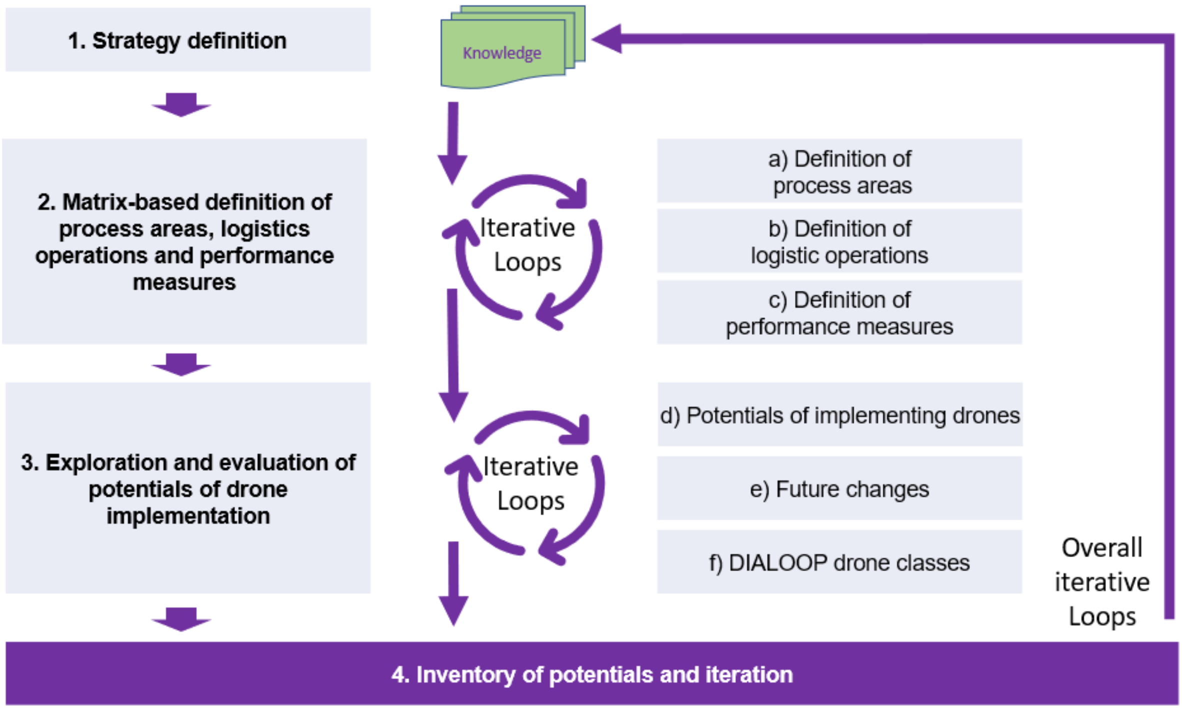


Figure 6.6 Final DIALOOP framework structure, Source, The author

Key Results regarding the comprehensive DIALOOP framework approach

The DIALOOP framework stands out by several aspects. Firstly, the tool features a comprehensive approach from strategy to operational implementation. Secondly, by focussing on an iterative approach in addressing numerous logistics challenges, the framework's core contents provide an opportunity to learn from previous iterations. Thirdly, although the steps are recommended to be executed subsequently, the framework offers the possibility to jump back and forth, while still arriving at outcomes that support implementation decisions and efforts. The DIALOOP framework as a whole contributes to theory as there is no other framework to date that addresses the application of drones in automotive OEM logistics operations. At the same time, it is aligned with frameworks for other, neighbouring applications and draws on their strengths. The validated framework marks the achievement of research objectives 4 and 5. The DIALOOP framework is immediately applicable and can serve as a guide method for further research regarding the implementation of drones in automotive OEM logistic operations.

The theoretical contributions shown in this and the previous sections are complemented by the contribution to practice discussed in the following section.

6.2 CONTRIBUTION TO PRACTICE: AN APPLICABLE FRAMEWORK

The practice orientation of this thesis was already manifest in the literature review (section 2.1.1), where the fast-changing environment of the automotive industry was acknowledged and investigated. The automotive industry is, in this regard, certainly pioneering new terrain for other manufacturing sectors. Technology integration is major driver of developments in logistics operations. As far as drone technology in logistics is concerned, however, previous research and development efforts addressed different areas of implementation, such as long-range rural delivery. Only a few publications focussed on automotive OEM plants, and, in doing so, found that their complexity increased at a fast pace due to the extraordinarily high, and continuously growing, number of parts that need to be supplied and the concomitant challenges of limited, and shrinking, space availability and maximised traffic.

Applying the DIALOOP framework in a professional environment makes many of the theoretical contributions of this thesis available to practice and provides the practitioner with a guideline needed to navigate the steps toward optimising intralogistics operations, which is a precondition of maintaining or enhancing competitiveness. In addition, the DIALOOP framework with its iterative approach offers multiple entry points, such as strategy or logistics operations, thus enabling top-down, strategy-driven as well as bottom-up, operations-driven efforts at optimisation. When following an already defined strategy, logistics operations relevant to this strategy's implementation can be chosen using this framework. Also, the framework guides decisions about the performance measures used to direct drone implementation and, eventually, to measure the success of the implementation. However, the framework does not presuppose that a decision in favour of drone implementation has been made nor does it block out alternative avenues toward optimisation other than drone technology. Rather, the solution-finding process guided by the framework is open-ended.

Furthermore, the framework distinguished several drone classes, thus offering a highly detailed view on possible application scenarios. The drone classification used in the framework was developed using interview data from automotive experts with and without drone experience, but also from drone experts and is therefore highly practice-oriented. The results of this thesis show that practitioners can benefit from focussing on rotor-based drones, as they, along with fixed-wing, drones have not only often been discussed in the literature for automotive practice, but have also been shown in this research to be well-suited to operating under the conditions of a logistics environment in a direct functional and spatial vicinity to production. Although hybrid drones are often included in current use cases and discussed in the literature, the experts' view on this type vary greatly and the utility of hybrid drones for possible applications is largely uncertain. Practitioners can thus use the DIALOOP framework to become aware of applicable drone classes and, as a result, improve their implementation rate if adequate use cases are given. The practical perspective of the framework established by discussing drone applications against the background of current logistics operations increase the value of the DIALOOP drone classification and makes the framework a potential vantage point for the consideration of many other implementations.

As a third entry point into the DIALOOP framework, this research has highlighted possible developments and changes which may significantly influence drone implementation in the future (section 5.3). With a strategy geared toward competitiveness, defined processes and a drone classification that organises the field of drone application in a practice-oriented manner, the framework user can take the developments and changes into circumspect consideration and future-oriented planning. This also includes ‘soft factors’, such as the acceptance of drone technology by stakeholders such as employees and the social ramifications of drone implementation, such as changing job descriptions.

The challenges of implementing drones have also been shown to stem largely from legal and organisational restrictions. As far as legal regulation is concerned, the lack of regulations, which has been identified as a factor in the low social acceptance of drones, cannot be addressed by the DIALOOP framework. However, the framework could help policy-makers to create further, more practice-oriented regulations. As the framework also harmonises with the legally binding EASA classification of drones, it can be applied without losing sight of legal considerations. This, too, strengthens its applicability in practice and constitutes an important contribution to practice out of this research.

Further contributions to practice also originate from the synthesis of expert knowledge from both the drone-technology and the automotive-intralogistics area. As the framework is prospectively be used in an automotive setting, the information from the drone-technology field contained in the framework helps to remove blind spots and facilitate a fresh perspective on possible solutions. The research at hand has clearly shown that the experts, while sharing the same views on many topics, also differ in important aspects, with the drone experts considering possible problem solutions from a mainly technical perspective, while the automotive experts’ perspective is often directed at processes and performance measures.

Against this background, this thesis points out the potential of a future collaboration between automotive and drone experts. The results of such a cooperation could transform the automotive environment.

The DIALOOP framework offers a guideline for practitioners to explore opportunities to increase competitiveness through drone technology solving the numerous problems that nowadays have to be confronted by logistics operations in an automotive OEM in-house environment.

7 CONCLUSION

This chapter concludes the thesis by summarising its main conclusion and suggesting recommendations regarding the use of the DIALOOP framework. It further discusses the limitations of this thesis and recommend areas of further research in the field of the nascent theory of drone application in automotive OEM logistics operations.

7.1 MAIN CONCLUSIONS AND RECOMMENDATIONS

This thesis set out to explore how drones could be implemented in automotive OEM intralogistics operations. In doing so, it broached a new research field defined by a combination of research on aerial drones and automotive OEM intralogistics operations. Despite the still nascent nature of this novel field of exploration, the thesis's results show that drones can certainly be applied in this area of in-house logistics.

The primary goal of this thesis, however, was to develop a framework for drones in automotive OEM logistics operations. This DIALOOP framework requires as a constituent part a drone classification system.

The drone classification developed in this thesis and integrated into framework was informed by literature as well as qualitative data gained from semi-structured interviews with drone experts and automotive experts. The drone classification was first drafted on a literature basis and then presented to the interviewees, who confirmed the classification as suitable for distinguishing drone types and classes in a way that is relevant to automotive intralogistics. The classification focusses on drone types (rotor-based drones, fixed-wing drones and hybrid drones), yet also differentiates them between according to weight. The classification also follows the legally binding EASA classification, which it enhances through additional layers of differentiation without contradicting its classification criteria. The classification developed in this thesis is thus industry specific and, at the same time, in agreement with non-industry-specific legal classifications. It is thus highly useful and applicable.

The DIALOOP framework designed and tested in this thesis is the second main contribution. By including both strategic and operational elements, the framework can be applied in very early stages of a decision or exploration process as well as in late stages of drone implementation. Its applicability was confirmed by the automotive experts in both the main interviews and in an additional interview round conducted for validation purposes. Especially the iterative nature of the framework boosts results and broadens its application cases.

By using the DIALOOP framework in the interviews as both a structuring tool and an object of enquiry, the thesis arrived at empirical findings concerning logistics operations and performance measures. It was shown that drones can be a valuable addition to the existing operational setting. While the operations within a process area only share a few common characteristics, this research has shown that drones can be implemented in several processes in each process area. The performance measures that were identified as relevant as they may be affected by drone implementation were shown to belong to the group of measures commonly used in a logistics context. They make evident that drone applications can add value if applied in specific operations, which can be identified using the DIALOOP framework. As this research and application field is of a still nascent nature, it is recommended to apply this framework in several projects relating to drone application, thus accumulating experiential learning through an iterative approach, to which the DIALOOP framework lends itself.

This research has led to initial results in the combination of two hitherto separate fields of enquiry and has created a first path toward the implementation of aerial drones in automotive OEM logistics operations.

7.2 LIMITATIONS

The following section considers limitations of this thesis and that affected data gathering, data analysis and framework creation. Mostly, these limitations result on a methodological level, especially concerning validity (section 3.8.1) and reliability (section 3.8.2).

A first limitation that has to be considered is inherent in the number of interviewees in both sets of interviews, which was limited to nine automotive and nine drone experts. The three automotive experts drawn on for participant validation were recruited from the existing sample of automotive experts. The size of the samples can be considered appropriate for qualitative research on a nascent topic, especially if saturation is reached, which was the case in this thesis as explained in section 3.6.3. With respect to the validation interviews, the Corona pandemic presumably increased the workload of potential interviewees and, therefore, may have reduced their willingness to participate. Some interviewees mentioned massive changes in the mindset of the industry regarding costs, and their concern for job security caused them to concentrate on their work and to refrain from expending time on participating in research. The validation sample was thus rather small, but there was also a clear pattern in that all three experts confirmed the results, adding only rather marginal comments. The interview results can thus be assumed to be valid, but a larger sample might have added further facets to the validation. Furthermore, although in this research the advantages are highlighted, one could hold similar set of interviews in a sequence as well. Especially in more specific cases in single process areas, a start with a process-oriented view followed by a drones based-view could be a valuable approach which is similar to the overall DIALOOP framework approach. In future cases, the results can vary on basis of this sequencing if applying the DIALOOP framework and in some case detailed measurement results can change as well. However, the DIALOOP framework structure itself might not be touched by such sequencing.

Another external limiting factor for this research was the German automotive diesel emissions crisis. It may have prevented experts from participating in this research because of restrictions on managers' communication with outside parties or because of fear of working with an external researcher.

Specific legal regulations, the existence of work councils or culture in general may limit the generalisability of the research at hand and the transferability of the insights and results to companies in other countries. In addition, the EASA drone classification is valid in the entire European Union and, thus, also not particular to a German setting. This, too, enhances the transferability of results at least in a European context. Nevertheless, especially in the case that the framework is amended to accommodate supply-chain-focussed approaches, such regulatory specifics have a higher impact given that supply chains span countries and continents. If, however, the framework should be amended to accommodate the strategic use of drone technology, there would be a greater potential of alignment with companies in other countries.

A further limitation can be seen in the fact that the framework development did not include a differentiation of all the different process variants in the intralogistics of car manufacturers. While the researcher acknowledges the existence of a broad range of process variants as there are multiple methods of supplying and storing parts and that information can be collected using a variety of sensors, the focus of the research was not on accounting for this multitude in an encyclopaedic way. Instead, the decision was made to use defined process areas for the purpose of clustering logistics operations. This approach enhances the flexibility in using the framework and, thus, appears suitable to the still-nascent nature of the topic. The trade-off is, however, a certain lack of specificity in the matching of logistics operations, performance measures and drone classes, which has to be compensated for at the level of the framework's application in practice.

7.3 FUTURE RESEARCH RECOMMENDATIONS

Following the limitations discussed in the above section, this section recommends paths for future research. Further research could validate the framework with a larger number of participants and identify further connections between performance measures and areas of drone application.

The topic can be further researched by adding quantitative methods in order to investigate the predominance of problems in automotive OEM intralogistics that would lend themselves to a drone-based solution. This could help gauge the potential for drone application in this industry in a quantitative manner. With an increase of application cases over time – ideally cases using the DIALOOP framework - a case-based comparative research and evaluation of the framework could take place and lead to further refinements in its structure, content and application.

Also, research focussing on single process areas could lead to more in-depth results and a thorough evaluation of the findings of this thesis. In contrast, the focus of future research could be broader in adjusting the framework so that it can be applied to entire supply chains. This would broach a much more expansive research field and potentially unlock additional potentials of drone technology. Especially the field of supplier integration could lead to an integration of drone-based long-range rural delivery in the DIALOOP framework.

As this thesis focussed on German automotive OEMs, its results should be checked with respect to automotive OEMs in other countries as well. In a first step, plants of the German OEMs in other part of the world could be included in such research. As the production facilities of an OEM certainly share characteristics regardless of where they are located, the results could help understand differences in intralogistics, and in the potentials of drone application that are country- and not OEM-specific. An investigation of non-German OEMs located outside of Germany could also be carried out. This could lead to modifications in the framework's structure and content to make the framework more applicable in other national settings. This would prepare a comprehensive world-wide comparison of automotive OEM logistics operations with regard to their potential for drone implementation. Similar substantial changes in the framework could occur if the framework were applied in sectors other than automotive OEMs.

Research could also be conducted on the degree of process integration in the near future. Thus, the goods transport could be routed directly through the area of incoming goods processing, with suppliers delivering the goods directly to the warehouse, to picking or even to the line. Similarly, integrated processes exist even today. If goods are routed through processing areas, their movement would allow for stationary scanning. The flexibility afforded by drones in information gathering would then be irrelevant. Further research could also investigate transportation- or, respectively, information-oriented uses of drones.

Further research could help transform the DIALOOP framework into a performance measurement system of high maturity. Both the DIALOOOP framework and a performance measurement system developed on its basis could be further researched with respect to how knowledge gained from applying them can be stored and used to update them and to enhance their practical applicability.

The thesis strived for a close insight into practice as well as for the practical relevance of its findings. It is to be hoped that it serves as a vantage point for further investigations that strengthen the practical application of the DIALOOP framework, facilitate its further development and analysis as to how the future implementation of drones in automotive OEM logistics operations is affected by its guidance.

REFERENCES

Aheleroff, S., Philip, R., Zhong, R. Y., & Xu, X. (2019). The degree of mass personalisation under industry 4.0. *52nd CIRP Conference on Manufacturing Systems*, *81*, 1394–1399. https://doi.org/10.1016/j.procir.2019.04.050

Anderson, L., Gold, J., Stewart, J., & Thorpe, R. (2015). *A Guide to Professional Doctorates in Business and Management* (Kirsty Smy, Ed.). London: SAGE Publications Ltd.

Anderson, V. (2017). Criteria for Evaluating Qualitative Research. *Human Resource Develepment Quarterly*, *2*(1), 1–9. https://doi.org/10.1002/hrdq

Andreewsky, E., & Bourcier, D. (2000). Abduction in language interpretation and law making. *Kybernetes*, *29*(7/8), 836–845. https://doi.org/10.1108/03684920010341991

Apics. (2017). *Supply Chain Operations Reference Model (SCOR); Version 12.0*. 0–23. Retrieved from http://www.leanportal.sk/Files/Modely/SCOR.pdf

Arjomandi, D. M., Agostino, S., Mammone, M., Nelson, M., & Zhou, T. (2007). Classification of Unmanned Aerial Vehicles. *The University Of Adelaide*. Retrieved from http://personal.mecheng.adelaide.edu.au/maziar.arjomandi/aeronautical engineering projects/2006/group9.pdf

Arroyo, D., Lucho, C., Roncal, S. J., & Cuellar, F. (2014). Daedalus: A sUAV for human-robot interaction. *Proceedings of the 2014 ACM/IEEE International Conference on Human-Robot Interaction*, 116–117. https://doi.org/10.1145/2559636.2563709

Avanzini, G., De Angelis, E. L., & Giulietti, F. (2016). Optimal performance and sizing of a battery-powered aircraft. *Aerospace Science and Technology*, *59*, 132–144. https://doi.org/10.1016/j.ast.2016.10.015

Bai, C., Dallasega, P., Orzes, G., & Sarkis, J. (2020). Industry 4.0 technologies assessment: A sustainability perspective. *International Journal of Production Economics*, *229*, 107776. https://doi.org/10.1016/j.ijpe.2020.107776

Ballou, R. H. (2007). The evolution and future of logistics and supply chain management. *European Business Review*, *19*(4), 332–348. https://doi.org/10.1108/09555340710760152

Barmpounakis, E. N., Vlahogianni, E. I., & Golias, J. C. (2016). Unmanned Aerial Aircraft Systems for transportation engineering: Current practice and future challenges.

International Journal of Transportation Science and Technology, *5*(3), 111–122. https://doi.org/10.1016/j.ijtst.2017.02.001

Bauernhansl, T., Hompel, M. ten, & Vogel-Heuser, B. (2014). *Industrie 4.0 in Produktion, Automatisierung und Logistik*. https://doi.org/https://doi.org/10.1007/978-3-658-04682-8

Bechtsis, D., Tsolakis, N., Vlachos, D., & Srai, J. S. (2018). Intelligent Autonomous Vehicles in digital supply chains: A framework for integrating innovations towards sustainable value networks. *Journal of Cleaner Production*, *181*, 60–71. https://doi.org/10.1016/j.jclepro.2018.01.173

Beke, É., Bódi, A., Katalin, T. G., Kovács, T., Maros, D., & Gáspár, L. (2018). The Role of Drones in Linking Industry 4.0 and ITS Ecosystems. *18th IEEE International Symposium on Computational Intelligence and Informatics, CINTI 2018 - Proceedings*, 191–197. https://doi.org/10.1109/CINTI.2018.8928239

Benaim, A. (2015). *Innovation Capabilities – Measurement, Assessment and Development*. Lund University.

Bernard, M., Kondak, K., Maza, I., & Ollero, A. (2011). Autonomous transportation and deployment with aerial robots for search and rescue missions. *Journal of Field Robotics*, *28*(6), 914–931. https://doi.org/10.1002/rob.20401

Beul, M., Droeschel, D., Nieuwenhuisen, M., Quenzel, J., Houben, S., & Behnke, S. (2018). Fast Autonomous Flight in Warehouses for Inventory Applications. *IEEE Robotics and Automation Letters*, *3*(4), 3121–3128. https://doi.org/10.1109/LRA.2018.2849833

Bhatnagar, R., & Teo, C. (2009). Role of logistics in enhancing competitive advantage. *International Journal of Physical Distribution & Logistics Management*, *39*(3), 202–226. https://doi.org/10.1108/09600030910951700

Bigliardi, B., Bottani, E., & Casella, G. (2020). Enabling technologies, application areas and impact of industry 4.0: A bibliographic analysis. *Procedia Manufacturing*, *42*(2019), 322–326. https://doi.org/10.1016/j.promfg.2020.02.086

Bobbitt, L. M. (2004). *An Examination of the Logistics Leverage Process: Implications for Marketing Strategy and Competitive Advantage*. University of Tennessee.

Bonaccorsi, A., Chiarello, F., Fantoni, G., & Kammering, H. (2020). Emerging technologies and industrial leadership. A Wikipedia-based strategic analysis of Industry 4.0. *Expert Systems with Applications*, *160*, 113645. https://doi.org/10.1016/j.eswa.2020.113645

Bormann, R., Philipp, F., Helmut, H., Stephan, R., Thomas, S.-S., Heinrich, T., … Boris, W.

(2018). The Future of the German Automotive Industry - Transformation by disaster or by design? In *Wiso Diskurs* (Vol. 10). Retrieved from https://library.fes.de/pdf-files/wiso/14450.pdf

Boucher, P. (2015). Domesticating the Drone: The Demilitarisation of Unmanned Aircraft for Civil Markets. *Science and Engineering Ethics*, *21*(6), 1393–1412. https://doi.org/10.1007/s11948-014-9603-3

Boysen, N., Emde, S., Hoeck, M., & Kauderer, M. (2015). Part logistics in the automotive industry: Decision problems, literature review and research agenda. *European Journal of Operational Research*, *242*(1), 107–120. https://doi.org/10.1016/j.ejor.2014.09.065

Bozkurt, A., Hagg, M., & Schulz, R. (2020). *Innovative logistics concepts for a versatile and flexible manufacturing of lot size one*. 38–47.

Brettel, M., Klein, M., & Friederichsen, N. (2016). The relevance of manufacturing flexibility in the context of Industrie 4.0. *Procedia CIRP*, *41*, 105–110. https://doi.org/10.1016/j.procir.2015.12.047

Bryan, V. (2014). Drone delivery: DHL “parcelcopter” flies to German isle. Retrieved January 8, 2018, from World News website: https://www.reuters.com/article/us-deutsche-post-drones-idUSKCN0HJ1ED20140924

Bryman, A., & Bell, E. (2015). *Business Research Methods* (4th Editio). Oxford University Press.

Büchi, G., Cugno, M., & Castagnoli, R. (2020). Smart factory performance and Industry 4.0. *Technological Forecasting and Social Change*, *150*(October 2019), 1–10. https://doi.org/10.1016/j.techfore.2019.119790

Cai, G., Dias, J., & Seneviratne, L. (2014). A Survey of Small-Scale Unmanned Aerial Vehicles : Recent Advances and Future Development Trends. *Unmanned Systems*, *2*(2), 1–25. https://doi.org/10.1142/S2301385014300017

Caridade, R., Pereira, T., Pinto Ferreira, L., & Silva, F. J. G. (2017). Analysis and optimisation of a logistic warehouse in the automotive industry. *Procedia Manufacturing*, *13*, 1096–1103. https://doi.org/10.1016/j.promfg.2017.09.170

Cavalcante, T. R. F., Bessa, I. V. De, & Cordeiro, L. C. (2017). Planning and Evaluation of UAV Mission Planner for Intralogistics Problems. *Brazilian Symposium on Computing System Engineering, SBESC*, 9–16. https://doi.org/10.1109/SBESC.2017.8

Chatzimichailidou, M. M., Karanikas, N., & Plioutsias, A. (2017). Application of STPA on Small Drone Operations: A Benchmarking Approach. *Procedia Engineering*, *179*, 13–

22. https://doi.org/10.1016/j.proeng.2017.03.091

Cho, J., Lim, G., Biobaku, T., Kim, S., & Parsaei, H. (2015). Safety and security management with Unmanned Aerial Vehicle (UAV) in oil and gas industry. *Procedia Manufacturing*, *3*, 1343–1349. https://doi.org/10.1016/j.promfg.2015.07.290

Choi-Fitzpatrick, A. (2014). Drones for good: Technological Innovations , Social Movements, And the State. *Journal of International Affairs*, *68*(1), 19–37.

Clothier, R. A., Greer, D. A., Greer, D. G., & Mehta, A. M. (2015). Risk Perception and the Public Acceptance of Drones. *Risk Analysis*, *35*(6), 1167–1183. https://doi.org/10.1111/risa.12330

Coppejans, H. H. G., & Myburgh, H. C. (2015). A Primer on Autonomous Aerial Vehicle Design. *Sensors*, *15*(12), 30033–30061. https://doi.org/10.3390/s151229785

Creswell, J. W. (2009). *Research design: Qualitative, quantitative and mixed methods approaches* (3rd Editio). https://doi.org/10.1002/tl.20234

Creutznacher, T., Berger, U., Lepratti, R., & Lamparter, S. (2016). The Transformable Factory: Adapting Automotive Production Capacities. *Procedia CIRP*, *41*, 171–176. https://doi.org/10.1016/j.procir.2015.12.138

Custers, B. (2016). *The Future of Drone Use* (Vol. 27; B. Custers, Ed.). https://doi.org/10.1007/978-94-6265-132-6

Czyba, R., Szafrański, G., Janusz, W., Niezabitowski, M., Czornik, A., & Błachuta, M. (2014). Concept and realization of unmanned aerial system with different modes of operation. *10th International Conference on Mathematical Problems in Engineering, Aerospace and Sciences*, 261–270. https://doi.org/10.1063/1.4904587

D'Andrea, R. (2014). Guest Editorial Can Drones Deliver? *IEEE Transactions on Automation Science and Engineering*, *11*(3), 647–648. https://doi.org/10.1109/TASE.2014.2326952

Das, A., & Nair, A. (2010). The use of manufacturing technologies–an external influence perspective. *International Journal of Production Research*, *48*(17), 4977–5006. https://doi.org/10.1080/00207540903055719

Davila, T., & Epstein, M.J., Shelton, R. (2013). *Making innovation work: How to manage it, measure it, and profit from it*. New Jersey: Pearson Education, Inc.

Davis, J., Edgar, T., Porter, J., Bernaden, J., & Sarli, M. (2012). Smart manufacturing, manufacturing intelligence and demand-dynamic performance. *Computers and Chemical Engineering*, *47*, 145–156.

https://doi.org/10.1016/j.compchemeng.2012.06.037

De Croon, G., & De Wagter, C. (2018). Challenges of Autonomous Flight in Indoor Environments. *IEEE International Conference on Intelligent Robots and Systems*, 1003–1009. https://doi.org/10.1109/IROS.2018.8593704

Deja, M., Siemiątkowski, M. S., Vosniakos, G.-C., & Maltezos, G. (2020). Opportunities and challenges for exploiting drones in agile manufacturing systems. *Procedia Manufacturing*, *51*(2019), 527–534. https://doi.org/10.1016/j.promfg.2020.10.074

Derpich, I., Miranda, D., & Sepulveda, J. (2018). Using drones in a warehouse with minimum energy consumption. *7th International Conference on Computers Communications and Control, ICCCC*, 97–102. https://doi.org/10.1109/ICCCC.2018.8390444

Dewangan, V., & Godse, M. (2014). Towards a holistic enterprise innovation performance measurement system. *Technovation*, *34*(9), 536–545. https://doi.org/10.1016/j.technovation.2014.04.002

DHL. (2016). Successful Trial Integration of DHL Parcelcopter into Logistics Chain. *Press Release DHL*, pp. 20–23. https://doi.org/10.5235/204976114814222476

Diffner, B., Björkman, M., & Johansen, K. (2018). Flexibility Challenges in Automotive Assembly , An Approach to Stay Competitive. *International Journal of Industrial Engineering and Management Science Flexibility*, *5*(1), 34–40.

Dobrindt, A. Verordnung zur Regelung des Betriebs von unbemannten Fluggeräten. , 1 Bundesgesetzblatt Jahrgang 2017 Teil I Nr. 17 § (2017).

Dörnhöfer, M., & Günthner, W. A. (2017). A research and industry perspective on automotive logistics performance measurement. *The International Journal of Logistics Management*, *28*(1), 102–126. https://doi.org/10.1108/IJLM-06-2015-0105

Dörnhöfer, M. S. (2016). *Entwicklung eines modularen Kennzahlensystems für die Automobillogistik im Kontext der schlanken Logistik*. Technische Universität München.

Dörnhöfer, M., Schröder, F., & Günthner, W. A. (2016). Logistics performance measurement system for the automotive industry. *Logistics Research*, *9*(1). https://doi.org/10.1007/s12159-016-0138-7

Dovere, E., Cavalieri, S., & Ierace, S. (2015). An assessment model for the implementation of RFID in tool management. *IFAC-PapersOnLine*, *28*(3), 1007–1012. https://doi.org/10.1016/j.ifacol.2015.06.215

Drones, Technology Driven Innovation. (2017). Retrieved November 24, 2018, from

Goldman Sachs Research website: https://www.goldmansachs.com/insights/technology-driving-innovation/drones/

EASA. (2018a). Drones Amsterdam Declaration. Retrieved January 12, 2019, from https://ec.europa.eu/transport/sites/transport/files/2018-drones-amsterdam-declaration.pdf

EASA. (2018b). *Introduction of a regulatory framework for the operation of drones Unmanned aircraft system operations in the open and specific category* (Vol. 05). Retrieved from https://www.easa.europa.eu/system/files/dfu/NPA 2017-05 %28B%29.pdf

Edmondson, A. C., & Mcmanus, S. E. (2007). Methodological Fit in Management Field Research. *The Academy of Management Review*, *32*(4), 1155–1179.

Emde, S., & Gendreau, M. (2017). Scheduling in-house transport vehicles to feed parts to automotive assembly lines. *European Journal of Operational Research*, *260*(1), 255–267. https://doi.org/10.1016/j.ejor.2016.12.012

Engelhardt-Nowitzki, C., & Zsifkovits, H. (2007). Open Variant Process Models in Supply Chains. In *Mass Customization Information Systems in Business* (pp. 77–105). https://doi.org/10.4018/978-1-59904-039-4.ch004

Esmaeilian, B., Behdad, S., & Wang, B. (2016). The evolution and future of manufacturing: A review. *Journal of Manufacturing Systems*, *39*, 79–100. https://doi.org/10.1016/j.jmsy.2016.03.001

Feldhütter, V., Steck, C., Hawer, S., & Ten Hompel, M. (2017). Impacts of Product-driven Complexity on the Success of Logistics in the Automotive Sector. *Procedia CIRP*, *62*, 129–134. https://doi.org/10.1016/j.procir.2016.06.078

Finlay, L. (2008). Reflecting on ‘Reflective practice.’ *PBPL Paper 52*, 1–27. https://doi.org/10.1016/0260-4779(91)90031-R

Flämig, H. (2016). Autonomous Vehicles and Autonomous Driving in Freight Transport. In *Autonomous Driving - Technical, Legal and Social Aspects* (pp. 365–385). https://doi.org/10.1007/978-3-662-48847-8

Fleetwood, S. (2005). *Ontology in organization and management studies: a critical realist perspective*. *12*(2), 197–222. https://doi.org/10.1177/1350508405051188

Flick, U. (2004). Triangulation in Qualitative Research. In U. Flick, E. von Kardorff, & I. Steinke (Eds.), *A Companion to qualitative research*. London: SAGE Publications Ltd.

Floreano, D., & Wood, R. J. (2015). Science, technology and the future of small autonomous drones. *Nature*, *521*, 460–466. https://doi.org/10.1038/nature14542

Foith-Förster, P., & Bauernhansl, T. (2016). Changeable Assembly Systems Through Flexibly Linked Process Modules. *Procedia CIRP*, *41*, 230–235. https://doi.org/10.1016/j.procir.2015.12.124

Fornasiero, R., Zangiacomi, A., Marchiori, I., Barros, A. C., Pires, K., Senna, P. P., … Matopoulos, A. (2018). *Next generation Technologies for networked Europe D2 . 1 : Report on trends and key factors*.

Fottner, J, Clauer, D., Hormes, F., Freitag, M., Beinke, T., Overmeyer, L., … Thomas, F. (2021). *Autonomous Systems in Intralogistics – State of the Art and Future Research Challenges*.

Fottner, Johannes, Hormes, F., Freitag, M., & Beinke, T. (2021). *Autonomous Systems in Intralogistics – State of the Art and Future Research Challenges*. (February). https://doi.org/10.23773/2021

Francis, J. J., Johnston, M., Robertson, C., & Glidewell, L. (2010). What is an adequate sample size? Operationalising data saturation for theory-based interview studies. *Psychology and Health*, *25*(10), 1229–1245. https://doi.org/10.1080/08870440903194015

Fraunhofer IML. (2016). Ein “R2D2” für die Logistik. Retrieved April 15, 2018, from https://www.iml.fraunhofer.de/de/presse_medien/pressemitteilungen/ein_r2d2_fuer_die_logistik.html

Fredriksson, P., & Gadde, L. E. (2005). Flexibility and rigidity in customization and build-to-order production. *Industrial Marketing Management*, *34*, 695–705. https://doi.org/10.1016/j.indmarman.2005.05.010

Fritzsch, B., Namneck, A., Stonis, M., Schwab, A., & Kirchner, L. (2020). *Wirtschaftlichkeitsbewertung von Drohnen zum innerbetrieblichen Materialtransport*. 9–14. https://doi.org/10.2195/lj

Fugate, B. S., Mentzer, J. T., & Stank, T. P. (2010). Logistic Performance: Efficiency, Effectiveness, and Differentiation. *Journal of Business Logistics*, *31*(1), 43–63.

Fulton, J., Kuit, J., Saunders, G., & Smith, P. (2013). *The Professional Doctorate*. New York: Palgrave Macmillan.

Furmann, R., Furmannová, B., & Więcek, D. (2017). Interactive Design of Reconfigurable Logistics Systems. *Procedia Engineering*, *192*, 207–212.

https://doi.org/10.1016/j.proeng.2017.06.036

Furmans, K., Seibold, Z., & Trenkle, A. (2019). Future Technologies in Intralogistics and Material Handling. In *Operations, Logistics and Supply Chain Management* (pp. 545–574). https://doi.org/10.1007/978-3-319-92447-2

Garcia, F. A., Marchetta, M. G., Camargo, M., Morel, L., & Forradellas, R. Q. (2012). A framework for measuring logistics performance in the wine industry. *International Journal of Production Economics*, *135*(1), 284–298. https://doi.org/10.1016/j.ijpe.2011.08.003

Garrido-Vega, P., Ortega Jimenez, C. H., De Los Ríos, J. L. D. P., & Morita, M. (2015). Implementation of technology and production strategy practices: Relationship levels in different industries. *International Journal of Production Economics*, *161*, 201–216. https://doi.org/10.1016/j.ijpe.2014.07.011

Gatti, M., Giulietti, F., & Turci, M. (2015). Maximum endurance for battery-powered rotary-wing aircraft. *Aerospace Science and Technology*, *45*, 174–179. https://doi.org/10.1016/j.ast.2015.05.009

Georges, D. (2020). *Transferring the benefits of Agile project management using Scrum to a firm-fixed-price context : A study of German software development projects*. University of Portsmouth.

Gephart, R. P. (2004). What is qualitative research and why is it important? *Academy of Management Journal*, *47*(4), 454–462. https://doi.org/10.5465/AMJ.2004.14438580

Germany Trade & Invest. (2020). The Automotive Industry in Germany. *Industry Overview 2020/21*, pp. 1–25. Berlin: Germany Trade and Invest Gesellschaft für Außenwirtschaft und Standortmarketing mbH.

Ghadge, A., Er Kara, M., Moradlou, H., & Goswami, M. (2020). The impact of Industry 4.0 implementation on supply chains. *Journal of Manufacturing Technology Management*, *31*(4), 669–686. https://doi.org/10.1108/JMTM-10-2019-0368

Ghalayini, A. M., & Noble, J. S. (1996). The changing basis of performance measurement. *International Journal of Operations & Production Management*, *16*(8), 63–80. https://doi.org/10.1108/01443579610125787

Ghazbi, S. N., Aghli, Y., Alimohammadi, M., & Akbari, A. A. (2016). Quadrotors Unmanned Aerial Vehicles : a Review. *International Journal of Smart Sensing and Intelligent Systems*, *9*(1), 309–333.

Ghobakhloo, M. (2018). The future of manufacturing industry : a strategic roadmap. *Journal* *of Manufacturing Technology Management*, *29*(6), 910–936. https://doi.org/10.1108/JMTM-02-2018-0057

Giones, F., & Brem, A. (2017). From toys to tools: The co-evolution of technological and entrepreneurial developments in the drone industry. *Business Horizons*, *60*(6), 875–884. https://doi.org/10.1016/j.bushor.2017.08.001

Gladysz, B., & Santarek, K. (2015). An Assessment of Technologies with Wide Range of Impact. A Case of RFID. *Procedia Manufacturing*, *3*, 1966–1973. https://doi.org/10.1016/j.promfg.2015.07.242

Glock, C. H., & Grosse, E. H. (2012). Storage policies and order picking strategies in U-shaped order-picking sytems with a movable base. *International Journal of Production Research*, *50*(16), 4344–4357. https://doi.org/10.1080/00207543.2011.588621

Golafshani, N. (2003). Understanding Reliability and Validity in Qualitative Research. *The Qualitative Report*, *8*(4), 597–607. Retrieved from http://nsuworks.nova.edu/tqr%0Ahttp://nsuworks.nova.edu/tqr/vol8/iss4/6%0Ahttps://nsuworks.nova.edu/tqr/vol8/iss4/6

Golz, J., Gujjula, R., Günther, H. O., Rinderer, S., & Ziegler, M. (2012). Part feeding at high-variant mixed-model assembly lines. *Flexible Services and Manufacturing Journal*, *24*(2), 119–141. https://doi.org/10.1007/s10696-011-9116-1

González-Jorge, H., Martínez-Sánchez, J., Bueno, M., & Arias, and P. (2017). Unmanned Aerial Systems for Civil Applications: A Review. *Drones*, *1*(1), 2. https://doi.org/10.3390/drones1010002

Goodchild, A., & Toy, J. (2017). Delivery by drone: An evaluation of unmanned aerial vehicle technology in reducing CO2 emissions in the delivery service industry. *Transportation Research Part D*. https://doi.org/10.1016/j.trd.2017.02.017

Grawe, S. J. (2009). Logistics innovation: A literature-based conceptual framework. *The International Journal of Logistics Management*, *20*(3), 360–377. https://doi.org/10.1108/09574090911002823

Große-Puppendhal, D., Lier, S., Roidl, M., & ten Hompel, M. (2016). Cyber-physical logistics modules as a key to a flexible and transformable production in the process industry. *Logistics Journal*, 1–10. https://doi.org/10.2195/lj

Guest, G., & Johnson, L. (2006). *How Many Interviews Are Enough ? An Experiment with Data Saturation and Variability*. *18*(1), 59–82. https://doi.org/10.1177/1525822X05279903

Gunasekaran, A., Patel, C., & McGaughey, R. E. (2004). A framework for supply chain performance measurement. *International Journal of Production Economics*, *87*(3), 333–347. https://doi.org/10.1016/j.ijpe.2003.08.003

Gunasekaran, Angappa, & Kobu, B. (2007). Performance measures and metrics in logistics and supply chain management: A review of recent literature (1995-2004) for research and applications. *International Journal of Production Research*, *45*(12), 2819–2840. https://doi.org/10.1080/00207540600806513

Gunasekaran, Angappa, & Ngai, E. W. T. (2012). The future of operations management: An outlook and analysis. *International Journal of Production Economics*, *135*(2), 687–701. https://doi.org/10.1016/j.ijpe.2011.11.002

Gupta, S. G., Ghonge, M. M., & Jawandhiya, D. P. M. (2013). Review of Unmanned Aircraft System (UAS). *International Journal of Advanced Research in Computer Engineering & Technology (IJARCET)*, *2*(4), 1646–1658.

Haidari, L. A., Brown, S. T., Ferguson, M., Bancroft, E., Spiker, M., Wilcox, A., … Lee, B. Y. (2016). The economic and operational value of using drones to transport vaccines. *Vaccine*, *34*(34), 4062–4067. https://doi.org/10.1016/j.vaccine.2016.06.022

Hassanalian, M., & Abdelkef, A. (2017). Methodologies for weight estimation of fixed and flapping wing micro air vehicles. *Meccanica*, *52*(9), 2047–2068. https://doi.org/10.1007/s11012-016-0568-y

Hassanalian, M., & Abdelkefi, A. (2017). Classifications , applications , and design challenges of drones : A review. *Progress in Aerospace Sciences Journal*, *91*, 99–131. https://doi.org/10.1016/j.paerosci.2017.04.003

Havar-Simonovich, T. (2012). *Transferring Soft Skills from the Performing Arts Curriculum to Business – A German-Based Exploration into the Possibilities for Training Management Consultants Administration*. Edinburgh Napier University.

Hedler Staudt, F., Alpan, G., Fugate, M. Di, & Taboada, C. M. (2015). Warehouse performance measurement: a literature review. *International Journal of Production Research*, *53*(18), 5524–5544.

Helfferich, C. (2014). Leitfaden- und Experteninterviews. In *Handbuch Methoden der empirischen Sozialforschung* (pp. 559–574). https://doi.org/10.1007/978-3-531-18939-0

Hermann, M., Pentek, T., & Otto, B. (2016). Design principles for industrie 4.0 scenarios. *Proceedings of the 49th Annual Hawaii International Conference on System Sciences*, 3928–3937. https://doi.org/10.1109/HICSS.2016.488

Hern, A. (2016). Amazon claims first successful Prime Air drone delivery. Retrieved from The Guardian Online website: https://www.theguardian.com/technology/2016/dec/14/amazon-claims-first-successful-prime-air-drone-delivery

Hocraffer, A., & Nam, C. S. (2017). A meta-analysis of human-system interfaces in unmanned aerial vehicle (UAV) swarm management. *Applied Ergonomics*, *58*, 66–80. https://doi.org/10.1016/j.apergo.2016.05.011

Hofbauer, G. (2020). German Automakers in Lead of Innovation Excellence. *International Journal of Public Administration, Management and Economic Dvelopement*, 3–15.

Hofmann, E., & Rüsch, M. (2017). Industry 4.0 and the current status as well as future prospects on logistics. *Computers in Industry*, *89*, 23–34. https://doi.org/10.1016/j.compind.2017.04.002

Holweg, M., & Miemczyk, J. (2003). Delivering the “3-day car” - The strategic implications for automotive logistics operations. *Journal of Purchasing and Supply Management*, *9*(2), 63–71. https://doi.org/10.1016/S1478-4092(03)00003-7

Hossein Motlagh, N., Taleb, T., & Arouk, O. (2016). Low-Altitude Unmanned Aerial Vehicles-Based Internet of Things Services: Comprehensive Survey and Future Perspectives. *IEEE Internet of Things Journal*, *9*, 1–27. https://doi.org/10.1109/JIOT.2016.2612119

Hüring, J. (2019). *Entwicklung einer Handlungsempfehlung zur Auswahl und Nutzung von Drohnen für interne Materialtransporte unter Einbezug von Sicherheitskriterien*. Hochschule Reutlingen.

Idries, A., Mohamed, N., Jawhar, I., Mohamed, F., & Al-Jaroodi, J. (2015). Challenges of developing UAV applications: A project management view. *IEOM 2015 - 5th International Conference on Industrial Engineering and Operations Management, Proceeding*. https://doi.org/10.1109/IEOM.2015.7093730

Intelligence, I. (2021). Drone market outlook in 2021: industry growth trends, market stats and forecast. Retrieved from https://www.businessinsider.com/drone-industry-analysis-market-trends-growth-forecasts?r=US&IR=T

Irfani, D. P., Wibisono, D., & Basri, M. H. (2019). Logistics performance measurement framework for companies with multiple roles. *Measuring Business Excellence*, MBE-11-2018-0091. https://doi.org/10.1108/MBE-11-2018-0091

Ishaq Bhatti, M., & Awan, H. M. (2014). The key performance indicators (KPIs) and their impact on overall organizational performance. *Quality and Quantity*, *48*(6), 3127–3143. https://doi.org/10.1007/s11135-013-9945-y

Jafari, H. (2015). Logistics flexibility: a systematic review. *International Journal of Productivity and Performance Management*, *64*(7), 947–970. https://doi.org/10.1108/IJPPM-05-2014-0069

Jahre, M., Pazirandeh, A., & Wassenhove, L. Van. (2016). Defining logistics preparedness: a framework and research agenda. *Journal of Humanitarian Logistics and Supply Chain Management*, *6*(3), 372–398. https://doi.org/10.1108/JHLSCM-04-2016-0012

Jensen, O. B. (2016). Drone city - power, design and aerial mobility in the age of “smart cities.” *Geographica Helvetica*, *71*, 67–75. https://doi.org/10.5194/gh-71-67-2016

Kamal, M. M. (2006). IT innovation adoption in the government sector: identifying the critical success factors. In *Journal of Enterprise Information Management* (Vol. 19). https://doi.org/10.1108/17410390610645085

Kanellakis, C., & Nikolakopoulos, G. (2017). Survey on Computer Vision for UAVs: Current Developments and Trends. *Journal of Intelligent & Robotic Systems*, 1–28. https://doi.org/10.1007/s10846-017-0483-z

Keebler, J. S., & Plank, R. E. (2009). Logistics performance measurement in the supply chain: a benchmark. *Benchmarking: An International Journal*, *16*(6), 785–798. https://doi.org/10.1108/14635770911000114

Kemppainen, K., & Vepsäläinen, A. P. J. (2007). Logistical and technological differentiation as a precondition of supply networking. *The International Journal of Logistics Management*, *18*(1), 81–101. https://doi.org/10.1108/09574090710748180

Kern, W., Lämmermann, H., & Bauernhansl, T. (2017). An Integrated Logistics Concept for a Modular Assembly System. *Procedia Manufacturing*, *11*, 957–964. https://doi.org/10.1016/j.promfg.2017.07.200

Kern, W., Rusitschka, F., & Bauernhansl, T. (2016). Planning of Workstations in a Modular Automotive Assembly System. *Procedia CIRP*, *57*, 327–332. https://doi.org/10.1016/j.procir.2016.11.057

Kern, W., Rusitschka, F., Kopytynski, W., Keckl, S., & Bauernhansl, T. (2015). Alternatives to assembly line production in the automotive industry. *23rd International Conference for Production Research, ICPR 2015*.

Kerna, J., & Wolff, P. (2019). *The digital transformation of the automotive supply chain - an empirical analysis with evidence from Germany and China: case study contribution to* *the OECD TIP digital and open innovation project*. 23. Retrieved from https://www.innovationpolicyplatform.org/system/files/imce/AutomotiveSupplyChain_GermanyChina_TIPDigitalCaseStudy2019_1.pdf

Khosiawan, Y., & Nielsen, I. (2016). A system of UAV application in indoor environment. *Production & Manufacturing Research*, *4*(1), 2–22. https://doi.org/10.1080/21693277.2016.1195304

Klingebiel, K. (2006). A classification framework for automotive build-to-order concepts. *2006 IEEE International Technology Management Conference, ICE 2006*. https://doi.org/10.1109/ICE.2006.7477052

Klingenberg, W., & Boksma, J. D. (2010). A conceptual framework for outsourcing of materials handling activities in automotive: Differentiation and implementation. *International Journal of Production Research*, *48*(16), 4877–4899. https://doi.org/10.1080/00207540903067177

Klug, F. (2017). Das Perlenkettenprinzip der stabilen Auftragsfolge in der Automobillogistik. In *Automobillogistik*. https://doi.org/10.1007/978-3-8349-7081-7

Klug, F. (2018). *Logistikmanagement in der Automobilindustrie* (2nd Editio). Heidelberg: Springer-Verlag.

Knox, K. (2004). A Researcher's dilemma-philosophical and methodological pluralism. *Electronic Journal of Business Research Methods*, *2*(2), 119–128. https://doi.org/10.1080/03085140500465899

Kolstoe, S. (2020). Ethics Policy. Retrieved from http://policies.docstore.port.ac.uk/policy-028.pdf?_ga=2.218148057.1769916377.1546510070-2027419741.1544540471

Koren, Y., Gu, X., Badurdeen, F., & Jawahir, I. S. (2018). Sustainable Living Factories for Next Generation Manufacturing. *Procedia Manufacturing*, *21*, 26–36. https://doi.org/10.1016/j.promfg.2018.02.091

Kovács, G., & Spens, K. M. (2005). Abductive reasoning in logistics research. *International Journal of Physical Distribution & Logistics Management*, *35*(2), 132–144. https://doi.org/10.1108/09600030510590318

Kovács, G., & Spens, K. M. (2007). Logistics Theory Building. *THe Icfai Journal of Supply Chain Management*, *4*(4), 7–28.

Kückelhaus, M. (2014). Unmanned Aerial Vehicle in Logistics. *DHL Trend Research*, 24.

Kumar, M., Tsolakis, N., Agarwal, A., & Srai, J. S. (2020). Developing distributed manufacturing strategies from the perspective of a product-process matrix. *International Journal of Production Economics*, *219*, 1–17. https://doi.org/10.1016/j.ijpe.2019.05.005

Kumar, V., & Michael, N. (2012). Opportunities and challenges with autonomous micro aerial vehicles. *The International Journal of Robotics Research*, *31*(11), 1279–1291. https://doi.org/10.1177/0278364912455954

Kunze, O. (2016). Replicators, Ground Drones and Crowd Logistics A Vision of Urban Logistics in the Year 2030. *Transportation Research Procedia*, *19*, 286–299. https://doi.org/10.1016/j.trpro.2016.12.088

Lade, P., Ghosh, R., & Srinivasan, S. (2017). Manufacturing analytics and industrial Internet of Things. *IEEE Intelligent Systems*, *32*(3), 74–79. https://doi.org/10.1109/MIS.2017.49

Lafou, M., Mathieu, L., Pois, S., & Alochet, M. (2015). Manufacturing system configuration: Flexibility analysis for automotive mixed-model assembly lines. *IFAC-PapersOnLine*, *28*(3), 94–99. https://doi.org/10.1016/j.ifacol.2015.06.064

Lambert, D. M., García-Dastugue, S. J., & Croxton, K. L. (2005). An Evaluation of Process-Oriented Supply Chain Management Frameworks. *Journal of Business Logistics*, *26*(1), 25–51. https://doi.org/10.1002/j.2158-1592.2005.tb00193.x

Landrock, H., & Baumgärtel, A. (2018). Die Industriedrohne – der fliegende Roboter. In *Die Industriedrohne – der fliegende Roboter*. https://doi.org/10.1007/978-3-658-21355-8

Lauri, M. A. (2011). Triangulation of Data Analysis Techniques. *Papers on Social Representations*, *20*, 34–35. Retrieved from http://www.psych.lse.ac.uk/psr/]

Lemghari, R., Okar, C., & Sarsri, D. (2018). Benefits and limitations of the SCOR ® model in Automotive Industries. *MATEC Web of Conferences*, *200*, 00019. https://doi.org/10.1051/matecconf/201820000019

Leung, L. (2015). Validity, reliability, and generalizability in qualitative research. *Journal of Family Medicine and Primary Care*, *4*(3), 324. https://doi.org/10.4103/2249-4863.161306

Li, F., Zlatanova, S., Koopman, M., Bai, X., & Diakité, A. (2018). Universal path planning for an indoor drone. *Automation in Construction*, *95*(December 2017), 275–283. https://doi.org/10.1016/j.autcon.2018.07.025

Lieret, M., Kogan, V., Doll, S., & Franke, J. (2019). Automated in-house transportation of small load carriers with autonomous unmanned aerial vehicles. *IEEE International Conference on Automation Science and Engineering*, *2019-Augus*, 1010–1015. https://doi.org/10.1109/COASE.2019.8843183

Lin, C. E., Dimpudus, K. K., & Hsu, Y.-C. (2017). Airspace risk assessment in logistic path planning for UAV. *2017 Integrated Communications, Navigation and Surveillance Conference (ICNS)*, 6A1-1-6A1-9. https://doi.org/10.1109/ICNSURV.2017.8011936

Liu, H., Balke, K. N., & Lin, W. H. (2008). A reverse causal-effect modeling approach for signal control of an oversaturated intersection. *Transportation Research Part C: Emerging Technologies*, *16*(6), 742–754. https://doi.org/10.1016/j.trc.2008.03.003

Loh, R., Bian, Y., & Roe, T. (2009). UAVs in Civil Airspace: Safety requirements. *IEEE Aerospace and Electronic Systems Magazine*, *24*(1), 5–17. https://doi.org/10.1109/MAES.2009.4772749

Luppicini, R., & So, A. (2016). A technoethical review of commercial drone use in the context of governance, ethics, and privacy. *Technology in Society*, *46*, 109–119. https://doi.org/10.1016/j.techsoc.2016.03.003

Maghazei, O., & Netland, T. (2019). Drones in manufacturing : exploring opportunities for research and practice. *Journal of Manufacturing Technology Management*. https://doi.org/10.1108/JMTM-03-2019-0099

Maloni, M. J., Carter, C. R., & Carr, A. S. (2009). Assessing logistics maturation through author concentration. *International Journal of Physical Distribution & Logistics Management*, *39*(3), 250–268. https://doi.org/10.1108/09600030910951728

Manzini, R., Bozer, Y., & Heragu, S. (2015). Decision models for the design, optimization and management of warehousing and material handling systems. *International Journal of Production Economics*, *170*, 711–716. https://doi.org/10.1016/j.ijpe.2015.08.007

Marchesini, M. M. P., & Alcântara, R. L. C. (2016). Logistics activities in supply chain business process. *The International Journal of Logistics Management*, *27*(1), 6–30. https://doi.org/10.1108/IJLM-04-2014-0068

Mayring, P., & Fenz, T. (2014). Qualitative Inhaltsanalyse. In *Handbuch Methoden der empirischen Sozialforschung* (pp. 543–556). https://doi.org/10.1007/978-3-531-18939-0

Melnyk, S. A., Bititci, U., Platts, K., Tobias, J., & Andersen, B. (2013). Is performance measurement and management fit for the future? *Management Accounting Research*, *25*(2), 173–186. https://doi.org/10.1016/j.mar.2013.07.007

Mentzer, J. T., & Kahn, K. B. (1995). A framework of logistic research. *Journal of Business Logistics*, *16*(1), 231–251.

Mentzer, J. T., Min, S., & Michelle Bobbitt, L. (2004). Toward a unified theory of logistics.

International Journal of Physical Distribution & Logistics Management, *34*(8), 606–627. https://doi.org/10.1108/09600030410557758

Meyr, H. (2004). Supply chain planning in the German automotive industry. *OR Spectrum*, *26*, 447–470. https://doi.org/10.1007/s00291-004-0168-4

Micieta, B., Hercko, J., Botka, M., & Zrnic, N. (2016). Concept of intelligent logistic for automotive industry. *Journal of Applied Engineering Science*, *17*(14–4), 233–238. https://doi.org/https://doi.org/10.5937/jaes14-10907

Mohammed, F., Idries, A., Mohamed, N., Al-Jaroodi, J., & Jawhar, I. (2014). UAVs for smart cities: Opportunities and challenges. *2014 International Conference on Unmanned Aircraft Systems, ICUAS 2014 - Conference Proceedings*, 267–273. https://doi.org/10.1109/ICUAS.2014.6842265

Mohr, S., & Khan, O. (2015). 3D Printing and Its Disruptive Impacts on Supply Chains of the Future. *Technology Innovation Management Review*, *5*(11), 20–24. Retrieved from http://timreview.ca/article/942

Mondragon, A. E. C., Lyons, A. C., Michaelides, Z., & Kehoe, D. F. (2006). Automotive supply chain models and technologies : a review of some latest developments. *Journal of Enterprise Information Management*, *19*(5), 551–562. https://doi.org/10.1108/17410390610703675

Moniz, A., & Krings, B.-J. (2016). Robots Working with Humans or Humans Working with Robots? Searching for Social Dimensions in New Human-Robot Interaction in Industry. *Societies*, *6*(23), 1–21. https://doi.org/10.3390/soc6030023

Morse, J. M. (2015). Critical Analysis of Strategies for Determining Rigor in Qualitative Inquiry. *Qualitative Health Research*, *25*(9), 1212–1222. https://doi.org/10.1177/1049732315588501

Moschetta, J. M., & Namuduri, K. (2017). Introduction to UAV systems. *UAV Networks and Communications*, 1–25. https://doi.org/10.1017/9781316335765.002

Müller, S., Rudolph, C., Janke, C., & Deutsches, S. (2019). Drones for last mile logistics : Baloney or part of the solution ? *Transportation Research Procedia*, *41*(2016), 73–87. https://doi.org/10.1016/j.trpro.2019.09.017

Murphy, M. (2016). The future is here, Drones are delivering Domino's pizzas to customers. Retrieved May 14, 2017, from https://qz.com/838254/dominos-is-delivering-pizza-with-autonomous-drones-to-customers-in-new-zealand/

Murray, C. C., & Chu, A. G. (2015). The flying sidekick traveling salesman problem:

Optimization of drone-assisted parcel delivery. *Transportation Research Part C*, *54*, 86–109. https://doi.org/10.1016/j.trc.2015.03.005

Neely, A., Mills, J., Platts, K., Richards, H., Gregory, M., Bourne, M., & Kennerley, M. (2000). Performance measurement system design: developing and testing a process-based approach. *International Journal of Operations & Production Management*, *20*(10), 1119–1145. https://doi.org/10.1108/01443570010343708

Nilsson, F. (2005). *Adaptive Logistics-using complexity theory to facilitate increased effectiveness in logistics*. Lund University.

Novaro Mascarello, L., & Quagliotti, F. (2017). The civil use of small unmanned aerial systems (sUASs): operational and safety challenges. *Aircraft Engineering and Aerospace Technology*, *89*(5), 703–708. https://doi.org/10.1108/AEAT-01-2017-0014

O'Connor, R. (2013). *Developing a multicopter UAV platform to carry out research into autonomous behaviours , using on-board image processing techniques*. The University of Western Australia.

O'Reilly, M., & Parker, N. (2012). "Unsatisfactory Saturation": A critical exploration of the notion of saturated sample sizes in qualitative research. *Qualitative Research*, *13*(2), 190–197. https://doi.org/10.1177/1468794112446106

Olbert, H., Protopappa-Sieke, M., & Thonemann, U. W. (2016). Analyzing the Effect of Express Orders on Supply Chain Costs and Delivery Times. *Production and Operations Management*, *25*(12), 2035–2050. https://doi.org/10.1111/poms.12588

Olivares, V., & Cordova, F. (2016). Design of Drone Fleet Management Model in A Production System of Customized Products. *6th International Conference on Computers Communications and Control, ICCCC 2016*, 165–172. https://doi.org/10.1109/ICCCC.2016.7496756

Olivares, V., Cordova, F., Sepulveda, J. M., & Derpich, I. (2015). Modeling internal logistics by using drones on the stage of assembly of products. *Procedia Computer Science*, *55*, 1240–1249. https://doi.org/10.1016/j.procs.2015.07.132

Olsen, J., & Gjerding, A. (2019). Modalities of Abduction: a Philosophy of Science-Based Investigation of Abduction. *Human Arenas*, *2*(2), 129–152. https://doi.org/10.1007/s42087-018-0044-4

Paião, A. (2014). *Development of a framework for the flexibility measurement of intralogistic systems based on a fuzzy logic approach*. TU Dortmund.

Parry, G., & Roehrich, J. (2013). Automotive enterprise transformation: Build to order as a sustainable and innovative strategy for the automotive industry? *Journal of Enterprise Transformation*, *3*(1), 33–52. https://doi.org/10.1080/19488289.2013.784223

Pauner, C., Kamara, I., & Viguri, J. (2015). Drones. Current challenges and standardisation solutions in the field of privacy and data protection. *ITU Kaleidoscope Academic Conference: Trust in the Information Society*, *8*, 1–7. https://doi.org/10.1109/Kaleidoscope.2015.7383633

Petricca, L., Ohlckers, P., & Grinde, C. (2011). Micro- and nano-air vehicles: State of the art. *International Journal of Aerospace Engineering*, *2011*. https://doi.org/10.1155/2011/214549

Phillips, F., & Linstone, H. (2016). Key ideas from a 25-year collaboration at technological forecasting & social change. *Technological Forecasting and Social Change*, *105*, 158–166. https://doi.org/10.1016/j.techfore.2016.01.007

Quinlan, C., Babin, B., Carr, J., Griffin, M., & Zikmund, W. (2018). *Business Research Methods* (Second Edi). Cengage Learning EMEA.

Rafele, C. (2004). Logistic service measurement: a reference framework. *Journal of Manufacturing Technology Management*, *15*(3), 280–290. https://doi.org/10.1108/17410380410523506

Rao, B., Gopi, A. G., & Maione, R. (2016). The societal impact of commercial drones. *Technology in Society Journal*, *45*, 83–90. https://doi.org/10.1016/j.techsoc.2016.02.009

Ritz, B. (2020). Comparing abduction and retroduction in Peircean pragmatism and critical realism. *Journal of Critical Realism*, *19*(5), 456–465. https://doi.org/10.1080/14767430.2020.1831817

Roehrich, J. K., Parry, G. C., & Graves, A. P. (2009). Implementing Build-to-Order Strategies: Enablers and Barriers in the European Automotive Industry ’. *International Journal of Automotive Technology and Management (IJATM)*, 1–18. https://doi.org/https://doi.org/10.1504/IJATM.2011.040869

Roy Suddaby. (2006). From the Editors: What grounded theory is not. *Academy of Management Journal*, *49*(4), 633–642. https://doi.org/Editorial

Saatcıoglu, O. Y., Denktas-Sakar, G., & Karatas-Cetın, C. (2014). Logistics innovation: A service-dominant logic- based conceptual framework. In *Handbook of Research on Effective Marketing in Contemporary Globalism* (pp. 1–26). https://doi.org/10.4018/978-1-4666-6220-9.ch001

Saldaña, J. (2013). The Coding Manual for qualitative researchers. In *International Journal* (Second Edi). https://doi.org/10.1017/CBO9781107415324.004

Saunders, M., & Lewis, P. (2012). *Doing research in business & management*. Essex: Pearson Education Limited.

Saunders, M., Lewis, P., & Thornhill, A. (2009). *Research Methods for Business Students* (5th ed.). Pearson Education Limited.

Saunders, M., Lewis, P., & Thornhill, A. (2016). *Research Methods for Business Students* (7th Editio). Pearson Education Limited.

Schauwecker, K., Ke, N. R., Scherer, S. A., & Zell, A. (2012). Markerless Visual Control of a Quad-Rotor Micro Aerial Vehicles by Menas of On-Board Stereo Processing. *Autonomous Mobile Systems*, 11–20. https://doi.org/10.1007/978-3-642-32217-4

Scholz, M., Serno, M., Franke, J., & Schuderer, P. (2017). A Hybrid Transport Concept for the Material Supply of a Modular Manufacturing Environment. *Procedia Manufacturing*, *11*, 1448–1453. https://doi.org/10.1016/j.promfg.2017.07.275

Scholz, M., Zhang, X., Kreitlein, S., & Franke, J. (2018). Decentralized Intelligence: The Key for an Energy Efficient and Sustainable Intralogistics. *Procedia Manufacturing*, *21*(2017), 679–685. https://doi.org/10.1016/j.promfg.2018.02.171

Schroth, L. (2020). The drone market size 2020-2025: 5 key takeaways. Retrieved March 18, 2021, from https://droneii.com/the-drone-market-size-2020-2025-5-key-takeaways

Selchow, S. (2015). The Drones of Others: An Insight into the Imagination of UAVs in Germany. *Behemoth. A Journal on Civilisation*, *8*(2), 55–72. https://doi.org/10.6094/behemoth.2015.8.2.869

Silverman, D. (2016). *Qualitative Research* (4th ed.). SAGE Publications Ltd.

Škrinjar, J. P., Škorput, P., & Furdić, M. (2019). Application of Unmanned Aerial Vehicles in Logistics Processes. In I. Karabegović (Ed.), *New Technologies, Development and Application. NT 2018. Lecture Notes in Networks and System* (Vol. 42, pp. 359–366). https://doi.org/10.1007/978-3-319-90893-9

Slettebø, T. (2020). Participant validation: Exploring a contested tool in qualitative research. *Qualitative Social Work*. https://doi.org/10.1177/1473325020968189

Staedtler, F., & Haberstroh, M. (2018). *ZF is First in Germany to Fly Drones Over Plant Premises*. Friedrichshafen.

Stark, M. (2015). Delivery drones: how far should we go? *Logistics & Transport Focus*, *41*(4), 22–23. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=113174856&lang=es&site=ehost-live

Stefansson, G., & Lumsden, K. (2008). Performance issues of Smart Transportation Management systems. *International Journal of Productivity and Performance Management*, *58*(1), 55–70. https://doi.org/10.1108/17410400910921083

Stepanić, J., Kasać, J., & Merkač, M. (2014). A Contribution to Considerations of the Role of Embedded Systems. *Business Systems Research Journal*, *5*(1), 47–56. https://doi.org/10.2478/bsrj-2014-0004

Stock, Gregory N., Greis, N. P., & Kasarda, J. D. (2000). Enterprise logistics and supply chain structure: the role of fit. *Journal of Operations Management*, *18*(5), 531–547. https://doi.org/10.1016/S0272-6963(00)00035-8

Stock, Gregory Neal, Greis, N. P., & Kasarda, J. D. (1998). Logistics, Strategy and Structure: A Conceptual Framework. *International Journal of Physical Distribution & Logistics Management*, *18*(1), 37–52. https://doi.org/10.1108/09600039910273948

Strange, R., & Zucchella, A. (2017). Industry 4.0 , Global Value Chains and International Business. *Multinational Business Review*. https://doi.org/https://doi.org/10.1108/MBR-05-2017-0028

Stuart, T., & Anderson, C. (2015). 3D Robotics: Disrupting the drone market. *California Management Review*, *57*(2), 91–113.

Szczepański, C. (2015). UAVs and their avionic systems: development trends and their influence on Polish research and market. *Aviation*, *19*(1), 49–57. https://doi.org/10.3846/16487788.2015.1015295

Tang, C., & Tomlin, B. (2008). The power of flexibility for mitigating supply chain risks. *Int. J. Production Economics*, *116*, 12–27. https://doi.org/10.1016/j.ijpe.2008.07.008

Tavana, M., Khalili-Damghani, K., Santos-Arteaga, F. J., & Zandi, M. H. (2017). Drone shipping versus truck delivery in a cross-docking system with multiple fleets and products. *Expert Systems with Applications*, *72*, 93–107. https://doi.org/10.1016/j.eswa.2016.12.014

Thiels, C. A., Aho, J. M., Zietlow, S. P., & Jenkins, D. H. (2015). Use of Unmanned Aerial Vehicles for Medical Product Transport. *Air Medical Journal*, *34*(2), 104–108. https://doi.org/10.1016/j.amj.2014.10.011

Thun, O.-H., & Hoenig, D. (2011). An empirical analysis of supply chain risk management in the German automotive industry. *Intern. Journal of Production Economics*, *131*, 242–249. https://doi.org/10.1016/j.ijpe.2009.10.010

Toma, S. (2020). Japanese versus German Supremacy in the Global Automotive Sector. *"Ovidius" University Annals, Economic Sciences Series Volume*, *XX*(1), 78–83.

Trienekens, J., van Uffelen, R., Debaire, J., & Omta, O. (2008). Assessment of innovation and performance in the fruit chain. *British Food Journal*, *110*(1), 98–127. https://doi.org/10.1108/00070700810844812

Troudi, A., Addouche, S., Dellagi, S., & El Mhamedi, A. (2017). Logistics Support Approach for Drone Delivery Fleet. https://doi.org/10.1007/978-3-319-59513-9

Trujillo, A. C., Fan, H., Cross, C. D., Hempley, L. E., Cichella, V., Puig-Navarro, J., & Mehdi, S. B. (2015). Operator Informational Needs for Multiple Autonomous Small Vehicles. *Procedia Manufacturing*, *3*, 936–943. https://doi.org/10.1016/j.promfg.2015.07.141

Tuan, L. T. (2017). Under entrepreneurial orientation, how does logistics performance activate customer value co-creation behavior? *The International Journal of Logistics Management*, *28*(2), 600–633. https://doi.org/10.1108/IJLM-12-2015-0242

Unger, H., Markert, T., Müller, E., Markert, T., & Trade-off, M. (2018). Evaluation of use cases of autonomous mobile in factory environments. *Procedia Manufacturing*, *17*, 254–261. https://doi.org/10.1016/j.promfg.2018.10.044

Vázquez-Bustelo, D., Avella, L., & Fernández, E. (2007). Agility drivers, enablers and outcomes: Empirical test of an integrated agile manufacturing model. *International Journal of Operations & Production Management*, *27*(12), 1303–1332. https://doi.org/10.1108/01443570710835633

Vempati, A. S., Choudhary, V., & Behera, L. (2014). Quadrotor: Design, Control and Vision Based Localization. *IFAC Proceedings Volumes*, *47*(1), 1104–1110. https://doi.org/10.3182/20140313-3-IN-3024.00229

Vidal Vieira, J. G., Ramos Toso, M., da Silva, J. E. A. R., & Cabral Ribeiro, P. C. (2017). An AHP-based framework for logistics operations in distribution centres. *International Journal of Production Economics*, *187*, 246–259. https://doi.org/10.1016/j.ijpe.2017.03.001

Vincenzi, D. A., Terwilliger, B. A., & Ison, D. C. (2015). Unmanned aerial system (UAS) human-machine interfaces: new paradigms in command and control. *Procedia Manufacturing*, *3*, 920–927. https://doi.org/10.1016/j.promfg.2015.07.139

Vogt, R. (2016). *Exploring Enabling Factors for Purchasing integration into the innovation* *process in a german medium-sized system integrator of consumer electronics products*. University of Gloucestershire.

von Randow, M., & Thum, V. (2021). Analyse des deutschen Drohnenmarktes. Retrieved from https://www.verband-unbemannte-luftfahrt.de/analyse-des-deutschen-drohnenmarktes/

Wagner, S. M., & Silveira-Camargos, V. (2011). Decision model for the application of just-in-sequence. *International Journal of Production Research*, *49*(19), 5713–5736. https://doi.org/10.1080/00207543.2010.505216

Wang, D. (2016). The Economics of Drone Delivery. Retrieved October 21, 2017, from IEEE Spectrum website: https://spectrum.ieee.org/automaton/robotics/drones/the-economics-of-drone-delivery

Watts, A. C., Ambrosia, V. G., & Hinkley, E. A. (2012). Unmanned aircraft systems in remote sensing and scientific research: Classification and considerations of use. *Remote Sensing*, *4*, 1671–1692. https://doi.org/10.3390/rs4061671

Wawrla, L., Maghazei, O., & Netland, T. (2019). *-Applications of drones in warehouse operations*. Retrieved from www.pom.ethz.ch

Wehking, K.-H., Korte, D. ., & Hagg, M. (2018). Challenges of a safe value-added production logistics of the future. *Internationales Stuttgarter Symposium*, 179–187. https://doi.org/10.1007/978-3-658-21194-3

Weibel, R., & Hansman, R. J. (2004). Safety Considerations for Operation of Different Classes of UAVs in the NAS. *AIAA 3Rd “Unmanned Unlimited” Technical Conference, Workshop and Exhibit*, 1–11. https://doi.org/10.2514/6.2004-6421

Winkler, H., & Zinsmeister, L. (2019). Trends in digitalization of intralogistics and the critical success factors of its implementation. *Brazilian Journal of Operations & Production Management*, *16*(3), 537–549. https://doi.org/10.14488/bjopm.2019.v16.n3.a15

Winkvist, S., Rushforth, E., & Young, K. (2013). Towards an Autonomous Indoor Aerial Inspection Vehicle. *Industrial Robot: An International Journal*, *40*(3), 196–207. https://doi.org/10.1108/01439911311309870

Wu, D., Rosen, D. W., Wang, L., & Schaefer, D. (2015). Cloud-based design and manufacturing: A new paradigm in digital manufacturing and design innovation. *CAD Computer Aided Design*, *59*, 1–14. https://doi.org/10.1016/j.cad.2014.07.006

Yin, R. K. (2014). *Case Study Research: design and methods* (5th ed.). SAGE Publications, Inc.

Yu, K., Cadeaux, J., & Luo, B. N. (2015). Operational flexibility: Review and meta-analysis. *International Journal of Production Economics*, *169*, 190–202. https://doi.org/10.1016/j.ijpe.2015.07.035

Zhang, G., Liang, H., & Yue, Y. (2015). An investigation of the use of robots in public spaces. *5th Annual IEEE International Conference on Cyber Technology in Automation, Control and Intelligent Systems*, 850–855.

Zhang, T., Li, Q., Zhang, C., Liang, H., & Li, P. (2017). Current trends in the development of intelligent unmanned autonomous systems. *Frontiers of Information Technology & Electronic Engineering*, *18*(1), 68–85. https://doi.org/10.1631/FITEE.1601650

Zhang, Y., & Wildemuth, B. M. (2017). Qualitative Analysis of Content. In B. M. Wildemuth (Ed.), *Application of social research methods to questions in information and library science* (Second edi). Santa Barbara, California: Libaries Unlimited.

APPENDIX A, PROFESSIONAL REVIEW AND DEVELOPMENT

This chapter describes my personal and professional development journey during the last four DBA years. Basis for this reflection are elements from the first taught DBA year in 2016/17. The purpose of gaining academic knowledge and applying to professional life is to see things in different ways and find better solutions for different personal and professional situations in life (Fulton, Kuit, Saunders, & Smith, 2013). Another main aim in the learning process of the author was the possibility of becoming a professional researcher to learn about how to tackle challenges un-emotional and more critically (Fulton et al., 2013). This overview is about the authors individual position and academic learning from the beginning till the end of the DBA research. On a basis of first years analysis the following paragraphs reflects on the developments.

Individual position

The background of the researcher was very family-based in a rural background combined with a certain world-openness. Overall the author was described as a family person with strong relation to the parents. In personal life, the partner played a significant role. In sports the author preferred to play Golf which brings quite a lot of privacy. In professional life, the studies started with an Engineering Bachelor already focussing on business topics wherever possible and continued with a consecutive master which brought more business-related topics. After the studies the career started as a strategy consultant in automotive and went on as a more implementing consultant in the last scope of duties. Especially the last career mark added special knowledge to the research topic in logistics. A doctorate is about to add significantly to the profession, so the profession needed to be defined first (Fulton et al., 2013).

During the DBA research the author switched jobs and is working as a project leader in a process-changing software implementation program for one automotive OEM. Overall, the decision to aim for a practically oriented DBA course instead of a more theory-based Doctor of Philosophy (PhD) study was found a perfect match, what is described in the paragraphs to come. Still, from the beginning till the end of the research the motivation of the researcher was, to gain in-depth knowledge and understanding of this specific topic. From a content view, the research at hand contributes as derived in all chapters above. Additionally, the reflection to the development in the DBA journey is summarised in the following with focussing on overall academic learning, personal development and professional development. Overall the author always tried to aim for new challenges and successfully reach the highest level of the academic career.

Academic learning, Overall

Overall, the professional developments are linked to the personal developments during the doctorate studies and how the research practice influenced those (L. Anderson, Gold, Stewart, & Thorpe, 2015). The author tried to critically reflect with applying the reflection cycle which is described in the next paragraphs. Most important part here is to reflect on actions (Finlay, 2008).

> "*In the case of reflection-on-action, professionals are understood consciously to review, describe, analyse and evaluate their past practice with a view to gaining insight to improve future practice*" (Finlay, 2008).

In order to have a sufficient result it was also important to take care about stakeholders impacts (Fulton et al., 2013) as well as personal feeling and understanding of situations (Finlay, 2008). The purpose was to know the achieved qualified standing and to ongoing develop new skills in different fields in further life (Fulton et al., 2013). Being critical in research, in this case about personal and professional development, meant that there is no structures problem and also no solution to a challenge and one has to be open-minded and ask the right questions (L. Anderson et al., 2015). The following path of describing and analysing the professional development is basically grounded on Gibbs (1988) Reflective Cycle (Finlay, 2008), which can be seen in the following Figure A.1

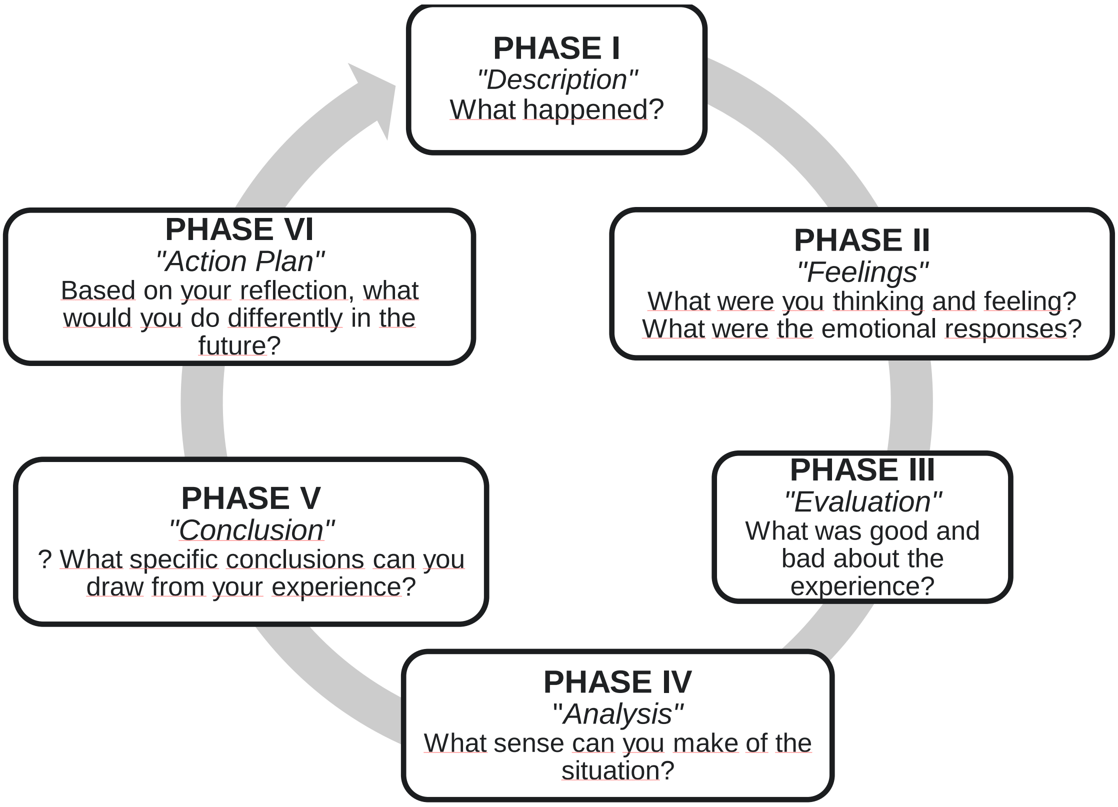


Figure A.1 Reflective Cycle by Gibbs (1988)

Knowledge as a basis for stability in mind and therefore in professional life. Within academic thinking it was important at the doctoral-level especially to show that the author can be a though-leader with the ability to reflect (Fulton et al., 2013). More knowledge was generated by the work with experts. A big factor was to understand which knowledge is generated during the professional doctorate and how it contributes to the profession (Fulton et al., 2013). The professional doctorate in general could be the bridge of academic knowledge and professional practice (L. Anderson et al., 2015) what means that properly applied academic knowledge can significantly contribute knowledge and change perspectives. Social and political description and analysis is also an important part of critical reflection (Fulton et al., 2013) in personal and professional development therefore. In the opinion of the author the personal review and development section was very important for the development over the years.

The aim was to be open-minded and always try to change perspectives. In case of the author the research was the reason to start to reflect the actual situation. However, in some situations there is the possibility that the people around the researcher have different opinion or are working actively against the idea (Fulton et al., 2013) what happened during the author's research situation.

Personal review

Starting with a personal development, the author can reflect, that he overcame challenges regarding insecurities through more healthy nutrition and sports. Yet, the DBA studies required a lot of extra hours, which were no longer usable for sports and hobbies, it was possible for the author to create a permanent balance for both DBA and free time.

One major aspect, as reflected in the first year, was as well, that the author was able to land a new job and got rid of the consultancy life with now having fixed working hours on a regular basis. Before this job change happened, the researcher had to compensate through long hours during the week and working all day during the weekends. Even though, as reflections in the first year also mentioned a difficult level of relationship to line manager, the author now faces innovative managers, which were very interested in the research and are of supportive character as well. The research influenced the author in choosing the new employer on basis of innovativeness and open-minded culture of managers and colleagues.

Both facts, having a better time management and supportive line managers now lead to the fact that the author felt better over time and realised that working on the DBA made extremely more progress as of the positive vibes and energy and the re-gained mentality to contribute to a worthy practice again. Some experience was additionally given by the experts from the interviews, which stated, that they are positively impressed by the braveness of the author to tackle such an innovative topic.

Overall from a personal perspective, it can be said, that the DBA was the most challenging project in the researchers life. During the DBA period, all activities, like buying of a new flat, marriage, job change, weight reduction, sports planning and other happenings, everything, was less important as the researchers studies. However, it was very challenging to have a day-to-day guilt and an always existent curiosity, if someone else is working on the same research topic – somewhere in the world.

Professional review:

In the first year the author described a very unhappy situation being on consultancy level and always kind of not having an in-depth view to certain topics yet only fly over certain project steps. The DBA research adds massively to the authors thinking, especially at critical thinking and going into deep reflections on single options in every research objective. The higher awareness to a more intense feedback structure and reflection over a long term developed the researchers skills towards being a better researcher as well as a better and more patient practitioner. A mentioned duality of being a researcher and a practitioner was given in the researchers period at least in three of four years. The researcher experiences lot of misunderstanding from former line managers and faced crucial decisions regarding the given jobs and projects, as the researcher stuck on the DBA. Yet, another learning for the researcher was to stand for a personal purpose and to also defend certain free hours a day for the one thing, that really counted, namely the doctoral research. To stand for own knowledge and to defend certain thought is a major outcome here.

An interesting development regarding professional mentality was, that at the beginning the researcher was unhappy for not developing in an intellectual way. During the literature review, with having hundreds of upcoming papers the researcher at first was very afraid of having so much input and in relation knowing nothing about the research. With having more and more literature reviewed and classified mostly as not relevant, the author developed confidence instead, and is now very happy about having an intellectual stand from that point on.

Summary

Overall, summarising the development, it can be said, that the authors desired progress was made, and the research was applied in a sufficient way. Not only the critical thinking and the in-depth approach added to the authors professional development but also the improved English language skills and the feedback awareness added significantly. The personal development of the researcher towards more empathic and more durable work ethics added another significant portion to this exciting journey made in the last 4,5 years.

Having summarised all the learnings, it is important to mention, that the research is ongoing at a certain point and the author plans to go one working on the DIALOOP framework on both ways: applying the framework in practice and possibly present some further results on academic conferences to come.

APPENDIX B, UPR16 SUBMISSION FORM

FORM UPR16

Research Ethics Review Checklist

Please include this completed form as an appendix to your thesis (see the Research Degrees Operational Handbook for more information

UNIVERSITY of PORTSMOUTH

Postgraduate Research Student (PGRS) Information		Student ID:	UP838682
PGRS Name:	Sebastian Hartl		
Department:	BaL, Operations and Systems Management	First Supervisor:	Dr. Jana Ries
Start Date: (or progression date for Prof Doc students)	01.10.2016		

Study Mode and Route:						
Part-time	[X]	MPhil	[ ]	MD	[ ]
Full-time	[ ]	PhD	[ ]	Professional Doctorate	[X]

Title of Thesis:	A Framework for the implementation of drones in German automotive OEM logistics operations
Thesis Word Count: (excluding ancillary data)	53272

If you are unsure about any of the following, please contact the local representative on your Faculty Ethics Committee for advice. Please note that it is your responsibility to follow the University's Ethics Policy and any relevant University, academic or professional guidelines in the conduct of your study

Although the Ethics Committee may have given your study a favourable opinion, the final responsibility for the ethical conduct of this work lies with the researcher(s).

UKRIO Finished Research Checklist: (If you would like to know more about the checklist, please see your Faculty or Departmental Ethics Committee rep or see the online version of the full checklist at: http://www.ukrio.org/what-we-do/code-of-practice-for-research/)		
a) Have all of your research and findings been reported accurately, honestly and within a reasonable time frame?	YES NO	[X] [ ]
b) Have all contributions to knowledge been acknowledged?	YES NO	[X] [ ]
c) Have you complied with all agreements relating to intellectual property, publication and authorship?	YES NO	[X] [ ]
d) Has your research data been retained in a secure and accessible form and will it remain so for the required duration?	YES NO	[X] [ ]
e) Does your research comply with all legal, ethical, and contractual requirements?	YES NO	[X] [ ]

Candidate Statement:			
I have considered the ethical dimensions of the above named research project, and have successfully obtained the necessary ethical approval(s)			
Ethical review number(s) from Faculty Ethics Committee (or from NRES/SCREC):		BAL/2018/E531/HARTL	
If you have *not* submitted your work for ethical review, and/or you have answered 'No' to one or more of questions a) to e), please explain below why this is so:			
n/a			
Signed (*PGRS*):	 Sebastian Hartl	Date:	27.12.2020

UPR16 – April 2018

APPENDIX C, INTERVIEW RELATED DOCUMENTS

This appendix contains: Ethics approval, Invitation letter, Participant information, Consent form, Interview questions(guide), Code list

UNIVERSITY OF PORTSMOUTH

Sebastian Hartl
Faculty of Business and Law
Richmond Building
Portland Street
PO1 3DE

FAVOURABLE ETHICAL OPINION

Study Title: A Framework to evaluate the potentials of implementing drones in automotive original equipment manufacturer (OEM) logistics operations.

Reference Number: BAL/2018/E531/HARTL

Date Resubmitted: 08/01/2019

Dear Sebastian,

Thank you for resubmitting your application to the Faculty Ethics Committee and for making the requested changes/ clarifications.

I am pleased to inform you that the Faculty Ethics Committee was content to grant a favourable ethical opinion of the above research on the basis described in the submitted documents listed at Annex A, subject to standard general conditions (*See Annex B)*, and subject to the condition that you incorporate the following changes:

1. 11.10. The procedure for data destruction described must be in case of lack of reconsent by the participants, rather than in the case of participants reconsenting. Please can this be corrected.

2. Section 15 of ethics form and participant documentation. The dates have been updated, but the version numbers of documents given (version 1) have not, and are now wrong. Please can the researcher ensure that version numbers and dates are changed, where necessary, in section 15 and on the documents to be issued to participants so that there is no ambiguity about which versions of documents are the versions that have received ethical approval.

Please note that the favourable opinion of the Faculty Ethics Committee does not grant permission or approval to undertake the research/ work. Management permission or approval must be obtained from any host organisation, including the University of Portsmouth or supervisor, prior to the start of the study.

Wishing you every success in your research

Peter Scott, Chair of the Faculty of Business and

Law Ethics Committee

Annexes

A - Documents reviewed

B - After ethical review

ANNEX A **Documents reviewed**

The documents ethically reviewed for this application

Document	*Version*	*Date*
Application Form	1	23/11/2018
Application Form	2	08/01/2019
Sample Interview Questions	1	23/11/2018
Sample Interview Questions	2	08/01/2019
Invitation Letter	1	23/11/2018
Invitation Letter	2	08/01/2019
Participant Information Sheet	1	23/11/2018
Participant Information Sheet	2	08/01/2019
Consent Form for Organisation	1	23/11/2018
Consent Form for Organisation	2	08/01/2019
Supervisor Email Confirming Application	1	23/11/2018
Supervisor Email Confirming Application	2	08/01/2018

Dear Mrs/Mr ……………………………,

I am currently working on my doctoral thesis at the University of Portsmouth. The research investigates the design of "A Framework to evaluate the potentials of implementing drones in automotive OEM logistics operations". Overall, the primary objective of the research is to find out, how drones can be used in automotive OEM logistics operations.

In order to explorer the "how", preconditions of drones for the use in current 'automotive OEM logistics operations' (LO) requirements need to be defined. The explorative comparison will be made in a framework for 'drones in automotive logistic operations' (DIALOOP).

The research is structured in five research objectives, which are mainly to explore current logistics processes in the multiple process areas of an OEM, to explore current application of aerial drones and existing classifications and to explore the preconditions for drones to meet the requirements of current automotive OEM logistics operations and the related performance criteria. Having done this, the author wants to establish a framework, which can be used to compare drone preconditions and properties (based on the classification) to the current logistics operations. Finally, this framework needs to be validated including the possible changes of the work within automotive OEMs.

I am looking for an interview partner for my research topic, with a minimum of three years of relevant experience in one of the above-named fields, and believe that, based on your experience, your participation would be particularly valuable.

For this reason, I would like to invite you to participate in a semi-structured interview. Your answers and contribution will form a significant input for this research project.

If you decide to take part in this voluntary interview, please contact me by email (Sebastian.Hartl@myport.ac.uk) or phone (+49 160 9691 6886). The interview will take about 60 minutes and will be arranged at your convenience. While an interview in person is favourable, a Skype or phone call can be organised as an alternative.

I would be grateful for your participation in this study. You will be provided with further detail about the study in the participant information sheet.

Thank you for your time in advance. I am looking forwards to your answer.

Best regards

Sebastian Hartl

Participant Information Sheet

Title of study

A Framework to evaluate the potentials of implementing drones in automotive OEM logistics operations.

Name of investigating student and principal supervisor

Interviewer: Mr. Sebastian Hartl

Supervisory team: Principal supervisor Dr. Jana Ries, second supervisor Prof. Dr. Daniel Palm, third supervisor Dr. Debbie Reed

Invitation text:

I would like to invite you to an interview in the context of a research study. The following information will inform you about the content and the process of the study. Please read the following paragraphs to important aspects and ask me any questions you may have.

What is the purpose of the study?

The purpose of this study is to create a framework, which evaluates the implementation of aerial drones to logistics operations of build-to-order European automotive OEMs. For this purpose, first of all the interviews will seek to explore logistics operations to be considered and map to processes, named by the interviewees. A second objective will be to explore a drone classification, which was designed explicitly for the automotive OEM case on the basis of existing literature. Finally, the interview will aim to explore the required preconditions of drones, that need to be met in order for drones to be a feasible alternative to existing logistics operational design.

Why have I been invited?

You have been selected as interviewee because of your professional expertise in the area of drones or the automotive OEM logistics sector. Interviews will be conducted with 15 experts and/or managers from relevant companies and organisations.

Do I have to take part?

Participation is voluntary and whilst participating you can withdraw without giving any reason. Withdrawing will not have any further implications. Please read the important notice below.

IMPORTANT NOTICE:

In case of participating, signing a consent form will be necessary. The consent form also is attached to this invitation. Please note, that data will be pseudonymising immediately after the interviews. Once data has been analysed and findings from the interviews are drawn, it will not be possible anymore to withdraw from the study.

What will happen if I take part?

The interviews will last about 60 minutes. The interview and analysis stage then will last about 4 months from the first interview. After the study is finished a summary will be given to the participants. Meeting facilities will be organised as near as possible to the interviewees working environment to reduce traveling hours.

What do I have to do?

Answer the questions of the interviewer to the best of your knowledge and experience from your working environment.

What are the possible disadvantages and risks of taking part?
No disadvantages and risks have been identified. Please note that your data will be handled anonymously.

What are the possible benefits of taking part?
As a participant you contribute to knowledge. The study outcomes will be made available for the interviewee's interest.

What will happen when the research study stops?
Stopping or finishing the research study will lead to the deletion of all relevant data, which are of critical character after 10 years, in order to have the possibility to further work with the data in a publication.

Will my taking part in the study be kept confidential?
The taking part in the study will be kept absolute confidential. Audio records will be hold pseudonymised and transcribed pseudonymously. Data are saved securely on an extra drive of the University of Portsmouth, which has password protected access.

What should I do if I want to take part?
Please answer to this email to organise a timeslot and location with the researcher. In addition, prior to the participation the consent form needs to be signed. In case you are not sure if you are entitled to take part, you should ask for consent or permission to give consent from your line managers or from a responsible department within your employing company.

What will happen to results of the research study?
The results of this research will only be used for the doctoral thesis, which might be published online in the library sites of the University of Portsmouth. Additionally, to the thesis, there is the possibility given, that there will be publications in journals.

What will happen if I do not want to carry on with the study?
You interview data will be deleted. Nothing else will happen. Please see "Important Notice" on the first page.

Who has reviewed the study?
The study has been approved by Research Ethics Committee of the University of Portsmouth (Faculty BaL), what is part of the approval process for the interview phase.

Further information and contact details

__**DBA Student:**__
Sebastian Hartl **Sebastian.Hartl@myport.ac.uk**

Supervisory Team:
Dr. Jana Ries, **Jana.ries@port.ac.uk**
Prof. Dr.-Ing. Daniel Palm, **Daniel.palm@reutlingen-university.de**
Dr. Debbie Reed, **debbie.x.reed@port.ac.uk**

Thank you for reading the participant information sheet.

Date: 08. January 2019 **Version: I**

CONSENT FORM

The institution for this research project is the University of Portsmouth – UK. Faculty: Business & Law.

Title of project: A Framework to evaluate the potentials of implementing drones in automotive OEM logistics operations

Name and Contact Details of Researcher: Sebastian Hartl, Sebastian.Hartl@myport.ac.uk

Name and Contact Details of Supervisor: Dr Jana Ries, Jana.ries@port.ac.uk

Prof. Dr.-Ing. Daniel Palm, Daniel.palm@reutlingen-university.de;

University Data Protection Officer: Samantha Hill, 023 9284 3642 or data-protection@port.ac.uk; Ethics Committee Reference Number: BAL/2018/E531/HARTL Ethics Committee Reference Number: (not available currently)

1. I confirm that I have read and understood the information sheet dated December 18th, 2018 for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time before my pseudonymised data had been analysed without giving any reason. ☐

3. I understand that data collected during this study will be processed in accordance with data protection law as explained in the Participant Information Sheet dated December 18th 2018 ☐

4. I agree to take part in the above study. ☐

Name of Participant: **Date:** **Signature:**

Name of Person taking Consent: **Date:** **Signature:**

***Note**: When completed, one copy to be given to the participant, one copy to be retained in the study file*

Interview question areas as applied for ethical approval, 08.01.2019

Interview Questions

This document contains an overview of question areas and example list of question for semi-structured interviews as an appendix to the ethics application form.

Group A (automotive)		
Objective/ Topic area	**Areas of questions**	**Some Examples**
Expert Level	**Find out about the expert level of the interviewee and explore the work environment**	For you many years do you work in automotive OEM logistics now?
		What is your academic background to this experience?
		What is your current position and work in this environment?
		How would you describe your level of experience?
Logistic operations	**Explore the process areas and the related logistics operations**	What process area(s) are you focusing on?
		What detailed logistics operations are there?
	Explore related tasks and most important performance measures	Are there visual based tasks?
		What are transportation based tasks?
		What are the most important performance measures?
Drones	**Explore the knowledge of the interviewee to drones and possible classification**	Can you tell me what you know about drones?
		How would you classify drones in automotive OEM logistics operations?
Changes/ potentials for drones	**Discussion of possible change of drones or logistics operations as well as potentials for drones**	How can drones enhance your logistic operations?

		What changes will occur in automotive OEM logistics operations?
		What changes in the process could lead to drone usage?
		What changes are needed to happen in the environment to make drones a suitable alternative?
Framework	**Discussion of development and use of a framework in the research topic**	How could a framework for drones be used in automotive OEM logistics operations?

Group B (non-Automotive)		
Objective/Topic area	**Areas of questions**	**Questions**
Expert Level	**Find out about the expert level of the interviewee and explore the work environment**	For you many years do you work with drones?
		What is your academic background to this experience?
		What is your current position and work in this environment?
		How would you describe your level of experience?
Drones	**Discuss different types of drones and characteristics**	What drones (UAVs) do you know?
		What drones do you work with?
		What are the advantages?
		What are the disadvantages?
		How would you classify drones?
	Explore development of drones and possible new areas of application	What tasks can be handled by drones?
		In which branches are drones upcoming?
		How will the development of drones in the future will be?
Classification	**Discussion of a possible classification of drones**	What do you think about a classification of drones in automotive OEM logistics operations?
Logistic operations	**Discuss linkage of drones towards logistics operations**	How can drones be used in automotive OEM logistics operations?

		Which performance measures could be improved by using drones?
Future developments	**Explore future development and changes of drones and logistics operations**	How will drone usage in automotive OEM logistics operations will increase in the near future?
		What changes would need to happen for making drones more suitable to use?
		How could current use of drones be transferred from other branches to automotive OEM logistics operations?

Further information and contact details

Student:
Sebastian Hartl, Sebastian.Hartl@myport.ac.uk

Supervisory Team:
Dr. Jana Ries, Jana.ries@port.ac.uk
Prof. Dr.-Ing. Daniel Palm, Daniel.palm@reutlingen-university.de
Dr. Debbie Reed, debbie.x.reed@port.ac.uk

Date: 19 June 2020 **Version: I**

---------------- (End of document "interview questions") ------------------

After the ethics approval, reviews from the supervisory team and peer review as well as the two pilot interviews (in each question set) the following questions were used in the interviews.

Automotive expert interview questions:

Automotive Interview Questions

This document contains a list of question for semi-structured interviews as well as a conversation support for the researcher.

1. **For how many years have you worked in automotive OEM logistics?**
2. **Please describe the process area(s) you are focusing on in your work currently?**
3. **Can you tell me what you know about the current application of aerial drones?**
4. **Could you please describe the inhouse logistic of automotive OEM and of possible roughly group it into process area?**
5. **Generally, with focusing on inhouse logistics of automotive OEMs, what performance measures do you know and are relevant in your opinion?**
6. **Focusing on "Receiving", could you please describe relevant logistic operations?**
7. **What are the relevant performance measures in the process area of "Receiving"?**
8. **How could drones be used in the named process area of "Receiving"?**
9. **Focusing on "Storing", could you please describe relevant logistic operations?**
10. **What are the relevant performance measures in the process area of "Storing"?**
11. **How could drones be used in the named process area of "Storing"?**
12. **Focusing on "Inventory Handling", could you please describe relevant logistic operations?**
13. **What are the relevant performance measures in the process area of "Inventory Handling"?**
14. **How could drones be used in the named process area of "Inventory Handling"?**
15. **Focusing on "Picking/Sequencing", could you please describe relevant logistic operations?**
16. **What are the relevant performance measures in the process area of "Picking/Sequencing"?**

17. How could drones be used in the named process area of "Picking/Sequencing"?

18. Focusing on "Delivery to line", could you please describe relevant logistic operations?

19. What are the relevant performance measures in the process area of "Delivery to line"?

20. How could drones be used in the named process area of "Delivery to line"?

(# overall focus from here again)

21. Please describe, how drones would need to change to have more potentials of being implemented in automotive OEM inhouse logistics operations?

22. Please describe how the inhouse logistics operations would need to change to provide more potentials for implementing drones.

(Talk about classification of drones in OEM Logistics operations)

23. How would you classify drones in automotive OEM logistics operations?

Further information and contact details

Student:
Sebastian Hartl, Sebastian.Hartl@myport.ac.uk

Supervisory Team:
Dr. Jana Ries, Jana.ries@port.ac.uk
Prof. Dr.-Ing. Daniel Palm, Daniel.palm@reutlingen-university.de
Dr. Debbie Reed, debbie.x.reed@port.ac.uk

Date: 09.02.2019 Version:1

---------------- (End of document "interview questions") -----------------

Drone expert interview questions:

UNIVERSITY OF PORTSMOUTH

Sebastian Hartl | DBA Portsmouth – Reutlingen Cohort
email Sebastian.Hartl@myport.ac.uk| mobile 004916096916886
doc Drohnenexperten – Interview Fragen

Drone expert interview questions

This documents contains a list of questions (1-n) for the semi-structured interviews.

Questions ENG

1. **For how many years have you been working with drones (aerial vehicles)?**
2. **Which drones (UAVs, MAVs >> Aerial Vehicles) are you familiar with?**
3. **How would you classify drones?**

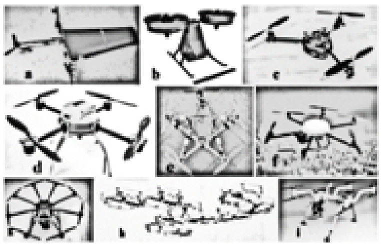
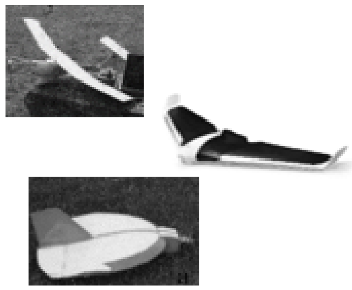
NOTE FOR INTERVIEWER: HERE THE CLASSIFICATION SUGGESTION (FROM LITERATURE) NEEDS TO BE PRESENTED

4. **Could you describe what you know about Rotor-based drones?**
5. **What tasks can be done by rotor-based drones and why?**
6. **Please describe which key performance indicators could be changed in logistics processes by using rotor-based drones.**
7. **How could rotor-based drones be used explicitly in the logistics of car manufacturers?**
8. **How will rotor-based drones change in the future?**
9. **Could you describe what you know about Fixed Wing drones?**
10. **What tasks could be done by fixed - wing drones and why?**
11. **Please describe which key performance indicators could be changed in logistical processes through the use of fixed wing drones.**
12. **How could fixed-wing drones be used in the logistics of automobile manufacturers?**
13. **How will fixed wing drones change in the future?**
14. **Can you describe what you know about hybrid or tilt drones?**
15. **What tasks could be done by hybrid or tilt drones and why?**
16. **Please describe which key performance indicators could be changed in logistical processes through the use of hybrid or tilt drones.**
17. **How could hybrid or tilt drones be used in the logistics of car manufacturers?**
18. **How will hybrid or tilt drones change in the future?**
19. **What changes would have to be made to make drones work better?**

Communication Support Paper
(used in second part of the automotive expert interviews to have guidance through drone classes)

Sebastian Hartl | DBA Portsmouth – Reutlingen Cohort
email UP838682@myport.ac.uk | mobile 004916096916886
doc Communication Support Paper

Rating of "drones in process areas"
– showing visual examples **Respondent:**

Drones	Class 1-3		Rating 1	2	3	4	5	Examples/Pictures
ROTOR	C 1 - R	small	☐	☐	☐	☐	☐	
	C 2 - R	medium	☐	☐	☐	☐	☐	
	C 3 - R	large	☐	☐	☐	☐	☐	
FIXED WING	C 1 - F	small	☐	☐	☐	☐	☐	
	C 2 - F	medium	☐	☐	☐	☐	☐	
	C 3 - F	large	☐	☐	☐	☐	☐	
HYBRID & TILT APPL.	C 1 - HT	small	☐	☐	☐	☐	☐	
	C 2 - HT	medium	☐	☐	☐	☐	☐	
	C 3 - HT	large	☐	☐	☐	☐	☐	

Rating [1 very, 2 good, 3 reasonable, 4 slight/bit, 5 non/not at all]

SIZE / TYPE	Rotor	Fixed	Hybrid/Tilt
small [bis 2kg]	DC 1-R	DC 1-F	DC 1-HT
medium [bis 10kg]	DC 2-R	DC 2-F	DC 2-HT
large [bis 25kg]	DC 3-R	DC 3-F	DC 3-HT

Page 1 of 1

Coding Protocol for corroborating the interview transcript:

Sebastian Hartl | DBA Portsmouth – Reutlingen Cohort
email Sebastian.Hartl@myport.ac.uk | **mobile** 004916096916886
doc Coding protocol to peer

Coding Protocol for corroborating the interview transcript

The following protocol is used in order to do the coding on the research for the purpose of corroboration.

Please read the interview data and try to find themes and some key aspects, which refer to the themes (A - J). Please take care of sentences and paragraphs which might be relevant for some related themes or emerging topics which in your opinion are relevant for the research.

A main structure is given by the author (namely the letters A to J) in the following description. Anyways, please try to code also freely and amend any other themes you find. Please be curious and explore any relations or patterns you might find in the data.

If possible, go through the data repeatedly to clearly identify all codes, sentences and phrases. The core parts of the interviews are separated into the expert's knowledge about processes, second about the knowledge to drones, third about the performance measures in the process areas and fourth about the changes.

Please to carefully reflect on the content of the data and the coding you will do. If necessary, please put into effect any changes.

(A) The introduction of the interviews was an open conversation about the interviewee's position in his/her company and any responsibilities.

(B) Also, the integration and access to the logistics operations will be asked for in order to have an understanding how familiar the interviewee is with the subject area. These questions aim to explore the expert level of the interviewee. Possible non-experts, which could be falsely identified, e.g. by the gatekeepers, can hereby be identified.

(C) The second area of questions will address, what logistic operations are in the focus of the interviewee. During the interviews, the questions often will be open at first in order to have the possibility to react to the answers and ask the interviewees for some further explaining in-between in the following.

(D) A third area of questions will then focus on the explicit use of drones.

(E) At first, a shorter sub-part will be focussing on the question towards the understanding of the interviewees' to drones and if/how they have been actively using drones. If interviewees have been actively involved with the use of drones, some additional answers will be asked any further viewpoints on the topic.

(F) Following to these questions, there also will be questions to possible use of drones within their work environment at the interviewee's employer and not reduced to special processes or areas.

The iterative returning question set (G – J) are meant for each process area (goods receipt, storing, picking & sequencing and delivery to line). After having talked about drones, it is planned to direct the questions towards the explicit use of drones in the above-named process areas and logistics operations.

(G) Each process area starts with asking an opinion of existing logistics operations and

(H) the related performance measures, which are in use.

(I) However, the following questions also will address possible usage of drones in the related areas and

(J) potentially changeable performance measures by the use of drones again in the specific process area.

(K) The last focus of interview question is on an opinion of the expert to possible chances, that have to take place in future – either a) by focussing on the process or b) by focussing on the drones. The author wants to find out, what the preconditions are meaning and what factors influence the implementation of drones.

Learnings from 1. pilot interview, Automotive expert:

Overall feedback & Learnings

1. Smalltalk and preparation takes quite long (important for planning of the participants time)

2. The interviewer always was reading the questions differently

3. Often it was unclear, how deep a content driven question/leading question can be

4. Key performance measures should be discussed before the iteration

5. Questions missing to different types of delivery

6. Differentiation "transportation task" and "visual based" is not good for the interview (is somehow wrong: Visual might be "Information gathering" which could also be done with other senses,

Notes during the interview:

1. Do I give a question (list) sheet to the interviewer? Or perhaps 1-question-sheets?

2. Question2 repeats somehow to question 1 – topic

3. Question3 partly not understandable

4. OVERALL Iteration to the different process areas does not make sense of many reasons

    - Participant repeats answer sometimes

    - Participant does not know the detailed processes

    - many parts of the process areas are quit the same especially for the answers

5. Differentiation of transport und visually based tasks/processes is perhaps not good

6. Prior to question 6, the automotive participant was not sure about what a drones are > an explanation of drones might be needed?

7. With asking for changes is performance measures, somehow the answer of advantages repeats

8. Differentiation tech./economic/social unclear

9. What are leading question?

Learnings from 1. pilot interview, Drone expert:

1. Questions #3 are repeating to 1 and 2

2. Iteration rotor/hybrids/fixed wing does not work as the experts started to compare between the types in the first iteration

3. in Question7 there is an iteration

4. relation to order process or modularity is missing

Learnings from 2. Pilot interviews

Overall feedback & Learnings

1. Add "Übergreifend" "Overall" process area?

Notes/Learnings from the 2. automotive interview:

1. KPIs are difficult to understand and difficult to point out to in the different processes
2. Agility is difficult to handle in this context
3. It could help to think about /define, who will read and use the future framework
    a. Assignment
    b. Category
4. Alternative questioning to process: What difficulties are there in the process areas or what critical process
    a. Which probably could be solved by using drones?
    b. Are the process designs correct?
5. Overall: Questions seem to be not clear or precise enough
6. Communication Sheet generally good but is given guidance to the interviewee in case of using iterations. It might be helpful to use "prompts in the own list of interviews"

Notes/Learnings from the 2. drone expert interview:

1. Level of autonomy unclear regarding the steps prior to autonomy like controlled, semi-automated, automated
2. Questions might be to far away from the process of interest
3. Take care of bias, when talking about experience and examples
4. Questions should <u>not</u> be provided in total but probably "question areas"
5. Questions should be provided separately

Final facts:

1. 2nd pilot interviews were eye openers
2. Communication sheet might be good but need better timing related to the questions, give it to interviewee in the middle of the interviews
3. Probably it is better to go through all questions without any Communication Sheet and later discuss through all performance measures?

APPENDIX D, VALIDATION RELATED DOCUMENTS

Favourable ethics opinion to validation amendments:

UNIVERSITY OF PORTSMOUTH

FAVOURABLE ETHICAL OPINION

Study Title: A Framework to evaluate the potentials of implementing drones in automotive original equipment manufacturer (OEM) logistics operations.

Reference Number: BAL/2018/E531/HARTL

Date Resubmitted: 09/06/2020

Thank you for resubmitting your application to the Faculty Ethics Committee and for making the requested changes/ clarifications.

I am pleased to inform you that the Faculty Ethics Committee was content to grant a favourable ethical opinion of the above research on the basis described in the submitted documents listed at Annex A, subject to standard general conditions (*See Annex B)*. In addition, the Ethics Committee have also added the following conditions which must be followed before approval can be given;

1) Please specify in the 'What will happen if I take part?' section of your participant information sheet that the interview will be carried out through Webex rather than in person. You will therefore also need to delete the following sentence from the same section: 'Meeting facilities will be organised as near as possible to the interviewees working environment to reduce traveling hours.'

2) Please make a similar change concerning the method of data capture in your invitation letter. In particular, you will have to change this sentence: 'While an interview in person is favourable, a Skype or phone call can be organised as an alternative.'

3) This favourable opinion is given on the assumption that you will adopt your existing stated practice to record the interviews via an off-line digital voice recorder. If you wish to use the record option in Webex to capture the data, you will have to seek a further ethical amendment, as Webex will capture video as well as audio and this will require specific additional consent.

Please send copies of your amended invitation letter and participant information sheet by email, as per conditions 1 and 2 above, for the accuracy of our records.

Please note that the favourable opinion of the Faculty Ethics Committee does not grant permission or approval to undertake the research/ work. Management permission or approval must be obtained from any host organisation, including the University of Portsmouth or supervisor, prior to the start of the study.

Wishing you every success in your research

Peter Scott, Chair of the Faculty of Business and

Law Ethics Committee

Annexes

A - Documents reviewed

B - After ethical review

ANNEX A **Documents reviewed**

The documents ethically reviewed for this application

Document	*Version*	*Date*
Application form	1	09/06/2020
Invitation Letter	1	09/06/2020
Participant Information Sheet	1	09/06/2020
Consent Form	1	09/06/2020
Interview Questions / Topic List	1	09/06/2020

ANNEX B - After ethical review

1. This Annex sets out important guidance for those with a favourable opinion from a University of Portsmouth Ethics Committee. Please read the guidance carefully. A failure to follow the guidance could lead to the committee reviewing and possibly revoking its opinion on the research.

2. It is assumed that the work will commence within 1 year of the date of the favourable ethical opinion or the start date stated in the application, whichever is the latest.

3. The work must not commence until the researcher has obtained any necessary management permissions or approvals – this is particularly pertinent in cases of research hosted by external organisations. The appropriate head of department should be aware of a member of staff's plans.

4. If it is proposed to extend the duration of the study beyond that stated in the application, the Ethics Committee must be informed.

5. Any proposed substantial amendments must be submitted to the Ethics Committee for review. A substantial amendment is any amendment to the terms of the application for ethical review, or to the protocol or other supporting documentation approved by the Committee that is likely to affect to a significant degree:

(a) the safety or physical or mental integrity of participants
(b) the scientific value of the study
(c) the conduct or management of the study.

5.1 A substantial amendment should not be implemented until a favourable ethical opinion has been given by the Committee.

Invitation letter validation:

Sebastian Hartl | DBA Portsmouth – Reutlingen Cohort
email Sebastian.Hartl@myport.ac.uk | **mobile** 004916096916886

(Amendment to ethics application BAL/2018/E531/HARTL, approved on 18.02.2019)

Dear Mrs/Mr ……………………………,

I am currently working on my doctoral thesis at the University of Portsmouth. The research investigates the design of "A Framework to evaluate the potentials of implementing drones in automotive OEM logistics operations". Overall, the primary objective of the research is to find out, how drones can be used in automotive OEM logistics operations.

In order to explorer the "how", preconditions of drones for the use in current 'automotive OEM logistics operations' (LO) requirements need to be defined. The explorative comparison will be made in a framework for 'drones in automotive logistic operations' (DIALOOP).

The research was structured in five research objectives, which are mainly to explore current logistics processes in the multiple process areas of an OEM, to explore current application of aerial drones and existing classifications and to explore the preconditions for drones to meet the requirements of current automotive OEM logistics operations and the related performance criteria. Having done this, the author established a framework, which can be used to compare drone preconditions and properties (based on the classification) to the current logistics operations. Finally, this framework needs to be validated including the possible changes of the work within automotive OEMs.

I am looking for you as validating interview partner for my research topic as you participated in the initial interviews, and I believe that, based on your experience, your participation would be particularly valuable for the final validation.

For this reason, I would like to invite you to participate in a short validating interview. Your answers and contribution will form a significant input for this research project.

If you decide to take part in this voluntary interview, please contact me by email (Sebastian.Hartl@myport.ac.uk) or phone (+49 160 9691 6886). The interview will take about 45 minutes and will be arranged at your convenience. The interviews will take place in an online Webex session and recorded by an off-line digital voice recorder.

I would be grateful for your participation in this study. You will be provided with further detail about the study in the participant information sheet.

Thank you for your time in advance. I am looking forwards to your answer.

Best regards

Sebastian Hartl

Participant information sheet validation:

(Amendment to ethics application BAL/2018/E531/HARTL, approved on 18.02.2019)

Participant Information Sheet

Title of study

A Framework to evaluate the potentials of implementing drones in automotive OEM logistics operations.

Name of investigating student and principal supervisor

Interviewer: Mr. Sebastian Hartl

Supervisory team: Principal supervisor Dr. Jana Ries, second supervisor Prof. Dr. Daniel Palm, third supervisor Dr. Debbie Reed

Invitation text:

I would like to invite you to a final validating interview in the context of a research study. The following information will inform you again about the content and the process of the study. Please read the following paragraphs to important aspects and ask me any questions you may have.

What is the purpose of the study?
The purpose of this study is to create a framework, which evaluates the implementation of aerial drones to logistics operations of build-to-order European automotive OEMs. For this purpose, first of all the interviews will seek to explore logistics operations to be considered and map to processes, named by the interviewees. A second objective will be to explore a drone classification, which was designed explicitly for the automotive OEM case on the basis of existing literature. Finally, the interview will aim to explore the required preconditions of drones, that need to be met in order for drones to be a feasible alternative to existing logistics operational design.

Why have I been invited?
You have been selected as interviewee because you met the criteria for participation according to the initial participation criteria. Additionally, your employment at the automotive OEM, which is a used as case for the validating interviews, is a selection criteria. All validating experts have taken part in the prior interview sets as well.

Do I have to take part?
Participation is voluntary and whilst participating you can withdraw without giving any reason. Withdrawing will not have any further implications. Please read the important notice below.

IMPORTANT NOTICE:
In case of participating, signing a consent form will be necessary. The consent form also is attached to this invitation. Please note, that data will be pseudonymising immediately after the interviews. Once data has been analysed and findings from the interviews are drawn, it will not be possible anymore to withdraw from the study.

What will happen if I take part?
The interviews will last about 45 minutes. The validating interview and analysis stage then will last about another one to two months from the first interview. After the study is finished a summary will be given to the participants. The meeting will take place in online Webex sessions, recorded by a off-line digital voice recorder.

What do I have to do?
Answer the questions of the interviewer to the best of your knowledge and experience from your working environment.

What are the possible disadvantages and risks of taking part?
No disadvantages and risks have been identified. Please note that your data will be handled anonymously.

What are the possible benefits of taking part?
As a participant you contribute to knowledge. The study outcomes will be made available for the interviewee's interest.

What will happen when the research study stops?
Stopping or finishing the research study will lead to the deletion of all relevant data, which are of critical character after 10 years, in order to have the possibility to further work with the data in a publication.

Will my taking part in the study be kept confidential?
The taking part in the study will be kept absolute confidential. Audio records will be hold pseudonymised and transcribed pseudonymously. Data are saved securely on an extra drive of the University of Portsmouth, which has password protected access.

What should I do if I want to take part?
Please answer to this email to organise a timeslot and location with the researcher. In addition, prior to the participation the consent form needs to be signed. In case you are not sure if you are entitled to take part, you should ask for consent or permission to give consent from your line managers or from a responsible department within your employing company.

What will happen to results of the research study?
The results of this research will only be used for the doctoral thesis, which might be published online in the library sites of the University of Portsmouth. Additionally, to the thesis, there is the possibility given, that there will be publications in journals.

What will happen if I do not want to carry on with the study?
You interview data will be deleted. Nothing else will happen. Please see "Important Notice" on the first page.

Who has reviewed the study?
The study has been approved by Research Ethics Committee of the University of Portsmouth (Faculty BaL), what is part of the approval process for the interview phase.

Further information and contact details

DBA Student:
Sebastian Hartl Sebastian.Hartl@myport.ac.uk

Supervisory Team:
Dr. Jana Ries, Jana.ries@port.ac.uk
Prof. Dr.-Ing. Daniel Palm, Daniel.palm@reutlingen-university.de
Dr. Debbie Reed, debbie.x.reed@port.ac.uk

Thank you for reading the participant information sheet. Date: 14 June 2020
Version: II

Consent form validation:

UNIVERSITY OF PORTSMOUTH

Sebastian Hartl | DBA Portsmouth – Reutlingen Cohort
email Sebastian.Hartl@myport.ac.uk | **mobile** 004916096916886
doc Consent form Validation

(Amendment to ethics application BAL/2018/E531/HARTL, approved on 18.02.2019)

CONSENT FORM

The institution for this research project is the University of Portsmouth – UK. Faculty: Business & Law.

Title of project: A Framework to evaluate the potentials of implementing drones in automotive OEM logistics operations

Name and Contact Details of Researcher: Sebastian Hartl, Sebastian.Hartl@myport.ac.uk

Name and Contact Details of Supervisor: Dr. Jana Ries, Jana.ries@port.ac.uk

Prof. Dr.-Ing. Daniel Palm, Daniel.palm@reutlingen-university.de;

University Data Protection Officer: Samantha Hill, 023 9284 3642 or data-protection@port.ac.uk; Ethics Committee Reference Number: BAL/2018/E531/HARTL Ethics Committee Reference Number: (not available currently)

1. I confirm that I have read and understood the information sheet dated June 9th, 2020 for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time before my pseudonymised data had been analysed without giving any reason. ☐

3. I understand that data collected during this study will be processed in accordance with data protection law as explained in the Participant Information Sheet dated June 9th, 2020 ☐

4. I agree to take part in the above study. ☐

Name of Participant:	**Date:**	**Signature:**
Name of Person taking Consent:	**Date:**	**Signature:**

Note: *When completed, one copy to be given to the participant, one copy to be retained in the study file*

English validation questions (as proposed to ethics committee):

Sebastian Hartl | DBA Portsmouth – Reutlingen Cohort
email Sebastian.Hartl@myport.ac.uk| mobile 004916096916886

(Amendment to ethics application BAL/2018/E531/HARTL, approved on 18.02.2019)

Validation – Interview questions

This document contains a list of questions to validate the results of the interviews and the framework development. The research answers the question how drones could be implemented in the logistics operations of German automotive OEMs.

ENG

Structure and Surrounding Approach

1) What are your thoughts of the DIALOOP framework at the first view, compared to other frameworks you know?

2) What are your thoughts on the 4-step approach? Would you add any steps?
3) What do you think about the trinity – "4 step approach - logistic operations - performance measures and influential changes?
4) Are there any concerns of you about aligning drones in logistics operations with strategy/vision or with changes respectively?

Core structure.

5) What do you think about the logistic operations drones could do?
6) What do you think about the performance they might influence?
7) Which thoughts would you like to add?
8) Which processes or potentials would you like to highlight?

Changes

9) What do you think of the changes?
10) What would you highlight or add to these changes or in the changes?

Scenario
11) Let's us go through a scenario, how could the framework work for you.

a) Starting with the strategy ("to be more competitive, there is a need of modular solutions in OEM logistics operations"), think us through the framework, what could you read from the framework?

b) Strategy is set to use drones in all possible logistics operations. You are in charge to find out where drones could be implemented, and you are in charge to higher that implementation probability. Think about the sections of the influential changes in the framework?

Overall comment

12) What would you generally like to comment on the results of the interview or framework development?

Student:

Sebastian Hartl, Sebastian.Hartl@myport.ac.uk

Supervisory Team:

Dr. Jana Ries, Jana.ries@port.ac.uk

Prof. Dr.-Ing. Daniel Palm, Daniel.palm@reutlingen-university.de

Dr. Debbie Reed, debbie.x.reed@port.ac.uk

Date: June 09th 2020 Version: I

---------------- (End of document "validation interview questions") ------------------

Results overview validation:

UNIVERSITY OF PORTSMOUTH

Sebastian Hartl | DBA Portsmouth – Reutlingen Cohort
email Sebastian.Hartl@myport.ac.uk| mobile 004916096916886
doc Validation interview result overview

Overview Results

DIALOOP FRAMEWORK COMPREHENSIVE APPROACH – „übergreifender Ansatz“ visualisiert

Der Ansatz des übergreifende DIALOOP Framework umfasst aufeinanderfolgende Schritte, wie das Forschungsthema Drohnen in der Intra-Logistik von Automobil OEMs zukünftig bearbeitet werden kann.

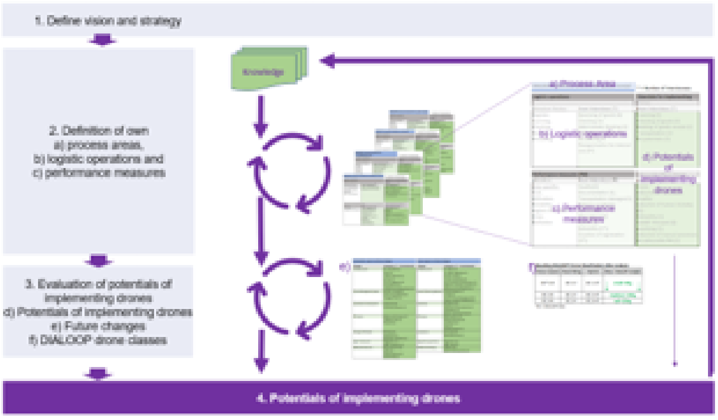


Figure 1 Strategic challenge-oriented use of the DIALOOP framework, Source: The Author

1. Definition Vision und Strategie

2 (a). Definition der Prozessbereiche

2 (b). Definition der logistischen Operationen

2 (c). Definition der Leistungskennzahlen

3 (d). Evaluierung der Potentiale einer Einführung von Drohnen (auf Basis b. und c.)

3 (e). Anwendung der Zukünftigen Veränderungen

3 (f). Anwendung DIALOOP Drohnenklassen

4. Ergebnis „Potenziale zur Einführung von Drohnen“

Page 1 of 5

Kern-struktur DIALOOP visualisiert, Core Structure

Folgende Struktur stellt die Hauptergebnisse dar bezüglich der logistischen Operationen, die von Drohnen dargestellt werden können, sowie die entsprechend von Drohnen adressierbaren Performance Measures.

DIALOOP framework element for 'goods receipt'

* = Number of interviewees
** = some experts didn't give any answer

Common logistic operations	**Potential for implementing drones** from interviews (*)	Common performance measures	**Adressable performance measures by drones** from interviews (*)
Receiving of goods		Time	**Time**
Scanning	**Scanning**	Quality	**Quality**
Checking	**Checking**	Costs	**Costs**
Booking	**Booking**	Flexibility	
Unloading	**Unloading**	Inventory	
	Transportation conrol	Reliability	**Reliability**
Relabeling &	**Relabeling**	Modularity	
		Asset managment	
		Utilisation	
		Scalability	
		Changeability	
		Reconfigurability	
		Safety	
		Controllability	
	No potentials**		**No adressable measures****

Figure 2 DIALOOP framework elements for 'goods receipt', Source: The Author

DIALOOP framework element for 'Storing'

* = Number of interviewees
** = some experts didn't give any answers

Common logistic operations	**Potential for implementing drones** from interviews (*)	Common performance measures	**Adressable performance measures by drones** from interviews (*)
Put-away		Efficiency	
Relabeling		Cost-efficiency	**Cost-efficiency**
Storing		Stock reduction	**Stock transperancy**
Location assignment	**Inventory tacking**	Lead time/speed	**Time/speed**
Replenishment		Area utilisation/filling level	**Utilisation**
Buffering		Delivery reliability	
Transportation		Flexibility	
Releasing from stock	**Delivery of parts (releasing)**		
	Emergency delivery process	Accuracy	
Parking space measuring	**Optimisation of parking space**	Quality	**Error-based measures**
	Checks for completeness	Perfection	
	Checks of warehouse structure	Performance	**Performance**
	Searches for lost loads		
	Box finding		
	Surveillance		
	No implementation**		

Figure 3 DIALOOP framework elements for 'Storing', Source: The Author

DIALOOP framework element for 'Picking&Sequencing'	* = Number of interviewees ** = some experts didn't give any answers		
Common logistic operations	**Potential for implementing drones** from Interviews (*)	Common performance measures	**Adressable performance measures by drones** from Interviews (*)
Delivery to picking line		Equipment utilisation	**Quality**
Picking	**Picking**	Picking accuracy	**Quality**
Handling	**Handling**	Order picked	**Throughput**
Auditing		Cycle time	**Number of empties movement**
Packing		Picking documentation	
Sequencing		Timeliness	**Time**
Delivery	**Parts emergency process,**	Cost-efficiency	
	Data collection	Quality and perfection	
		Damages and lean	
		Scan&labeling quote	
		Layout optimisation	
		Sequecing errors	
		Picking rate	
	No potential**		**No adressable measures****

Figure 4 DIALOOP framework elements for 'Picking&Sequencing', Source: The Author

DIALOOP framework element for 'Delivery to line'	* = Number of interviewees ** = some experts didn't give any answers		
Common logistic operations	**Potential for implementing drones** from Interviews (*)	Common performance measures	**Adressable performance measures by drones** from Interviews (*)
Sheer transportation	**Urgent delivery of supply**	Speed	**Speed**
	Error post-delivery	Time	
	Urgent resupply	On-time delivery	
	Long distance delivery	Costs	
	Non-series material delivery	Inventory	
Line allocation process		Security of supply	
Scheduling shuttle demands		Quality-based	
Parts identification		Efficiency	**Use of existing space**
			Utilisation of transport route
			Degree of automation
	No potentials**		**Flexiblity**

Figure 5 DIALOOP framework element for 'delivery to line', Source: The Author

Zukünftige einflussreiche Veränderungen

Folgende Veränderungen wurden von den Experten identifiziert und können die Implementierung von Drohnen in den logistischen Operationen von Automotive-OEMs beeinflussen.

	Automotive experts on future changes	Drone experts on future changes
Changes	**Categories (* = interviewees)**	**Categories (* = interviewees)**
Infrastructure	Infrastructure adjustments Air corridors Zoning Grids Traffic reduction Carrier adaption Accessability	Use of existing infrastructure Air space Air space regulation Process complexity Process costs
Drone Management	Delivery concept Vehicle management Change of flow	Central Drone Management Communikation Linkage Support-system connection
Automation	Autonomy Actuating elements	Automation Navigation Sensors and Computing
Efficiency	Battery performance Loading cycles Payload	Battery performance Energy efficiency Complexity Costs Standardisation
Acceptance	Mindset Job profile change Employee reduction	Use Cases Board decisions
Legal Action	Regulation Legal framework	Regulation Legal setup
Safety and Security	Noise emission Safety Data protection Downwinds	Safety for working in parallel Controllability by redundancy
Platform development		Drone as a platform Special developments

Figure 6 Graphical comparison of future changes, Source: The Author

Drohnen-Klassifizierung (Optional)

Die Klassifizierung gemäß der DIALOOP Herangehensweise entsprang der Literatur und wurde durch die Interviews leicht abgeändert bestätigt.

Conceptual Framework from literature

Rotor-based	Fixed-Wing	Hybrid	Max. Takeoff-weight
DC* 1-R	DC 1-F	DC 1-HT	small [<2kg]
DC 2-R	DC 2-F	DC 2-HT	medium [<10kg]
DC 3-R	DC 3-F	DC 3-HT	tall [<25kg]

*DC = DIALOOP Class

EASA Framework

Max. Takeoff-weight	Classes	Operation. Subcategory
<250g	C0	A1: fly over people
<900g		
<4kg		A2: fly close to people
<25kg	C3	A3: fly far from people
	C4	

Resulting DIALOOP Drone Classification after analysis

Rotor-based	Fixed-Wing	Hybrid	Max. Takeoff-weight
DC* 1-R	DC 1-F	DC 1-HT	small <4kg
DC 2-R	DC 2-F	DC 2-HT	medium <10kg
DC 3-R	DC 3-F	DC 3-HT	tall <25kg

*DC = DIALOOP Class

Figure 7 Resulting DIALOOP Classification after analysis, Source: The Author partly adopted from EASA (2018)

APPENDIX E, LITERATURE REVIEW SEARCH BACKGROUND

The literature review was conducted by using Portsmouth Library Search, EBSCOhost and Science Direct for most of the duration of the thesis. Furthermore, Google and Google Scholar were used to search for specific sources, which came up during reading the identified sources. At the beginning of the literature search the publication date was limited to a maximum of ten years. Motivation for this limitation was to be able to identify a current state of the research topic and to clarify if the research is justified. For a later search towards a broader basis, for example logistic operations and performance measures no such time-based limiters were used.

During the research phase an overall of 781 sources were saved in the Mendeley library. The themes followed the identified field of drones as well as logistic operations. Yet, besides the focus on the main fields, also sources to nearby research and research topics are counted in this matter.

The researcher acknowledged that the literature findings did rely on the output of the individual search platform. Therefore different platforms were used, and multiple times the same search strings were repeatedly used on other search engines to mitigate that search haziness. In addition, some platforms were restricted by costly monthly payments. In this case, the author tried to get one-month free access to get access to specific sources.

The process of reading the sources at all times started with an evaluation of the title and the abstract. An assessment by the author finalised in relevant work which was carefully read in detail. The relevant literatures' source lists then were screened in addition to evaluation the basis of the work as well as to identify further reading. Mendeley library provided the possibility to gather and structure the sources with regards to the related topics.

This reading procedure also included a rejection of source that did not have any of the defined focuses, either drones, logistic operations, process areas, automotive focus, innovation, future developments or nascent influences into logistics like Industrie 4.0, BTO or modular or smart manufacturing.

The following tables present an overview about the initial search of literature. Hereby, search strings are listed besides the field of the strings, limiters and returns. During the second half of the research, which then mainly focussed on interview gathering and analysis, individual searches with similar string were applied. Overall, the author is aware that possible sources were not included in the searches, yet by using multiple search stings as well as weekly email notifications about the updated on different platforms (during all research phases) it can be assumed that most influential literature was identified. Furthermore, as the author identified, that many authors used similar sources, it can be said, that all reviews literature parts reached a good level of common understanding. Thus, validity in the literature review is given.

An overall of 217 sources are finally used in this research.

All.No.	Search string 1	Fields	Search string 2	Fields	Search string 3	Fields	Data Basis	Limiters Fields Searched	Returns	Returns Saved
1	uav or unmanned aerial vehicle or drones	TI title	logistics	TX all text	automotive	TX all text	Portsmouth Search	Date Published: 20100101-20171231	142	5
2	unmanned aerial vehicles or drones or uav	TI title	production and operations management	TX all text	innovation management	TX all text	Portsmouth Search	Date Published: 20100101-20171230	144	5
3	unmanned aerial vehicles or drones or uav	TI title	logistics	TI title	logistics	none	Portsmouth Search	Date Published: 20100101-20171229	40	2
4	unmanned aerial vehicles or drones or uav	TI title	technology	SU subject terms	logistics	none	Portsmouth Search	Date Published: 20070101-20171229	10	1
5	unmanned aerial systems	TI title	technology		logistics	none	Portsmouth Search	Date Published: 20070101-20171229	35	2
6	unmanned aerial vehicles or drones or uav	TI title	review	TI title		none	Portsmouth Search	Date Published: 20070101-20171229	165	2
7	international journal of production economics	none	unmanned aerial vehicles or drones or uav	none	automotive	none	Portsmouth Search	Date Published: 20070101-20171229	266	2
8	Production and Operations Management	none	unmanned aerial vehicles or drones or uav	none	automotive	none	Portsmouth Search	Date Published: 20070101-20171229 >>Academic journals only >>plenty of other subject left away	115	2
9	Unmanned aerial vehicles	none	automotive	none		none	ScienceDirect	2006 and (Unmanned aerial vehicles) and Automotive AND LIMIT-TO(topics, "control,univ,system,vehicle,world congress,power,control system,design,robot,result,tech,battery") AND LIMIT-TO(contenttype, "JL,BS","Journal").	61	0
10	unmanned aerial vehicles or drones or uav	TI title	technology	TI title	relevance or importance or impact	none	Portsmouth Search	Date Published: 20070101-20171229	158	3
11	transportation or logistics	TI title	technology future		automotive industry	TI title	Portsmouth Search	Date Published: 20070101-20171229	27	1
12	drones or uav or unmanned aerial vehicles	TI title	manufacturing	TI title		none	Portsmouth Search	none	41	

All.No.	Search string 1	Fields	Search string 2	Fields	Search string 3	Fields	Data Basis	Limiters Fields Searched	Returns	Returns Saved
13	manufacturing logistics	none	drones or uav or unmanned aerial vehicles	none		none	Portsmouth Search	Date Published: 20070101-20171229,Journals only Subjects: drone aircraft, technological innovations, research, automation, unmanned aerial vehicles, logistics, production planning, robotics, decision making, manufacturing processes, simulation methods & mode, robots, big data, supply chain management	217	0
14	uav or unmanned aerial vehicle	AB	limits and potentials	AB	manufacturing	none	Portsmouth	none	4	
15	uav or unmanned aerial vehicle or drones	AB Abstract	limits and potentials	AB Abstract		none		Date Published: 20070101-20171229; academic journals	17	1
16	unmanned aerial vehicles or drones or uav	AB Abstract	manufacturing	AB Abstract		none	Portsmouth Search	Date Published: 20070101-20171229; academic journals	109	1
17	unmanned vehicles	AB Abstract	manufacturing	AB Abstract	logistics	none	Portsmouth Search	Date Published: 20070101-20171229; academic journals	5	1
18	manufacturing technology	AB Abstract	logistics	AB Abstract	innovation	AB Abstract	Portsmouth Search	Date Published: 20070101-20171229; academic journals	68	
19	uav or unmanned aerial vehicle or drones	AB Abstract	process innovation	AB Abstract			Portsmouth Search	Date Published: 20070101-20171229; academic journals	59	1
20	uav or unmanned aerial vehicle	AB	process management	AB			Portsmouth	Date Published: 20070101-20171229; academic	194	1
21	suav or small unmanned aerial vehicle or drones	AB Abstract	human-robot interaction	AB Abstract			Portsmouth Search	Date Published: 20070101-20171229; academic journals	6	0
22	quadrotor	AB Abstract	autonomous	AB Abstract	process management	AB Abstract	Portsmouth Search			
23	quadrotor	AB	autonomous	AB	review		Portsmouth	Date Published: 20070101-20171229; academic	30	0
24	unmanned aerial vehicle or unmanned aircraft system or unmanned aerial system or drone or uav or uas	AB Abstract	autonomous	AB Abstract	review		Portsmouth Search	Date Published: 20090101-20171229; academic journals	288	6
25	unmanned aerial vehicle or unmanned aircraft system or unmanned aerial system or drone or uav or uas	AB Abstract	operations research	AB Abstract			Portsmouth Search	Date Published: 20090101-20171229; academic journals Source Types: Academic Journals, Conference Materials Subject: unmanned aerial vehicles, uav, unmanned aerial vehicle, remotely piloted vehicles, research, aircraft, human, robotics, uavs, automation, operations research, robust control, technological innovations, simulation methods & mode, uas	83	6
26	innovation	TI title	assessment	TI title	Technology	TI title	Portsmouth Search	Date Published: 20070101-20171231 Source Types: Academic Journals, Dissertations/Theses, Conference Materials Subject: technological innovations, assessment, technology assessment, innovation, technology, technology innovation, management, research & development, automated assessment, high technology, impact assessment, multicriteria decision, technological innovation, assessment	85	5

All.No.	Search string 1	Fields	Search string 2	Fields	Search string 3	Fields	Data Basis	Limiters Fields Searched	Returns	Returns Saved
27	review	AB Abstract	innovation assessment	AB Abstract	model or theory or framework	AB Abstract	Portsmouth Search		18	0
28	innovation	TI title	assessment	TI title	model or theory or framework	AB Abstract	Portsmouth Search	Limiters Date Published: 20070101-20171231 Subject: innovation, technological innovations, assessment, evaluation, innovation management, innovations in business, risk assessment, technological innovation, qualitative research, technology, business, technology assessment, impact assessment,	243	2
29	success factors	TI title	technology	TI title	model	TI title	Portsmouth Search		19	3
30	success factors	TI title	innovation	TI title	implementation or implementing or adoption or acceptance	TI title	Portsmouth Search		22	
31	business process management	AB	innovation	AB	Logistics	AB	Ebsco	01.01.2007-31-12-2017	141	3
32	innovation	AB	logistics	AB			Ebscohost	01.01.2007-31-12-2017 , only disertations	122	2
33	factors driving innovation in logistics						Ggoogle Scholar			
34	business process	AB	logistics and supply chain	AB	assessment tools or	AB	Ebscohost	01.01.2007-31-12-2017	85	7
35	business process	AB	innovation management	AB	assessment tools or assessments or rating or evaluation	AB	Ebscohost	01.01.2007-31-12-2017, only dissertations	47	1
36	review or meta-analysis or metareview or meta-review or meta review or literature review	AB	business process	AB	innovation	AB	Ebscohost	01.01.2007-31-12-2017	534	
37	success*	SU	logistic*	SU	frame*	SU	Ebscohost		24	4
38	logistic*	SU	innovat*	SU	frame*	SU	Ebscohost		47	5
39	logistic*	SU	manufact*	SU	frame*	SU	Ebscohost		98	6
40	logistic*	SU	unmanned AND aerial AND vehicles	SU			Ebscohost		37	1
41	uavs or drones or unmanned flying vehicles	SU	logistic*	SU			Ebscohost		93	
42	framework or model or theory	SU	manufacturing process*	SU	logistic*	SU	Ebscohost	01.01.2007-31-12-2017	264	8
43	Robot skills for manufacturing: From concept to industrial deployment		M. R. Pedersen						253	5
44	logistic*	AB	technolog*	AB				01.01.2007-31-12-2017		

All.No.	Search string 1	Fields	Search string 2	Fields	Search string 3	Fields	Data Basis	Limiters Fields Searched	Returns	Returns Saved
45	assembly	AB	logistic*	AB	unmanned aerial vehicles or drones or uav	AB			7	
46	Unmanned aerial vehicles	TI, AB, Key	logistics	TI, AB, Key			Science Direct	01.01.2007-31-12-2017	3	0
47	Unmanned aerial vehicles	AB	transportation	AB			Science	01.01.2007-31-12-2017	12	
48	drones or uav or unmanned aerial vehicles	AB	transportation	AB			Ebscohost	01.01.2007-31-12-2017; Conference material, Journal Articles; subject: transportation	28	
49	logistic*	TI	model or theory or framework	TI					238	6
50	intralogistic*	TI	model or theory or framework	TI			Ebscohost		6	3
51	logistic*	TI	model or theory or framework	TI			Ebscohost		100	
52	business process*	AB	"logistic"	AB	Automo*	AB	Ebscohost	Academic, Conference and Journals	65	
53	business proces*	AB	uav* or unmanned aerial vehicle or drones	AB			Ebscohost	Academic, Conference and Journals	34	
54	review	TI	framework or model or theory	TI	logistic*	TI	Ebscohost		96	
55	logistic operation*	AB	conceptual framework	AB			Ebscohost			
56	Framework or model or frame*	SU	Logistic* operation*	SU	drone or UAV or unmanned aerial vehicle	SU	Ebscohost		2	0
57	Framework or model or frame*	AB	Logistic* operation*	AB	drone or UAV or unmanned aerial vehicle	AB	Ebscohost		17	0
58	Framework or model or frame*	TI	Logistic* operation*	AB	Automo*	AB	Ebscohost	01.01.2007-31.12.2018	21	1
59	Framework or model or frame*	TI	Logistic* operation*	AB	Automo*	AB	Ebscohost	01.01.2007-31.12.2018	139	0
60	Framework or model or frame*	TI	Logistic* operation*	TI			Science	01.01.2007-31.12.2018	11	2
61	uav or unmanned aerial vehicle or drones	AB	logistic* operation*	AB			Ebscohost		97	3
62	OEM or original equipment manufacturer	AB	logistic* operation*	AB			Ebscohost	01.01.2000-31.12.2018	95	1
63										
64	OEM	AB	Logistic*	AB	framework*	AB	Ebscohost		28	1
65	in-house	AB	Logistic*	AB	framework*	AB	Ebscohost		79	2
66	SCOR Model	AB	Logistics	AB			Ebscohost		130	5
67	SCOR Model	AB	Automotive	AB			Ebscohost		10	2
68	supply chain operations reference model	TI					Ebscohost		46	

APPENDIX F, CODES FROM THE INTERVIEWS

The following appendix lists the themes, categories and codes that were used in the interviews. If examples would be needed, appendix F clusters the quotes to either themes or even categories.

For defining the logic on themes, categories and codes, two examples are shown:

Automotive Interviews

The automotive interview codes follow the structure of the interview questioning (appendix C). Hereby there are structural nodes above all content-relevant nodes, like “04 Process areas inhouse” that summarise all answers regarding this area of interest. Further clusters are shown as:

Theme: “041 Goods receipt”

Category: “0416 Performance measures influenced by drones”

Code: “04161 (2) Speed of handling”

Drone Interviews

The drone interview codes follow the structure of the interview questioning (appendix C). Hereby there are structural nodes above all content-relevant nodes, like “03 Rotor-based drones” that summarise all answers regarding this area of interest. Further clusters are shown as:

Theme: there are “033 Disadvantages [regarding] rotor-based drones”

Category: “0331 Flight behaviour”

Code: “03313 Flight distance and range”

The coding also presents a note, in which the statement firstly occurred. In the example from automotive the code “04161 (2) Speed of handling” contains a “(2)”: this indicates, in which interview the code was mentioned the first time (if no number occurs, the answer was given in the first of each set of interviews). On basis of these notes, the author was able to conclude about a saturation in both sets of interviews.

2020	Codebook	Description	Interview files	References
DBA Sebastian Hartl, Automotive Interviews Code Structure				
01 Participant information		Information about interviewee to ensure rightfulness of participation	0	0
	011 Experience	Experience ensures that participant meets requirements	10	10
	012 Academic background	Academic background ensures that participant meets requirements	9	9
	013 Current position	Current position informs the participation requirements	10	10
	014 Current processes in working environment	Participant describes processes and validates participation requirements	2	2
02 Knowledge to drones		Summarises knowledge of automotive experts to drones	0	0
	021 Known types of drones	Summarises known types of drones	1	1
	0210 (2) Type and company nomenclature	Experts know drones by type	2	2
	0211 Rotor-based	Experts know rotor-based drones	10	17
	0212 Fixed wing systems	Experts know fixed wing drones	7	9
	0213 Hybrid solutions	Experts know hybrid solutions	4	7
	021x Differentiations not known	Experts can not differentiate between different drones	4	4
	022 Differentiation by application	Experts differ drones by the application they are used for	1	1
	0221 Transportation	Drones are used for transportation	3	4
	02211 (3) Transportation Postal Service	Drones are used for postal services	1	1
	02212 (3) Medical supply	Drones are used to medically supply	1	1
	02214 (3) Air taxi	Drones are used as aerial taxis	2	2
	02215 (8) Transportation in case of rework	Drones are used in case of transportation towards rework	1	2
	0222 Information gathering	Drones are used for information gathering	1	1
	02221 (2) Inventory	Inventory is tracked by drones	3	3
	02222 (2) Quality investigations	Drones do quality checks	1	1
	02223 (2) Building investigations	Drones do certain inspections on buildings	2	2
	02224 (3) Stock control empties	Drones are used to control the stock of empties	3	3
	02225 (5) Recognition of RFIDs	Drones can recognise RFIDs	2	2
	02226 (5) Current situation of buildings	Drones do check the situation of buildings	1	2
	0223 No application known	The experts do not know about any drone application	2	2

Table, part 1 of 22

024 Application Automobile-Inhouse-Logistic	Automotive experts name key facts about application of drones in automotive inhouse logistic environment	1	1
0241 Requirements	Requirements named for drones to be applicable	1	3
02411 (3) Landing space in hall	Landing space must be provided for drones	2	2
02412 (3) Corridors	Corridors must be present for drones	1	1
02413 (4) Reliability of technology	Drone technology has to be sufficiently reliable	1	1
02414 (4) Availability	Drones have to be available in case of need	1	1
02415 (4) Flight stability	Flight stability of drones has to be granted	1	1
02416 (7) Efficiency	Drones have to be efficient enough for the usage	1	1
02417 (7) Omni directional behaviour	Drones have to be able to fly in every direction	1	1
0242 Challenges	Challenges general named for applying drones	1	1
02421 (2) Law	Law restrictions hinder drone application	3	3
02422 (2) Performance	Performance of drones is currently not sufficient	4	4
02423 (2) Safety	Safety has to be guaranteed	5	8
02424 (3) Process reliability	Drone need to be reliable regarding the processes	2	2
02425 (4) Limited space	Limited space hinders the application of drones	3	3
02426 (4) Noise	Drones produce extreme noise	1	1
02427 (5) Capacity	Drones have a low capacity	2	2
0243 Advantages	Advantages that drones have	0	0
02421 (3) Precise steering	Drones can be steered very precisely	1	1
02422 (3) Precise flight behaviour	Drones flight is very precise	1	1
02423 (3) Positioning	Drones are very good in positioning	1	1
02434 (6) Using of 3D space	Drones can use the existing 3D space	1	1
03 Classification	Automotive experts discuss the classification of drones from their perspective	0	0
030 Usage of a classification	Experts talk about why a classification can be used	7	14
031 Known classifications	Experts give some classifications that the know or could imagine	0	0
0311 (2) Use case or process	Experts differ drones by their use case or to certain processes	2	2
0312 (2) Type	Experts differ drones by type	2	2
0313 (3) Weight	Experts differ drones by weight	4	4
0314 (2) Performance	Experts differ drones by performance	1	1
0315 (2) Speed	Experts differ drones by speed	1	1
032 Evaluation of classification at hand	Experts talk about the proposed classification of the author, which was derived from literature	1	1
0320 (2) Good	Experts think the classification is good	3	3
0321 Possible additions	Experts have some additions	1	2

Table, part 2 of 22

03211 Danger differentiation Safety classes	The addition could be a safety classification	1	4
03212 Indoor-Outdoor differentiation	Addition could be indoor and outdoor differentiation	3	6
03213 (2) Change in weight limits	From the existing classifications the expert suggest to change the weight limits towards EASA	1	1
03214 (3) Addition of Helicopters and small planes	Addition could be towards helicopters and planes	1	1
03215 (7) Addition bigger classes	Bigger classes of drones could be added to the classification	1	1
034 not able to classify	The expert is not able to classify drones	1	1
04 Process areas Inhouse	This theme summarises existing process areas in the opinion of the experts	0	0
040 Overall to processes	Experts opinion on processes, performance measures and differentiation possibilities	0	0
0401 Known processes	All process that the experts mentioned from their understanding of the research area	2	2
04010 (2) Disposition und ordering (in)	Disposition and ordering is part of the automotive OEM logistics operations process	3	6
04011 Goods receipt	Goods receipt is part of the automotive OEM logistics operations process	9	14
04012 Storing	Storing is part of the automotive OEM logistics operations process	7	12
04013 Picking and Sequencing	Picking and Sequencing is part of the automotive OEM logistics operations process	7	10
04014 (2) Delivery to line or value add	Delivery to line or value add is part of the automotive OEM logistics operations process	7	12
04015 Car shipping Outbound (in)	Car shipping is part of the automotive OEM logistics operations process (yet out of scope)	4	5
04016 (2) Empties	Empties return is part of the automotive OEM logistics operations process (yet out of scope)	3	6
0402 Performance measures named	Experts name performance measures which are in their mind regarding the research area	1	4
04021 (2) Quality	Quality can be of product, process or packaging	3	5
04022 (2) Throughput	Throughput refers to amount of goods or products which are going through the process area	4	6
04023 (2) Efficiency_	Efficiency relates to logistic operations in the research area	8	12
04024 (2) Costs	Costs describe the logistic costs, transportation costs, vehicle costs	5	7
04025 (2) Effectiveness	Effectiveness related to the logistic process	8	11
04026 (3) Security of supply and days of inventory	Describes the ratio of missed supplies to ideal supply and how many days goods are in stock	6	10
04029 (5) Time	Time related how long a logistic process needs to be done	4	9
0402X Themes regarding Differentiation	Differentiation summarises certain methods how OEMs differ from other OEMs	2	2

	0402x1 Transparency	Transparency has to be given over all process areas	2	2
	0402x2 Gamification	Logistic operations could be part of certain gamification initiatives	1	1
	0402x3 (2) Flexibility	Flexibility can be a differing character	1	1
	0402x7 (4) Culture and employees	Culture and the opinion of employees can be a differing character	2	3
	0403x4 (2) Innovativeness	Innovativeness can be a differing character	1	1
	0403x5 (2) Mutability	Mutability can be a differing character	1	1
	0403x6 (3) Sustainability	Sustainability can be a differing character	1	1
	0403x7 (5) Perfectness	Perfectness can be a differing character	3	4
	0403x8 (5) Digitalisation	Digitisation can be a differing character	1	2
	0403 Process separation	Describes different elements of logistic operations	0	0
	04031 Transport vs. Information processes	Transportation and information gathering processes are the two elements	1	1
	04032 Rating of process separation	Rating differs both elements	2	4
041 Goods receipt		Summarises main operations, performance measures, drones operations and drone implementation for goods receipt	0	0
	0411 Main operations goods receipt	Main operations the experts see in goods receipt	0	0
	04111 Transfer of goods and customs	Goods are transferred from the carrier to the OEMs yard	6	6
	04112 Registration and labeling	Goods are registered in the system and labelled for internal transportation or destination	7	8
	04113 Unloading	Goods are physically unloaded from the truck	5	6
	04114 Quality checking	Goods, packages or boxes are checked for quality	5	6
	04115 Relabelling for internal transportation	Goods are labeled for internal transportation	4	4
	04116 (3) Payment triggering	Payment is triggered in the OEM system towards the supplier as goods are received	1	1
	0412 Performance measures goods receipt	Main performance measures in goods receipts which are seen by the experts	0	0
	04120 no answer	Expert didn't give any answer	2	2
	04121 Quality	Quality of goods received, often in parts per million	4	5
	04123 Delivery date	Does the supplier or carrier deliver on time	3	3
	04124 (2) Completeness	Is the delivery complete or are goods mission	1	1
	04125 (2) Throughput	How many goods are received in one day	4	7
	04126 (3) Registration duration and durability	Duration of receiving process	4	4
	0413 Crucial processes in goods receipt	Summarise processes with some potential of change	0	0
	04130 No answer, not known	Experts didn't answer or didn't know any	2	3
	04131 (2) Labeling processes	Labeling process has lot of potentials	2	2
	04132 (4) Overall automation	Automation has lot of potentials	3	3

Table, part 4 of 22

04133 (6) Voucherless goods receipt	Voucherless goods receipt has lot of potentials	3	4
04134 (7) Accurate tracking	Accurate tracking has lot of potentials	1	1
0414 Drone-rating goods receipt (in)	Experts rating of drones being applied in this process area based on communication support paper	4	10
04141 Rotor-based	Rating on rotor-based drones	9	19
04142 Fixed Wing	Rating on fixed-wing drones	9	16
04143 Hybrid	Rating on hybrid drones	8	10
04144 (6) none	No rating done by experts	3	4
0415 Drones in goods receipts	Summarise operations for drones and performance measures that could be influenced	0	0
04151 Operations for drones	Experts name operations that could be done by drones in goods receipt	1	1
041511 (2) Checking of goods	Checking of goods could be done by drones	3	5
041512 (2) Labeling	Labeling could be done by drones	1	1
041513 (4) Transportation and control	Transportation and control of transports could be done by drones	2	3
041514 (7) Booking and registering goods receipt	Booking and registering could be done by drones	2	3
04152 (6) none	No answer given by the expert	3	4
0416 Performance measures influenced by drones	Summarise the experts answers to performance measures that could be influenced by drones	0	0
04128 (4) Reliability	Reliability could be influenced by drones	1	1
04161 (2) Speed of handling	Speed of handling could be influenced by drones	4	8
04162 (2) Checking quality completeness	Checks for quality and completeness could be influenced by drones	2	2
04163 none	No answer given by the expert	2	2
0419 Alternatives to drones	Experts mention alternative technologies	2	2
042 Storing	Summarises main operations, performance measures, drones operations and drone implementation for Storing	1	2
0421 Main operations in storing	Main operations the experts see in Storing	0	0
04211 Relabelling	Goods are relabelled	1	1
04212 Storing	Goods are stored in the storing area	7	11
04213 Release from stock	Goods are taken out of the storing area and delivered	4	4
04216 (2) Transportation	Goods are transported within the area	2	2
04217 (3) Buffering	Goods are stored in buffers	4	6
0422 Performance measures Storing	Main performance measures in storing which are seen by the experts	1	2
04220 Speed	Storing, transportation and release fastness are a performance measure	2	3
04220a Damages	Ratio of damaged goods in storing are a performance measure	1	1
04220b Throughput and throughput time	Throughput as well as throughput time are a performance measure	2	3

Table, part 5 of 22

04221 (2) Outsourcing of storing structures	Outsourced structures numbers are a performance measure	5	6
04223 (4) Wrong storing	Number of wrong storing are a performance measure	1	1
04224 (4) Wrong labeling and delivery	Wrong labels and wrong delivery are a performance measure	2	2
04235 (6) Range	Range is a performance measure	2	2
0423 Crucial processes in Storing	Summarise processes with some potential of change	1	1
04231 Ergonomics topics	Ergonomic is of high potential in storing	1	1
04232 Workspace Human machine interaction	Interaction is high potential in storing	1	1
04233 (7) Automation	Automation has lot of potentials	2	4
0424 Drones rating in Storing	Experts rating of drones being applied in this process area based on communication support paper	2	6
04241 Rotor-based	Rating on rotor-based drones	9	24
04242 Fixed Wing	Rating on fixed-wing drones	9	22
04243 Hybrid	Rating on hybrid drones	9	13
0425 Drones in Storing	Summarise operations for drones and performance measures that could be influenced	0	0
04251 Operations for drones in Storing	Experts name operations that could be done by drones in Storing	1	1
042511 (2) Inventory	Inventory tracking could be done by drones	5	6
042512 (2) Checks for completeness	Checks of completeness could be done by drones	2	3
042513 (2) Optimisation storing locations	Optimisation of storing locations could be done by drones	1	1
042514 (3) Emergency or urgent delivery	Emergency delivery could be done by drones	2	4
042515 (3) Search for parts and carriers	Part and carrier searches could be done by drones	2	2
042516 (3) Delivery of parts and carriers	Part and carrier delivery could be done by drones	1	1
042518 (4) Surveillance and sensors	Surveillance could be done by drones	2	4
042519 (5) No operations	Experts didn't give any operations that could be done by drones	5	8
04252 Performance measures influenced by drones in Storing	Summarise the experts answers to performance measures that could be influenced by drones	0	0
042521 Filling level, capacity and utilisation	Filling level can be measures by drones	3	5
042522 (2) Stock transparency	Stock transparency can be measures by drones	3	4
042523 (2) Speed and time	Speed can be enhanced by drones	5	9
042524 (2) Costs and efficiency	Costs and efficiency can be enhanced by drones	2	3

042525 (4) Reduction of mistakes	Reduction can be enhanced by drones	2	2
042526 (6) Floor space requirement	Floor space requirements can be enhanced by drones	1	2
0429 Alternatives to drones	Experts name alternative technologies	1	4
043 Picking and Sequencing	Summarises main operations, performance measures, drones operations and drone implementation for picking and sequencing	0	0
0431 Main operations Picking and Sequencing	Main operations the experts see in Picking and Sequencing	0	0
04312 (3) Provision in the right order	Parts are provided in the right order or sequence	6	6
04313 (4) Placement on Picking-space	Parts are fetched from storing and placed in picking space	3	3
04314 (5) Gathering of shopping cart and pure picking	Parts are picked from storing into shopping carts	4	4
04315 (7) Delivery to place of use	Parts are delivered to place of use	1	1
0432 Performance measures in Picking and Sequencing	Main performance measures in Picking and Sequencing which are seen by the experts	1	1
04321 (2) Speed and throughput	Speed and throughput are seen as main performance measures	3	4
04322 (2) Cost reduction	Cost reduction is seen as main performance measures	1	1
04324 (4) Sequencing mistake	Sequencing mistakes are seen as main performance measures	3	5
04325 (5) Picking rate	Picking rate is seen as main performance measures	3	5
04326 (7) Areal utilisation	Areal utilisation is seen as main performance measures	1	1
0433 Crucial processes in Picking and Sequencing	Summarise processes with some potential of change	0	0
04331 Manual picking	Manual processes have potentials for change	2	2
04332 (2) Scanning processes	Scanning processes have potentials for change	1	1
04333 (2) Labeling processes	Labeling processes have potentials for change	1	1
04335 (4) Automation overall	Automation overall has potentials for change	4	4
04336 (5) Increase of flexibility	Increase of flexibility has potentials for change	1	1
04337 (7) Plant areal full		1	1
0434 Drone rating Picking and Sequencing	Experts rating of drones being applied in this process area based on communication support paper	0	0
04341 Rotor-based	Rotor-based drones are rated	9	14
04342 Fixed Wing	Fixed wing drones are rated	6	7
04343 Hybrid	Hybrid drone are rated	5	6
04344 No application	No rating done by experts	4	4

0435 Drones in Picking and Sequencing		0	0
04351 Operations possibly done by drones	Experts name operations that could be done by drones in Picking and Sequencing	0	0
043512 (3) Picking of parts	Picking of parts can be done by drones	3	3
04352 (5) Post and urgent delivery	Urgent delivery can be done by drones	2	2
04353 (4) Information gathering through sensors	Information can be gathered by drones	1	3
04354 (4) No tasks	No tasks were identified for drones	2	3
04352 Performance measures influenced by drones	Summarise the experts answers top performance measures that could be influenced by drones	0	0
043520 (4) None	No performance measures could be influenced by drones	2	2
043521 (2) Provision quality	Provision quality could be influenced by drones	2	2
043522 (2) Throughput	Throughput could be influenced by drones	1	1
043523 (3) Time effort	Timeliness could be influenced by drones	4	4
043524 (3) Number of empties movement	Number of empties movement could be influenced by drones	1	1
043525 (6) Part kilometres or ton kilometres	Parts kilometres could be influenced by drones	1	1
044 Delivery to line	Summarises main operations, performance measures, drones operations and drone implementation for Delivery to line	0	0
0441 Main operations Delivery to line	Main operations the experts see in Delivery to line	2	2
04411 (3) Transportation	Transportation are seen as main operation	5	6
04412 (2) Handover or provision at point of value creation	Handover or provision are seen as main operation	3	3
0442 Performance measures in Delivery to line	Main performance measures in delivery to line, which are seen by the experts	0	0
04431 Stock level	Stock level is seen as main performance measures	1	1
04432 Adherence on delivery dates	Describes how suppliers stick on delivery dates	5	5
04432 (2) Costs	Contains all cost of delivery to line process	1	1
04433 (3) Security of supply	Security of supply must be given in the delivery to line process	2	2
04434 (3) Delivery quality	Quality is given if right products are delivered at the right price at the right time	2	2
04434 (4) Time	Delivery and handling must be done in less time as possible	2	2
04435 (4) Efficiency	Delivery must be as efficient as possible	2	3
0443 Crucial measures in Delivery to line	Summarise processes with some potential of change	1	2
04431 (2) Automation material handover	Automation is of high potential	1	1

04432 (5) Complexity and variance	Reduction of complexity and variances of products and processes can have potentials	2	3
04433 (6) Reduction error rate	Reduction of errors can have potentials	2	2
04434 (10) Urgent delivery	Urgent deliver processes can be optimised	1	1
0444 Drone rating in Delivery to line	Experts rate drones for the delivery to line process	1	1
04441 Rotor-based	Rating on rotor-based drones	7	17
04442 Fixed Wing	Rating on fixed-wing drones	6	8
04443 Hybrid	Rating on hybrid drones	4	9
04444 (4) No application	Experts don't see any application	2	3
0445 Performance measures influences by drones in Delivery to line	Summarise the experts answers to performance measures that could be influenced by drones	1	4
04451 Operations	Experts name operations that could be done by drones in Delivery to line	0	0
04451 Delivery process or resupply	Drones can take over the delivery process	4	4
044511 (4) no tasks	Drones do not have any tasks in Delivery to line	1	1
044513 (8) non-series material partly	Drones could take over delivery of non-series material	1	3
04452 Performance measures influenced by drones	Summarises all performance measures named by experts	0	0
044521 (2) Utilisation transportation ways	The utilisation of the transportation ways between storing and picking can be higher	3	5
044522 (2) Speed	Relevant aspects to speed of drones influencing delivery to line	5	8
044523 (6) Area utilisation	Relevant aspects of areas utilisation in delivery to line e.g. usage of area above machines	2	2
044524 (6) Turnover	Relevant aspects of turnover in delivery to line which are done by drones	1	1
044525 (7) Widening of supplier reach in JIS	Relevant aspects of supply especially in emergency resupply e.g. with faster supply the suppliers can be farer away	1	1
045 Others, car delivery outdoor storage (out of process scope)	Experts mention car storage as other areas for drones	0	0
0451 Operations drones	Summarises operations for drones in car delivery storage	1	2
04512 (9) Inspection	Inspection of car storage can be done by drones	1	1
0454 Drone Rating in Delivery to line	Experts rating of drones being applied in this process area based on communication support paper	0	0
04541 Rotor	Rotor-based drones are rated	3	7
04542 Fixed Wing	Fixed wing drones are rated	2	4
04543 Hybrid	Hybrid drone are rated	2	5

046 Others (2) Empties management process (out of process scope)	Experts mention empties management as other areas for drones	0	0
0461 Operations	Summarises drone operations in empties management	0	0
04611 (2) Same as Delivery but the other way round	Processes describes as bringing the boxes away from line	2	2
04612 (5) Empties coverage	Empties are counted and position located	3	3
04613 (6) Complete process	Empties gathering, transportation and stacking as well as counting	3	5
0462 Drone Rating	Experts rating of drones being applied in the process area of empties management	0	0
04621 Rotor	Rotor-based drones are rated	2	5
04622 Fixed Wing	Fixed wing drones are rated	2	2
04623 Hybride	Hybrid drone are rated	1	2
04624 (4) no tasks	Experts don't see any application	1	1
0463 Performance measures influenced by drones in Empties processing	Summarise the experts answers to performance measures that could be influenced by drones	0	0
04631 (4) Empties counting	Drones fly around and count empties from the air	1	2
04632 (6) Headcount	Drones can reduce headcount of employees counting empties currently	1	1
05 Future Changes	Experts mention changes that could influence the implementation of drones	0	0
051 Infrastructure	Summarises changes of infrastructural concerns	0	0
0511 Aerial corridors	Aerial corridors between machines or between drones and employees	5	10
0512 Influences of production	Production paradigms could change drone usage	1	1
0531 (2) Modular paradigm_	Refer to modular paradigm influencing infrastructural concerns in logistic operations	6	11
0513 Adjustment carriers and parts	Refers to carriers and parts adjustments as infrastructural change influencing drone implementation e.g. parts become lighter	4	7
0514 Adjustment or creation of start and landing space	Starting and landing spaces influence drone implementation from infrastructural aspect	1	1
0515 Ensure accessibility of drones	Refers to accessibility of drones within the plant space to fulfil the required job	3	3
0516 Adjustment infrastructure	Refer to multiple further adjustments of infrastructure	3	6
052 Drone Management system	Summarises changes towards a drone management system	0	0
0521 Enablement of comprehensive drone delivery concept	Refers to the establishment of a comprehensive concept for drones in the research area	2	2

Table, part 10 of 22

0522 Enhance flexibility	Refers to changes in flexibility by implementing drones including a system	1	1
0523 (6) Central traffic management	Refer to a central traffic management system where drones are management besides other vehicles	2	7
0524 (7) Change of flow	Refers to change of flow to implement drones in existing areas	2	3
053 Automation development	Summarises categories to automation development which influences drone implementation	0	0
0531 (3) Development of actors and handling	Refers to development of actors and handling systems regarding automation	2	3
0519c (6) Form fit to goods	Refers to form fit between goods and drones for automation concerns	1	1
0519d (6) Standardised interface	Refers to standard interfaces between drones and other elements of the plant	1	1
0532 Autonomy	Refers to autonomy as the highest level of automation	6	14
054 Social Changes	Summarises categories of social changes influencing drone implementation	0	0
0541 Image	Refers to image changes of drones towards automotive use potentials	1	2
0542 Mindset of employees	Refers to the change of employees mindsets to accept drones and not being afraid any more	2	3
0543 Adjustment of job profiles	Refers to adjustment of jobs profiles from operations to controlling drones doing the operations	1	1
0544 (2) Reduction of employees	Refers to reduction of employees as a social change, leading to more flyable areas	1	1
055 Efficiency	Summarises categories of efficiency that could influence drone implementation	0	0
0551 Battery duration and range	Refers to battery duration and resulting range of drones	6	9
0552 Payload	Refers to payload concerns, that drones can handle, drones could get better or goods get lighter	6	9
055 Legal Framework	Summarises categories of legal concerns that influence drone implementation	0	0
0551 Authorities and regulations	Refers to authority and regulation specialised on drone usage and flight permission	4	8
056 Safety and Security	Summarises safety and security concerns that need to be solved	0	0
0561 Data protection	Refers to data security, that can influence drones	1	1
0562 Environment protection	Refers to environmental protection, so drones to not harm anybody or anything	1	2
0563 Noise and downwind reduction	Refers to the matter of noise that is produced by drones	5	8
0564 Safety	Refers to overall safety concerns to drone implementation	8	17

	057 (5) no changes	Experts see not significant changes that influence the implementation of drones	3	3

DBA Sebastian Hartl, Drone Interviews
Code Structure

01 Participant Information	Summarises the participant information of drone interviews	0	0
011 Experience with drones	Refers to the experience of the experts with drones	9	9
012 Academic Background	Refers to academic background of drone experts	9	9
013 Current Position	Refers to the current position of the drone experts	9	11
014 Familiarity w. Automotive Logistics	Summarises the familiarity of the drone experts with automotive logistics process landscape	0	0
0141 marginal	Refers to marginal process knowledge	4	4
0142 (2) not familiar	Experts mention not to be familiar with processes	1	1
0143 (3) very familiar	Experts mention to be very familiar with processes	1	1
0144 (5) partly familiar	Experts mention to be moderate familiar with processes also from projects	2	2
02 Knowledge to drones	Summarises the experts' knowledge to drones	1	1
021 Known Types	Summarises different named types	2	2
0210 Type nomenclature	Experts mention type nomenclature	3	6
02101 (1) Weight	Experts know drones types by different weight	1	1
0211 (2) VTOLs	Experts know VTOL drones	3	3
0212 (2) Fixed Wings	Experts know fixed-wing drones	5	6
0213 (2) Rotor-based	Experts know rotor-based drones	6	7
0214 (3) Hybrids	Experts know hybrid drones	3	3
022 Characteristics in general	Summarise mentioned characteristics in general	2	4
0221 (4) Advantages	Refer to advantages of drones	2	3
0222 Disadvantages	Refer to disadvantages of drones	2	5
02221 (4) Workers compensation board	Refer to difficulties with workers compensation board if applying drones	1	1
02222 (4) Need for instructions	Refer to needed instructions is using drones	1	1
02223 (1) GPS denied environment	Refer to current difficulties in GPS denied environment	1	1
024 Overall classification of drones	Summarise themes to classification of drones following the drone experts	1	2
0241 Known classes	Summarises the experts knowledge to classifications	0	0
02411 European Law	Experts mention importance of European Law	7	12
02411a (3) Risk	Experts mention classification by risk classes	4	8
02412 Commercial or private use	Refers to classification between commercial and private use	5	6
02413 Purpose and Mission	Refers to classification between purpose and mission	6	13
02414 Weight u Payload	Refers to classification by weight and payload	8	15

Table, part 13 of 22

	02415 (2) Design or functioning type	Refers to classification by design	6	12
	02416 (3) Indoor or Outdoor	Refers to classification between indoor and outdoor	3	8
	02417 (3) Military or non-military	Refers to classification between military and non-military	2	2
	0242 Differentiation given classification	Summarises the expert opinion on the proposed DIALOOP classification	3	3
	02421 Wing type construction	Refers to the experts opinions to wing type classification	5	8
	02422 Size and weight	Refers to the experts opinion to size and weight classification	9	29
	02423 Autonomy	Refers to the experts opinion to differentiation by autonomy	8	25
025 Known applications		Summarises experts knowledge to drone application	2	3
	0251 Information gathering	Summarise themes to information gathering applications	4	5
	02511 (3) Capture inventory	Refers to drone application to capture inventory	1	1
	02512 (3) Capturing of volumes and measures	Refers to drone application to capture volumes	2	2
	02512 (4) Inspection	Refers to drone application doing inspections	3	3
	02513 (4) Fire alarm systems	Refers to drone application maintaining fire alarm systems	1	1
	0252 Transportation and Actuating elements	Summarising transportation tasks of drones	6	10
	0253 Differentiation by application	Summarise experts opinion to further opinions on differentiation possibilities	0	0
	02531 Usable Inhouse or in-Plant area	Refers to a possible differentiation of drones for indoor and outdoor usage	1	1
	02532 Drones as tools	Refers to possible differentiation by tooling	1	1
026 Usage and approach to classification		Summarised themes to the usage and approach to a classification as of drone experts opinions	7	27
03 Rotor-based drones		Summarises the experts knowledge to rotor-based drones	0	0
030 Types of rotor-based drones known		Summarises the rotor-based drones that are known by the experts	2	2
	0301 Hobby drones	Refers to the experts mention hobby drones	1	1
	0302 Type name	Summarises type names mentioned by drone experts	0	0
	03021 Phantom class	Experts mention Phantom class as a drone	1	1
	03022 Inspire class	Experts mention Inspire class as a drone	1	2
	03023 Falcon8 Falcon 8+	Experts mention Falcon class as a drone	1	1
	03024 Matrice class	Experts mention Matrice class as a drone	1	1
	0303 (2) Quadrocopter	Refer to the expert statements to Quadrocopter	5	5
	0304 (2) Hexacopter	Refer to the expert statements to Hexacopter	5	5
	0305 (2) Octa-Copter	Refer to the expert statements to octa-copters	5	5

	0306 (4) further geometrical designs	Refer to an outline to multiple geometrical possibilities	2	2
	0307 (7) Tricopter	Refer to the expert statements to Tricopter	2	2
	0308 (7) Dedeca Copter	Refer to the expert statements to Dedeca Copter	1	1
031 Special Operations		Summarises the special operations that can be done by drones	1	1
	0311 Transport	Summarise transportation operations that can be done by drones	2	2
	03111 (2) Transport medical area	Refers to medical actions done by drones	3	4
	03112 (2) Transport objects	Refers to transporting objects by drones	4	4
	03113 (4) Transport urgent parts or spare parts	Refers to Transportation of urgent parts done by rotor-based drones	1	1
	0312 Information gathering		3	3
	03121 Fire brigade	Refer to operations done by rotor-based drones in	2	3
	03122 Warehousing	Refer to operations done by rotor-based drones in warehousing	1	3
	03123 (1) Inspection	Refer to operations done by rotor-based drones in inspection	7	12
	03124 (5) construction and agriculture	Refer to operations done by rotor-based drones in construction and agriculture	3	8
	03125 (6) Film and photo	Refer to operations done by rotor-based drones in film and photo area	2	3
	03126 (7) Mapping	Refer to operations done by rotor-based drones in mapping	3	4
032 Advantages rotor-based drones		Summarises advantages of rotor-based drones according drone experts	2	2
	0320a Flight characteristics	Summarised advantages of rotor-based drones regarding flight characteristics	0	0
	0320a1 (1) Avoidance indirection	Refers to possibility of direct flights	3	5
	0320a2 (1) Flexibility	Refers to flexibility brought by rotor-based drones	3	3
	0320a3 (2) Stable and efficient start and landing	Refers to quality of stable and efficient flight mode	5	6
	0320a4 (4) Vertical Take-off and landing	Refers to possibility of vertically take off and land	4	5
	0320a5 (4) Fastness	Refers to all matters of fastness compared to other vehicles	3	5
	0320a6 (5) Manoeuvrability	Refers to manoeuvrability given by rotor-based flight mode	4	7
	0320a7 (7) Mature and autonomous navigation	Refers to all aspects of navigation, which is very mature and autonomous at rotor-based drones	3	3
	0320b (4) Infrastructure and surroundings	Summarised advantages of rotor-based drones regarding infrastructure	0	0
	0320b1 (4) Avoidance of building infrastructure	Refers to not needed infrastructure if implementing rotor-based drones	2	4
	0320c Application fields	Summarised advantages of rotor-based drones regarding application	0	0

Table, part 15 of 22

	0320c1 (2) Transportation in rural areas	Refers to rotor-based drone doing transports in rural areas	1	1
	0320c2 (1) Additional supply of parts	Refers to possibility of doing additionally supply	1	1
	0320c3 (1) Indoor	Refers to application of rotor-based drones indoors	3	3
	0320d (2) Construction	Summarised advantages of rotor-based drones regarding construction	0	0
	0320d1 (8) Redundancy	Refers to the redundancy of the rotors, so a disfunction of one can be supported by the others	3	3
	0320d2 (8) Price worthiness	Refers to the current prices of the rotor-based drones as lot of development is done already	2	2
	0320d3 (2) Controllability	Refers to high controllability as of the multiple rotors	1	1
	0320d4 (10) Maintenance	Refers to good possibility to maintain the drones	1	1
	0320d5 (10) Lightweight	Refers to the lightweight construction of the drones	1	1
	0320d5 (10) Ratio Payload own weight	Compared to weight, this refers to high payload that can be carried by rotor-based drones	2	2
033 Disadvantages rotor-based drones		Summarises disadvantages of rotor-based drones	1	2
	0331 Flight behaviour	Summarises disadvantages of flight behaviour of rotor-based drone	0	0
	03311 Obstacle surroundings	Refers to surrounding obstacles that hinder drones in free flight	1	1
	03312 Safety	Refers to safety aspects regarding rotor-based drones	1	1
	03313 Flight distance and range	Refers flight range as disadvantages of rotor-based drones	6	10
	03314 (2) Noise	Refers to noise as a disadvantage of rotor-based drones	2	5
	03315 Energy efficiency	Refers to energy efficiency as a disadvantage of rotor-based drones	7	15
	03316 Downwind	Refers to downwind as a disadvantage of rotor-based drones	1	3
	0332 (3) Infrastructure and surroundings	Summarises disadvantages of rotor-based drones regarding infrastructure	0	0
	03321 (3) Integration in existing process landscape	Refers to difficulties of integrating rotor-based drones into existing process landscape	2	2
	03322 (3) Loading infrastructure	Refers to the need of loading infrastructure	0	0
	0333 Construction	Summarises disadvantages of rotor-based drones regarding construction	0	0
	03331 Size	Refers to needed size of drones to be useful in processes	3	6
	03332 Gaps in technology and development	Refers to current gaps in technology to have advantageous rotor-based drone flights	1	1
	03333 (4) Costs	Refers to the costs of rotor-based drones	1	2

Table, part 16 of 22

034 Influenced performance measures by rotor-based drones		Summarises experts knowledge to influncad performance measures by rotor-based drones	0	0
	0341 Additional supply and avoidance production stoppage	Refers to the possibility to use rotor-based drones to do some additional supply	1	1
	0342 (3) Costs	Refers to the possibility to use rotor-based drones to reduce costs	1	2
	0343 (3) Time	Refers to the possibility to use rotor-based drones to reduce time aspects	3	6
	0344 (3) Manpower	Refers to the possibility to use rotor-based drones to reduce manpower	2	2
035 Operations in future		Summarises experts knowledge to supposed future operations	1	1
	0351 (2) Rural areas	Refers to rotor-based drones future use in rural areas	1	1
	0352 (4) Junction with other handling technology	Refers to rotor-based drones future use in junction with other technology	1	2
	0353 (5) Short distance	Refers to rotor-based drones future use in short distance delivery	2	2
	0354 (7) Fire worker usage	Refers to rotor-based drones future use in fire usage	1	1
	0355 (7) Information gathering	Refers to rotor-based drones future use in information gathering	1	1
036 Differences in Size (op)		Refers to rotor-based drones differences in sizing	6	12
037 Differences in Autonomy		Refers to rotor-based drones differences in autonomy	2	3
04 Fixed-wing drones		Summarises experts knowledge to fixed-wing drones	0	0
040 Types		Summarises experts knowledge to types of fixed-wing drones	2	2
	0401 (4) VTOL as fixed wings	Gives a quote that integrated VTOL as fixed wing drone	1	1
041 Special operations		Summarises special operations that can be done by fixed-wing drones	3	3
	0411 Transportation	Summarise transportation operations that can be done by fixed-wing drones	3	6
	04111 Testing long range transportation	Refers to possible tests for long-range transportation	1	1
	04112 (4) Long range transportation	Refers to possible use-cases for fixed-wing drones in long range transportation	3	3
	0412 Information gathering	Summarises information gathering operations that can be done by fixed-wing drones	3	4
	04121 Measuring	Refers to possible measuring by drones	4	5
	04122 Stock and inventory	Refers to stock and inventory operations done by fixed-wing drones	1	1
	04123 (2) Agriculture	Refers to agricultural information gatherings done by fixed-wing drones	3	5
	04124 (2) Long distance inspection	Refers to long distance inspections done by fixed-wing drones	2	3

04125 (3) Data gathering large areal	Refers to data gathering in large areal done by fixed-wing drones	1	1
042 Advantages Fixed Wing	Summarised drone experts opinions to the advantages of fixed-wing drones	0	0
0421 Flight characteristics	Summarised drone experts opinions to flight characteristically advantages	0	0
04211 Long range and coverage	Experts highlight long range and coverage	9	27
04212 Large areal	Experts highlight large areal coverage	2	3
04213 (2) Slow flight	Experts highlight slow flight possibilities of fixed-wing drones	3	3
04214 (2) Efficient flying	Experts highlight efficiency flight mode of fixed-wing drones	7	14
04215 (3) Speed	Experts highlight speed as advantage of fixed-wing drones	4	5
0422 Infrastructure and surroundings	Summarised drone experts opinions to infrastructural advantages	0	0
04221 (6) Avoiding of current infrastructure	Experts highlight avoidance of current infrastructure	1	1
0423 Construction	Summarised drone experts opinions to construction advantages	0	0
04231 (2) low maintenance	Experts state a low maintenance of fixed-wing drones	2	2
04232 (7) Cheap manufacturing	Experts give opinion to cheap manufacturing of fixed-wing drones	1	2
04233 (7) Relative operations reliability		1	1
043 Disadvantages Fixed Wing	Summarised drone experts opinions to the disadvantages of fixed-wing drones	0	0
0431 Flight behaviour	Summarised drone experts opinions to flight characteristically disadvantages	0	0
04311 Missing accuracy	Experts mention a missing accuracy	1	1
04312 Few possibilities towards Autonomy	Experts mention that there is few possibility to bring fixed-wing drones towards autonomy	3	4
04313 Flight duration in relation parts weight	Experts mention that flight duration is a disadvantage relating parts weight	1	1
04314 (4) Need of balancing	Experts state that balancing is difficult	1	1
04315 (4) Manoeuvrability	Refers to low manoeuvrability of fixed-wing drones	3	4
04316 (7) needed minimum speed	Refers to the disadvantage of needing minimum speed	1	3
0432 Infrastructure and surroundings	Summarises drone experts opinions to infrastructural disadvantages	0	0
04321 Needed infrastructure	Refers to a needed infrastructure if applying fixed-wing drones	9	22
04322 Navigation GPS denied environment	Experts mention difficulties if applied in GPS denied environment	2	2
0433 Construction	Summarises drone experts opinions to construction disadvantages	0	0
04331 (4) Controllability of technology	Refers to controllability of technology as a disadvantage	2	2

Table, part 18 of 22

	04332 (5) Efficiency	Refers to low efficiency as a disadvantage of fixed-wing drones	1	1
044 Influenced performance measures by fixed-wing drones		Summarises statements of experts to influenced performance measures by fixed-wing drones	0	0
	0441 (3) Time	Time is given by experts as an improved performance measure	1	1
045 Differences in size		Summarises the stated differences in size of fixed-wing drones	5	10
046 Differences in autonomy		Summarises the stated differences in autonomy of fixed-wing drones	3	3
05 Hybrid und tilt drones		Summarises all statements to hybrid drones given by drone experts	1	1
050 Typs of hybrid and tilt drones		Summarises all given types of hybrid and tilt drones from the experts knowledge	1	1
	0501 Changing flight attitude	Refer to drones that change their flight attitude	4	4
	0502 Tilt wings or rotors	Refer to drones that tilt their wings of rotors	7	11
	0503 Vertical starting and landing	Refer to drones that start and land vertically	2	2
	0504 (4) Power unit	Refer to drones that use different power units	2	4
	0505 (4) Flying and Rolling	Refer to drones that either fly or roll	1	1
	0506 (4) Flying and swimming	Refer to drones that either fly or swim	1	1
	0507 (6) Flying and driving	Refer to drones that either fly or drive	1	1
051 Special operations hybrid or tilt drones		Summarises all special operations that could be done by hybrid drones	2	2
	0511 Transportation	Summarises all transportation operations that could be done by hybrid drones	0	0
	05111 Delivery	Refers to possible delivery operations	2	2
	05112 (3) less meaningful	Refers to quotes that say, hybrid drones are less meaningful in transportation	1	2
	0512 Information gathering	Summarises all information gathering operations that could be done by hybrid drones	1	1
	05121 Measuring and surveillance	Refers to measurements and surveillance operations that could be done by drones	2	2
	05122 (2) Air taxi	Refers to air taxi operations that could be done by drones	1	1
	05123 (3) Surveillance	Refers to surveillance operations that could be done by drones	1	1
	05124 (1) Tracking of inventory	Refers to tracking of inventory operations that could be done by drones	1	1
	05125 (5) infra-red and head imaging	Refers to infra-red and head imaging operations that could be done by drones	1	2
052 Advantages Hybrid Tilt drones		Summarises advantages of hybrid drones given by drone experts	2	2
	0520a Flight behaviour	Summarises advantages of hybrid drones given by drone experts regarding flight behaviour	0	0
	0520a1 Fastness compared to rotor-based drones	Refers to fastness advantages of hybrid drones	4	6
	0520a2 (3) Costs	Refers to cost advantages of hybrid drones	1	1

0520a3 (4) Efficiency of hybrid types	Refers to efficiency advantages of hybrid drones	5	5
0520a4 (3) Flying over obstacles	Refers to flying over obstacle advantages of hybrid drones	2	3
0520a5 (7) Range	Refers to range advantages of hybrid drones	4	7
0520a6 (1) Stability	Refers to stability advantages of hybrid drones	1	1
0520b Infrastructure and surroundings	Summarises advantages of hybrid drones given by drone experts regarding infrastructure	0	0
0520b1 (4) No infrastructure needed		4	6
0520c Construction	Summarises advantages of hybrid drones given by drone experts regarding construction	0	0
0520c1 Small types	Name advantages of small types	1	1
0520c2 Large types	Name advantages of large types	1	1
053 Disadvantage Hybrid and Tilt drones	Summarises disadvantages of hybrid drones given by drone experts	0	0
0530a Flight behaviour	Summarises disadvantages of hybrid drones given by drone experts regarding flight behaviour	0	0
0530a1 Usage of vertical starting progress at wing drones	Refer to mixture of disadvantages of vertical and horizontal flying	1	1
0530a2 Efficiency	Name efficiency as disadvantage of hybrid drones	2	3
0530a3 Stability	Name stability as disadvantage of hybrid drones	1	1
0530a5 Safety	Safety as a disadvantage of hybrid drones	1	1
0530a6 (2) Energy consumption	Name energy consumption as disadvantage of hybrid drones	4	5
0530a7 (4) Long transitions phase	Mention long transition from horizontal to vertical flying as disadvantage	2	2
0530b Infrastructure and surroundings	Summarises disadvantages of hybrid drones given by drone experts regarding infrastructure	1	1
0530c Construction	Summarises disadvantages of hybrid drones given by drone experts regarding construction	0	0
0530c1 (4) Complexity	Complexity aspect as disadvantage of hybrid drones	4	9
0530c2 (1) Weight	Weight aspect as disadvantage of hybrid drones	5	9
0530c3 (4) Costs	Cost aspect as disadvantage of hybrid drones	4	10
054 Improved performance measures by hybrid and tilt drones	Summarises influenced performance measures by hybrid drones given by drone experts	0	0
0541 (3) Time	Refers to time being a influenced performance measures by hybrid drones	1	1
0542 (3) Costs	Refers to costs being a influenced performance measures by hybrid drones	1	2
055 Differences in size	Summarises differences in size in hybrid drones	4	6

056 (1) Differences in Autonomy	Summarises differences in autonomy in hybrid drones	1	2
057 (3) Development in future	Summarises possible development in future in hybrid drones	6	10
06 Changes	Summarises future changes that could influence the implementation of drones following statements of drone experts	1	1
061 Acceptance	Summarises statements to acceptance that could influence the implementation of drones following statements of drone experts	0	0
0611 (2) Courage pilots and acceptance		4	7
062 Autonomy	Summarises statements to autonomy that could influence the implementation of drones following statements of drone experts	0	0
0621 (1) Autonomy and navigation	Refers to autonomy and navigation that effects implementation of drones	5	8
0622 (3) More automation	Refers to more automation that effects implementation of drones	3	4
0623 (4) Better sensors and computing power	Refers to better sensors and computing power that effects implementation of drones	4	8
063 Central Steering	Summarises statements to central steering that could influence the implementation of drones following statements of drone experts	0	0
0631 Combination delivery network of different drones	Refers to a combination of network of drones that effects implementation of drones	4	6
0632 Central management of drones	Refers to a central management of drones instead of only network that effects implementation of drones	2	4
064 Efficiency	Summarises statements to efficiency that could influence the implementation of drones following statements of drone experts	0	0
0641 Efficiency	Refers to efficiency regarding energy and battery that effects implementation of drones	4	10
0642 (5) Less complexity	Refers to less technical complexity that effects implementation of drones	2	2
0643 (5) Development of costs and maintenance	Refers to the costs of drones and maintenance effort that effects implementation of drones	2	2
0644 (5) Standardisation	Refers to standardisation that effects implementation of drones	1	4
065 Infrastructure	Summarises statements to infrastructure that could influence the implementation of drones following statements of drone experts	0	0
0651 (2) Corridors and infrastructure	Refers to corridors and infrastructural changes that effects implementation of drones	3	4
0652 (4) Security concepts for parallel work	Refers to security concepts for human drone interaction that effects implementation of drones	1	1
0653 (7) Usage of existing infrastructure	Refers to use of current infrastructure and space that effects implementation of drones	1	2

	0654 (7) Cost-optimised process without infrastructure	Refers to cost-optimised process landscape that effects implementation of drones	1	1
066 Platform development		Summarises statements to platform development that could influence the implementation of drones following statements of drone experts	0	0
	0661 Platform thinking	Refers to highlight of drones as a platform that can effects implementation of drones	4	6
	0662 (1) Special development	Refers to special developments of drone usage that effects implementation of drones	3	3
	0663 (8) Differentiation by process complexity and frequency		1	5
067 Regulations		Summarises statements to regulation that could influence the implementation of drones following statements of drone experts	0	0
	0671 (4) Regulation framework	Refers to the development of a regulation framework that effects implementation of drones	5	11
068 Safety			0	0
	0681 (3) Controllability and redundancy	Future developments of controllability and redundancy for further safety in drones	2	2
	0682 (4) Security concepts for parallel work	Future developments of security concepts for further safety in drones	1	1

APPENDIX G, TABLES WITH TRANSLATED QUOTATIONS

Table 4.1 *Quotations of drone expert on general way of use of classification (4.1.1), Source: The author*

		Quotations of drone expert on general way of use of classification
Respondents	D7	"the question is what the classification ultimately aims for" [i]
	D1	"to have a regulation that clearly defines in which area the drone can be used safely and how much staff or how much interaction takes place"[ii]
	D4	"in principle of the logistical problem, so what problem does the company have and there the drone is a technical solution"[iii]
	D4	"do not want to implement a drone to implement a drone, but simply because we want to solve a customer problem with it" [iv]
	D4	"you end up with an x-part matrix and not just one criterion" [v]
	D3	"comes too little to bear when users decide, what I need there because actually, as the focus is too much directed to the aircraft and far too little on what the aircraft actually carries with it"[vi]
	D3	"must always ask the result expectation question first and then deal with the aircraft"[vii]
	D5	by "either now coming from a technical specification side, or you come from the side of use cases"[viii]
	D5	"ultimately always depends on the need"[ix]
	D5	"purpose and we can calculate it"[x]
	D9	"would probably do it over some kind of evaluation matrix"[xi]
	D9	"rate and then application categories should actually need to come up"[xii]
	D9	"of course the classification of the systems according to their applications, of course, make sense"[xiii]
	D9	"must inevitably result in a combination of different classifications" [xiv]

Table 4.2 *Quotations of drone experts on European Union Classification (4.1.2.1), Source: The author*

		Quotations of drone experts on European Union Classification
Respondents	D1	"existing classifications such as those used in the relevant EU regulations etc. in individual countries"[i]
	D1	"more importantly, whether the drone has permission for a particular safety area, whether it meets certain safety aspects"[ii]
	D1	"it's all about the purpose and weight class mainly" [iii]
	D2	"classification of the EASA"[iv]
	D2	"explains the risk that the drones bring and the drone's performance" [v]
	D3	that "no matter if you see [...] Sora or simply the legislation, then the weight topic is always one that plays an extremely crucial role in the release for the flights in the outdoor area"[vi]
	D3	"this is more the risk assessment view, less the user view"[vii]
	D4	"German law is there or the regulation provides 2.5 kilos, 5 kilos [...] and then 25 kilos"[viii]
	D8	"the classification by weight according to the legislator has above all the background that it is based on a certain risk assessment"[ix]
	D9	"The existing classifications are ultimately a bit out of the air law"[x]
	D10	"according to what the EASA, the European Aviation Commission, suggests, it should be a purely risk-based approach, which follows the so-called SORA, i.e. the special operations risk assessment"[xi]
	D10	"weight in the kilogram range does not really matter, because then it's about the energy of such a device, so it depends on the airspeed" [xii]

Table 4.3 Quotations of drone experts on classification on payload and weight (4.1.2.2), Source: The author

		Quotations of drone experts on classification on payload and weight
Respondents	D1	"The smaller the lighter the drones are, the less regulated they are, the heavier they become, the more stringent the requirements will be" [i]
	D3	" the simplest distinction between large and small and payload"[ii]
	D5	"Finally, it's always about the payload, so whether I wear a sensor or if I hang a pallet or something else"[iii]
	D8	"as I said the weight class, which is not uninteresting for the classification of the corresponding legal situation"[iv]
	D1	"of course, if I really had to move larger components now, the drone must of course be large enough. This makes it difficult, and also offers a higher potential danger"[v]
	D1	"maybe even to understand, for which weight classes can I use it, which components could I carry with it"[vi]
	D2	"would classify by payload"[vii]
	D3	"from the customer's point of view, even the simplest distinction between large and small and load capacity, yes, that's precisely in the transport sector of course plays a crucial role" [viii]
	D4	"indoor [...] rather go to payload or size, which of course both are related"[ix]
	D4	that "90% of the drone in the range of 2-10 kilograms, so I would do [to have] a smaller-limbed distinction"[x]
	D4	"I would definitely make a class over 25 kilograms, because it is not forbidden to have a heavier drone, especially indoors I am allowed to"[xi]
	D4	"25 kilos Indoor that should be a very rare case"[xii]
	D5	"you can do, so depends on the use case"[xiii]
	D7	"the question again in logistics: what is the ratio of maximum-departure vs. payload"[xiv]
	D7	"if, for example, you get back to the question of soil risk, it may be that you should rather go for weight" [xv]
	D8	"a weight classification as the only underlying rating, um, well, I would reconsider"[xvi]
	D9	"of course you can always argue about the weight"[xvii]
	D9	adjust the classes to 2 kilo and around 5 kilo but is ok with 10 kilo, even states "they could also take 9 or 11"[xviii]
	D10	"the 25-kilo limit I would actually keep, everything underneath does not really matter"[xix]
	D10	"legislation that is now in the pipeline, is very much oriented to the risk that this drone has on the environment, and there the weight will probably not play a big role anymore" [xx]
	D10	"depending on the size, so there are a variety of ways to classify the drones"[xxi]

Table 4.4 *Quotations of drone experts on classification by type* (4.1.2.3), Source: The author

		Quotations of drone experts on classification by type
Respondents	D2	"about the mission and the type of operation"[i]
	D3	"distinction between just fixed wing systems, the rotary and the hybrid systems" [ii]
	D4	"wing drones"[ii] (D4) or "typical vertical take-off and landing"[iii]
	D5	"battery electric, hybrid, hydrogen systems or diesel or gas hybrid systems"[iv]
	D9	"do I have a rotor-craft, do I have a fixed wing aircraft?"[v]
	D9	"lighter than air or heavier than air"[vi]
	D2	„how they operate and it also depends on what area the logistics will take place and what kind of payload they will carry"[vii]
	D4	"Indoor makes only a multi-motor system sense"[viii]
	D7	„If you just want to classify, what are more or less the manufacturing or operating costs, what are the flight characteristics, then [they are] definitely useful"[ix]

Table 4.5 *Quotations of drone experts on classification by purpose and mission* (4.1.2.4), Source: The author

		Quotations of drone experts on classification by purpose and mission
Respondents	D1	it "on the one hand, according to purpose"[i]
	D2	"classify about the mission and the type of operation"[ii]
	D2	"this type of classification, due to the nature of the construction and the way they work, translates more into the missions that will serve them"[iii]
	D5	"Sensor-carrying systems, um, then logistics and transport systems that transport any loads from A to B, and then so in the upper end then man-carrying systems"[iv]
	D6	„Vertical take-off and landing but not more and then just the normal cruise speed via transition zone or whatever"[v]
	D7	"drones according to which applications they are suitable for"[vi]
	D8, D10	"operation purpose"[vii]

Table 4.6 *Quotations of drone experts on classification by commercial or private use* (4.1.2.5), Source: The author

		Quotations of drone experts on classification by commercial or private use
Respondents	D1, D3, D4, D8	"commercial and private use" [i]
	D10	"set at about 10,000 euros, so everything that is north, we would count as pure professional equipment" [ii]
	D10	"then I am, so to speak, in the prosumer area on the hobby side, and the prosumer also goes into the commercial track"[iii]

Table 4.7 *Quotations of drone experts on classification by indoor and outdoor use* (4.1.2.6), Source: The author

		Quotations of drone experts on classification by indoor and outdoor use
Respondents	D3	"most important distinction"[i]
	D4	"indoor in halls, warehousing, on conveyor technology, outdoor in factory or non-factory premises, public space and people"[ii]
	D8	"I would already differentiate minimum indoor and outdoor"[iii]

Table 4.8 *Quotations of drone experts on known use of rotor-based drones (4.1.3.1), Source: The author*

		Quotations of drone experts on known use of rotor-based drones
Respondents	D2	"daily use over the cities to transport the blood samples between the hospitals"[i]
	D8	"tests where drugs are taken from point A to point B"[ii]
	D8	"a life jacket [...] from the beach to the sea"[iii]
	D3	"transport for short distances"[iv]
	D4	"transport flights outdoor, of urgent parts, of spare parts" [v]
	D5	"everything that basically has to do with air reconnaissance, so everywhere where I get a topical view from above that is better than a situation picture in the two-dimensional area"[vi]
	D8	"very high precision very precise position, and in 3D mapping data from the
	D10	"to the inspection, then I do it over such a live picture before I let someone climb up there"[viii]
	D5	"construction and agriculture"[ix]
	D10	"easiest application is just the aerial picture"[x]
	D10	"next applications, which is very small but one level of difficulty higher, is the so-called mapping"[xi]
	D7	"I would like to map a street canyon and, for example, also map autonomous driving"[xii]

Table 4.9 *Quotations of drone experts on advantages of rotor-based drones (4.1.3.1), Source: The author*

	Quotations of drone experts on advantages of rotor-based drones		
Respondents	D1	Shorter ways	“not any detours over necessary corridors and [...] between warehouses”[i]
	D7		“shorten ways there, shorten times”[ii]
	D10		“such difficult infrastructure”[iii]
	D7		“a way that would otherwise be much longer, now in logistics, you can just fly to the point”[iv]
	D4	Speed	“of course with a drone much faster in the air than for example with a forklift”[v]
	D4		“ascending speed”[vi]
	D1	Flexibility	“could imagine, that in the logistics sector especially multi-rotor systems will prevail because of the flexibility” [vii]
	D5		“transport things from A to B with greater flexibility”[viii]
	D9		“significantly more agile and flexible in flight behaviour”[ix]
	D4	Manoeuvrability, Take-Off & Landing	“very precise flying, with flying on the spot” [x]
	D4		“I indoors definitely need vertical-take-off-and-landing”[xi]
	D5		“it comes down to flying off small areas very [...] specifically”[xii]
	D9		“they can start and land vertically”[xiii]
	D5	Manoeuvrability	“the possibility plays a role, that one can navigate well, and also must move rather vertically, then one must just select rotor systems”[xiv]
	D9		“advantage is that they are completely free, very much in their degrees of freedom, I can immediately change direction”[xv]
	D9		“the better controllability, so I can push it much more flexibly somewhere”[xvi]
	D8		“that the technology is under control, that it is very solid, that it is very precise and, in the meantime, reasonably priced”[xvii]
	D9		“they are incredibly easy to fly”[xviii]
	D10		“autopilots are very easy to create, they just have to be programmed, though there's also a lot of open source software”[xix]
	D4	No infrastructure	“all this, where I do not want to build any infrastructure and have to go up”[xx]
	D7		“infrastructure on the ground can be kept relatively slim” [xxi]
	D8	Redundancy	“the advantage of the multi-rotors is certainly the redundancy”[xxii]
	D10		“where one or sometimes two rotors can fail and you can still somehow land the thing controlled”[xxiii]
	D8	Price	“now also reasonably priced”[xxiv]
	D10		“because they are mass produced, they are available in abundance” [xxv]
	D10	Maintenance	“brushless motors, which means they are extremely low maintenance”[xxvi]
	D10	Lightweight	“that they are usually quite light weighted”[xxvii]
	D10	Payload	“a relatively high payload”[xxviii]

Table 4.10 *Quotations of drone experts on disadvantages of rotor-based drones (4.1.3.1), Source: The author*

	Quotations of drone experts on disadvantages of rotor-based drones		
Respondents	D1	Obstacles	"obstacles in the way"[i]
	D4	Safety	"to fly over people safely"[ii]
	D7	Down winds	"we also have a certain downwind"[iii]
	D2	Noise	"noise will be the problem"[iv]
	D7		"by rotation speeds for example"[v]
	D1	Distance	"of course, the flight distance is added"[vi]
	D4		"with multirotor system a maximum flight time of 30 to 40 minutes"[vii]
	D1	Energy efficiency	"way of flying is simply the most inefficient"[viii]
	D5		Not use "the classical physical lift, thus it needs a higher energy density"[ix]
	D7		"the power to weight ratio of the battery systems a bit limited"[x]
	D8		"if you have to lift weight with the multirotor, [...] of course the efficiency will drop over a stretch"[xi]
	D9		"let's say factor 5 between fixed-wing aircraft and copter"[xii]
	D10		"there is simply nothing that stabilizes the drone in flight, except itself"[xiii]
	D10	Maintenance / Integration in existing	"you really should not forget that you once again purchase a large new fleet of equipment, which must be maintained, must be operated, must be equipped"[xiv]
	D4	Costs	"price question and the economy"[xv]
	D10	Redundancy	"if you have a quadcopter and a motor breaks down, then the thing just crashes"[xvi]
	D1	Technology gaps	"still a good piece from my point of view, until it is resolved properly"[xvii]
	D10	Size	"the eternal trade, which one must lead there" [xviii]
	D7		"that limits the application a bit"[xix]
	D1		"due to the required flight time and additional technology that may need to be packed to work autonomously in such a complex area"[xx]

Table 4.11 *Quotations of drone experts on applications of fixed wing drones (4.1.3.2), Source: The author*

	Quotations of drone experts on applications of fixed wing drones		
Respondents	D2	Transportation	"the fixed-wing aircraft is therefore used for long-haul flights"[i]
	D9		"the projects that exist in Africa"[ii]
	D1	Information gathering	"most fixed wing systems are used for survey surveying"[iii]
	D4		surveying tasks of large plants"[iv]
	D2		fly not hundreds, but several or a dozen kilometres and be very efficient"[v]
	D10		"entire railway lines or power lines"[vi]
	D3		"data acquisition on large areas"[vii]
	D9		"at hospitals which have also partially distributed surfaces" [viii]
	D9		"campus"[ix]
	D1		"actually somehow depart high-shelves, scan barcodes"[x]

Table 4.12 *Quotations of drone experts on advantages of fixed wing drones (4.1.3.2), Source: The author*

Respondents	Quotations of drone experts on advantages of fixed wing drones		
	D1	Distance	"has to bridge a distance"[i]
	D2		"same payload can fly further"[ii]
	D4		"long fast big distances"[iii]
	D5		provide "a much higher range and a much higher tempo"[iv]
	D7		"energy efficiency is ultimately accompanied by a very large range"[v]
	D9	Great area reach	"depending on how far such a terrain extends, which can be quite a bit bigger, I see the advantage of the fixed wing drone simply in the efficiency"[vi]
	D5		"When it comes to flying over large areas of terrain are the means of choice, so because you just have a much higher range and a much higher tempo"[vii]
	D2	Slow flight	"can fly slow enough to take many pictures and put them together"[viii]
	D10		"if you want to go low and slow rather than very fast, that means you have to tend to fly a little bit slower with fixed wings to get good results"[ix]
	D1	Efficiency	"Fixed wing systems are usually efficient, if you have to fly longer distances and
	D4		"I can work very energy efficient and stay in the air for a long time"[xi]
	D9		" per se, at least three times as efficient or three times less in-efficient as a
	D10		"The huge advantage that they have [is] just that dynamic buoyancy over a
	D10	Speed	"the second point is the speed"[xiv]
	D3		"I can go with a hybrid or fixed wing quite different routes and at different speeds"[xv]
	D2	Maintenance	"They are also quite reliable and also quite cheap in maintenance"[xvi]
	D10		"Most are built relatively simple"[xvii]
	D7	Construction	"At the same time due to their design, they are so simple that they are so cheap to manufacture"[xviii]

Table 4.13 *Quotations of drone experts on disadvantages of fixed wing drones (4.1.3.2), Source: The author*

Respondents	Quotations of drone experts on disadvantages of fixed wing drones		
	D1	Infrastructure	"take-off and landing" [i]
	D2		"usually to lift by hand or catapults start"[ii]
	D4		they need space to make this transition"[iii]
	D7		"a certain effort and also a certain risk"[iv]
	D10		"if you save that, you can fly up to 46% longer on their account"[v]
	D8	Manoeuvrability	"the manoeuvrability is of course clearly limited"[vi]
	D9		"since I cannot say in straight flight suddenly, now I would like to turn sharply to the left"[vii]
	D9		"this turn flight always has a certain radius"[viii]
	D1	Autonomy	"they simply have few possibilities in autonomy"[ix]
	D3		"to automate the flight itself, yes, but take-off and landing is impossible"[x]
	D4		"I have to recognize obstacles at a much greater distance"[xi]
	D7	Minimum Speed	"fly through at a high minimum speed"[xii]
	D7		"therefore some data acquisitions are simply not possible"[xiii]

Table 4.14 *Quotations of drone experts on tasks of hybrid drones (4.1.3.3), Source: The author*

		Quotations of drone experts on tasks of hybrid drones
Respondents	D1	"by changing their flight position"[i]
	D7	"this flying wing then tilts, so a bit like a rocket at the start"[ii]
	D5	"A tilt-wing multiple device can start vertically, then goes into gliding flight and then can land vertically again" [iii]
	D1	"seen also in the range of such delivery drones area [...], I think the DHL has made attempts since relatively far"[iv]
	D3	"so for selective picking on smaller surfaces, I would never use a hybrid system, which is completely meaningless"[v]
	D5	"obvious or most widely established right now"[vi]
	D3	"congruent with the [...] fixed-wings [...] capturing of large areas"[vii]
	D3	"surveillance of large areas"[viii]

Table 4.15 *Quotations of drone experts on advantages of hybrid drones (4.1.3.3), Source: The author*

			Quotations of drone experts on advantages of hybrid drones
Respondents	D8	Combination	"this is in a sense a combination of two advantages"[i]
	D9		"I can start it from a vehicle, for example, or from some station, then transport it over a longer distance, with less energy consumption than with a copter, and could then land vertically again on a receiving station"[ii]
	D4		"I was able to roll up a staircase with this ball, I was able to fly over obstacles, that was the combination of both"[iii]
	D7	Speed	that "the tracks are bridged faster"[iv]
	D10		"things fly so what do I know 100 or 200 km / h"[v]
	D10		"super cool for logistics, you can fly very fast"[vi]
	D3		"in less time and at significantly lower costs"[vii]
	D1		"maybe faster but not so stable"[viii]
	D8	Efficiency	"lower energy input than with multirotor"[ix]
	D4		"but has used the shell as a kind of tread and so you only need 30% or maybe only 20% of the power or the energy needs of a flying drone"[x]
	D10		"Quite good potential is because it just reduces the inefficiency of the multicopter"[xi]
	D7	Range	"I just come now clearly beyond the 300 kilometer range out"[xii]
	D8		"if I have hybrid models because I can fly over long distances"[xiii]
	D10		"that it really is about big distances, so [...], we are not talking about 1 or 2 kilometers but rather 5 to 10 kilometers, because only then can they really develop their potential"[xiv]
	D8	Infrastructure	"without a huge infrastructure"[xv]

Table 4.16 *Quotations of drone experts on disadvantages of hybrid drones (4.1.3.3), Source: The author*

Quotations of drone experts on disadvantages of hybrid drones			
Respondents	D1	Energy	"the extra energy needed"[i]
	D10		but "the batteries are really only enough for take-off and landing in copter mode, um, and not hoover for 10 times and then fly on: that will not do"[ii]
	D2		"If you stay in suspension for too long, it will consume too much energy, and the question is whether that energy, this spent energy, will affect the range of the drone and how far it will fly"[iii]
	D10	Efficiency	"it is highly inefficient. It is nice that you can start and land vertically, but you can actually do it with it, otherwise you have no advantage"[iv]
	D1		"that one design can fly as a surface plane but is not quite as efficient"[v]
	D1	Transition	"But there the distance must be correspondingly large, that makes this transition worth respectively"[vi]
	D4		"the transition phase is far too long to operate in a hall"[vii]
	D5	Complexity	"complexity at take-off and landing"[viii]
	D4		"much more complex from the controlling"[ix]
	D7		"the construction is simply complex and the production and the things are more expensive"[x]
	D8		"significantly more complex than multi-rotor and also much more complex than a fixed wing"[xi]
	D7	Costs	"accordingly, a bit more expensive in the production of the parts"[xii]
	D7		"the multicopter inhouse on a short distance actually does the same cheaper, so the thing disqualifies itself because of the price a bit"[xiii]
	D7		"the operating costs are at least to be expected at least with multi-copter and tilt-prop higher than with the Fixed Wing"[xiv]
	D4	Weight + Costs	"the advantage of the combination must be so great that it outweighs the disadvantages, which are mainly weight and cost"[xv]
	D10		"the big disadvantage is that these platforms have an extreme weight problem, so they are way too heavy"[xvi]

Table 4.17 *Quotations of drone experts on future "infrastructural" changes (4.1.4.1), Source: The author*

Quotations of drone experts on future "infrastructural" change			
Respondents	D1	Air space	"must create larger areas where you can fly off and work" [i]
	D2		"crucially, how airspace is defined for the drones' flight, and even for internal logistics an airspace structure is required"[ii]
	D3		"also the topic of airspace surveillance, airspace regulation"[iii]
	D7	Process costs	"save me costs in infrastructure on the ground, I save me costs at the warehouses Hall A and Hall B […] and I may bring in a degree of flexibility"[iv]
	D8	Process+ Complexity	"possibility for drones, if it has to go very fast for example special parts" [v]
	D8		"before I have to take the car out of mass production and laboriously rework, the drone arrives within 2 minutes" [vi]
	D8		"can certainly be an additional element but not an exclusive one"[vii]
	D8	Safety+ Controllability	"taking into account appropriate safety requirements" [viii]

Table 4.18 *Quotations of drone experts on future "network system" changes (4.1.4.2), Source: The author*

Quotations of drone experts on future "network system" changes			
Respondents	D4	Network+ Communication	"clever communication information system between the various subareas"[i]
	D4		"something that better links these different systems"[ii]
	D1		"it would have to be organized via a central location, which would manage the logistics drones"[iii]
	D2		"not just the drone itself, but also the other supporting systems"[iv]
	D1		"of course it can make sense again if you have two steps, multirotor supplies, fixed wing flies and another multirotor takes over again"[v]
	D2		"also ways in which drones can interact with other drones or a kind of centralized system to manage drone airspace"[vi]
	D10		"a big challenge to automate these complete processes, and only then, as I think, is the drone technology really paying off, because as I said, if I have people who need to operate the drone, then I'll just do something wrong and then I'm not digital and automated enough"[vii]
	D4	Security+ Separation	"one has to find a clever, clever security concept, so you have to make sure somewhere that the human and the drone are physically separated, but I still do not have to shut down an alley somehow"[viii]
	D5	Standards+ Process	"if you really want to build scalable solutions now, not just what works for Supplier A or Supplier B, you have to push the process forward somehow"[ix]
	D5		"standardization of the package sizes, so big task in any form"[x]
	D3	Long term investment	"certainly, requires an uh long-term investment perspective"[xi]

Table 4.19 *Quotations of drone experts on platform thinking (4.1.4.3), Source: The author*

Quotations of drone experts on plattform thinking			
Respondents	D1	Platform thinking	"but there is also the approach to say, here is such a research platform that flies, and has interfaces. do what you want with it
	D2		"If you have a platform and then build applications that are just software applications that scale the function of the drone and the function of the smartphone - and the same thing happens with the drones"
	D2		"So I think that this flexible drone platform is the key here too. In the future, the platform should also be much more flexible"
	D8		"Of course, there must be the possibility that drones can be used flexibly"
	D10		"there has to be a lot going on in the environment, which also applies to the automation of such platforms"
		Spezial development	"there are many who take this approach to develop or adapt a drone to a very specific problem"
			"can not blindly develop something and hope that it works, but look very carefully that I develop something that the customer really needs"

Table 4.20 *Quotations of drone experts on required level of autonomy (4.1.4.4); Source: The author*

	Quotations of drone experts on required level of autonomy		
Respondents	D1	Autonomy + Navigation	"if it gets more complex environments the problem has to be solved" [i]
	D1		"adjust everything around the drone again"[ii]
	D2		"you have to have a high level of autonomy with the drones"[iii]
	D3		"the biggest challenge is that the topic of autonomous or automated navigation is finally solved"[iv]
	D3	Safety+ controllability	"are really controllable from everywhere, which may also be provided with parachute systems and sufficient redundancy, so on the software side a lot has
	D10	Automation	"I do not buy a drone, so that a man then somehow loads the thing and another controls that, then one can carry the part directly from A to B" [vi]
	D2		"a very important aspect of classification is how drones can be maintained automatically"[vii]
	D2		"if you create automation for battery replacement, that would be a great advantage"[viii]
	D9		"the autonomy, the automation will go up and I think we will see you more and more in the sky in the future"[ix]
	D4	Sensors	"the sensorics must be lighter and more powerful, the same applies to the computing power on the drone"[x]
	D9	Sensors+ electronics	"miniaturization of electronics, which will continue to be more powerful"[xi]
	D10		"next thing that drones will improve is so-called edge computing, so how much computing power"[xii]
	D3		"the systems will certainly become more intelligent"[xiii]

Table 4.21 *Quotations of drone experts on development of more efficiency (4.1.4.5), Source: The author*

	Quotations of drone experts on development of more efficiency		
Respondents	D1	Battery ability	"certainly, still advances in engines or batteries or likewise but just no quantum leaps"[i]
	D1		"the battery density and the energy efficiency of the engines"[ii]
	D9		"because somehow a quantum leap to 1000 to 2000 watt hours per kilogram is imminent, that would be factor 5 to 10"[iii]
	D9		"that's where we're starting to come to combustion-powered systems"[iv]
	D1	Energy efficiency	"energy efficiency must be higher"[v]
	D9		"if we now create factor 10 with an energy storage device with electrical or electrochemical [...] storage of electrical energy with batteries"[vi]
	D10		"the game starts all over again, how many batteries can you carry, and how is that in relation to each other"[vii]
	D5	Complexity	"that the complexity is likely to be greatly reduced"[viii]
	D5	Costs	"how much is maintenance and how complex is it in maintenance"[ix]
	D10		"because simply the miniaturization and the mass production simply will completely pulverize the prices"[x]

Table 4.22 *Quotations of drone experts on future changes of acceptance (4.1.4.6), Source: The author*

Respondents			Quotations of drone experts on future changes of acceptance
	D2	Acceptance	"people have to get used to the drones in the sky" [i]
	D3	Acceptance+ Cases	"more pilot projects" [ii]
	D7		branch "that one just blocks these negative-afflicted examples from the
	D7		"for example, a blood donation or a donation, organ donation"[iv]
	D8	Acceptance+ Boards	"there is something like a works council"[v]

Table 4.23 *Quotations of drone experts on legal changes and regulation requirements (4.1.4.7), Source: The author*

Respondents			Quotations of drone experts on legal changes and regulation requirements
	D7	Guidelines+ Regulation	"this then again closes the acceptance in the population from what again excludes the enormous legal situation"[i]
	D4		"I need clear guidelines"[ii]
	D7		"if public acceptance were higher, then politicians would be easier to approve things"[iii]
	D5		"The other is simply that the regulatory framework, especially in Europe, is becoming more unified, making it easier to calculate its applicability"[iv]
	D4		"need certifications for the drones in companies"[v]
	D5		"at the moment it is still very complex"[vi]
	D5		"uniformed simpler regulatory frame conditions" [vii]
	D7	Regulation+ Legal	"only by the legal situation, one can say that a smaller drone is often granted faster approval of critical infrastructures, so to speak" [viii]
	D8	Regulation+ Legal Cases	"in the US, there is now indeed the thrust to allow people to fly over with appropriate security device"[ix]

Table 4.24 *Quotations of automotive experts about the process landscape in automotive OEMs (4.2.1.1), Source: The author*

			Quotations of automotive experts about the process landscape in automotive OEMs
Respondents	A1	Goods receipt	"intralogistics begins [...] from the goods receipt" [i]
	A2		"classic goods receipt" [ii]
	A3		"that is, when the material from the external stock passes into our stock"[iii]
	A6		"goods receipt of the most different kind with the automotive OEM. Electronic, flat rate, per charge"[iv]
	A8		also "goods receipt is the same as receiving goods in our outdoor warehouses"[v]
	A2	Storing	"have different storage structures"[vi]
	A4		„most motorists have a relatively conventional warehouse for large load carriers, ie pallet racking"[vii]
	A4		„for small load carriers, we have a very high degree of automation in a high-bay warehouse"[viii]
	A5		"Warehouse providing area including supermarkets"[ix]
	A1	Picking& Sequencing	„picking zones, where corresponding shopping carts are picked"[x]
	A2		"so be prepared for our added value"[xi]
	A5		"We have small load carriers KLTs, we have large load carriers or SLTs, special load carriers, large load carriers, and these are then transported accordingly to
	A6		"often supported by an external service provider"[xiii]
	A10		„either bring the material to the lines unmixed or stop in sequence" [xiv]
	A3	Delivery to line	contains „both bite-sized and global provision of the material in the sheds"[xv]
	A3		"ends [...] when at the point of delivery, this material is then ready for production"[xvi]
	A10		„when we have the material at the place of need, the responsibility of the plant logistics is initially over"[xvii]
	A3	Empties processing	"the last process in this whole inhouse"[xviii]
	A3		"we make empties control for the shortest supplier of the part in the VW Group need" [xviv]

Table 4.25 *Most relevant quotations of automotive experts on logistics operations in 'goods receipt' (4.2.1.1), Source: The author*

Respondents		Most relevant quotations of automotive experts on logistics operations in goods receipt	
	A3	Receiving	"receiving is actually [...] only a passage of risk" [i]
	A10		"usually there's an e-point, where the goods will be collected"[ii]
	A6	Booking	"administrative booking"[iii]
	A1	Checking	„check before unloading the goods or the attached labels and labels"[iv]
	A8		"shipping documents are then checked"[v]
	A4		"there it is usually also labelled [...] [and] again examined in more detail"[vi]
	A10		„today happens mostly manual and how detailed that is is sometimes an open issue"[vii]
	A4		„confirmation that the goods arrived[viii]
	A1		„the quality of everything"[ix]
	A1		"there's transportation damage"[x]
	A4	Unloading	"unloading a truck and placing the goods on any checkpoints" [xi]
	A4		"partial container weights of one ton per cubic meter"[xii]
	A6		"we often change the mode of transport"[xiii]
	A1	Labeling	"internal labels, so that you can process accordingly"[xiv]

Table 4.26 *Quotations of automotive experts on implementation of drones in 'goods receipt' (4.2.1.1), Source: The author*

Respondents		Most relevant quotations of automotive experts on tasks for drones in goods receipt	
	A10	Transport	"truck is just piloted, is found by drone and then is piloted to its destination" [i]
	A4		"transport functionality [...] these drones would not be able to take over in the near future, because the weight of the carriers is just simply too high"[ii]
	A4		"the weight of the carriers [is] simply simply way too high" [iii]
	A7	Checking	"feasible [...] a drone flies and scans the containers"[iv]
	A2		"goods receiving inspections are done by drones"[v]
	A6		that "if I imagine, that I should take a drone in 2019 or in the year 2020 to determine where the truck is or where my load is, then I have actually prior to this another problem that I do not control" [vi]
	A10	Booking	„the only thing I can imagine, that they are very small and very well suited to make just a physical detection of the containers of the estate"[vii]

Table 4.27 *Quotations of automotive experts on named performance measures in 'goods receipt' (4.2.1.1), Source: The author*

Respondents	Most relevant quotations of automotive experts on named performance measures in goods receipt		
	A4	Quality	"how often is something thrown around in a certain area, so there's a qualification problem"[i]
	A4		"documentation could be significantly improved"[ii]
	A1		"transport damage is a query"[iii]
	A2		"delivery quality"[iv]
	A2	Completeness	"what has been delivered, checked for completeness" [v]
	A2	Throughput	"are of course also limited in terms of throughputs or capacities"[vi]
	A4		"We cannot say what kind of performance area has how much throughput"[vii]
	A4		"we can say it very roughly, afterwards in the post evaluation"[viii]
	A7		"trucks a day, BGLs per day and relevant numbers"[ix]
	A8		"completed goods receipt transactions"[x]
	A9	Punctuality	"the vehicles are then punctual"[xi]
	A10		"how punctual are the goods" [xii]
	A3	Lead time	„how long do I need for a truck like this until it is registered or until it is
	A6	Downtime	„especially after the downtimes, [...] because they cost money"[xiv]

Table 4.28 *Quotations of automotive experts on potentially changed performance measures in 'goods receipt' (4.2.1.1), Source: The author*

Respondents	Most relevant quotations of automotive experts on potentially changed performance measures in goods receipt		
	A2	Speed	"speed in the clearance"[i]
	A4	Speed + Throughput	"throughput time in the goods receipt could be reduced because yes this manual activity of the labeling uh or the label check and the controlling of Kollis could be automated on the Ident-point actually"[ii]
	A7	Throughput	"maybe still parallelizing"[iii]
	A7		"turnover rate per hour, per day "[iv]
	A10		"ultimately also in the field of personnel deployment"[v]
	A10	Checks+ Quality	"quality of the collection, of the collected goods"[vi]
	A2		„of course I have the claim from an automated system, that this works stupidly, and according to me then there can be safer, that I got everything"[vii]

Table 4.29 *Quotations of automotive experts on logistics operations in 'storing' (4.2.1.4), Source: The author*

Respondents		Most relevant quotations of automotive experts on logistics operations in 'Storing'
A4	Inventory	„what I see again that visual activities are already taking place in the warehouse area, one of my favorite stories is inventory"[i]
A5		"the drone flies through the hall again late at night or during non-operating times" [ii]
A7		„Are target and actual correct and may we have to replenish them so that the quantities in circulation are still correct"[iii]
A1	Relabelling	"the re-labeling perhaps one can already count to this"[iv]
A1		"possibly even repacking in intra-logistic packaging material"[v]
A9	Storing	"basically the removal of the pallets from the trucks, yes, so the unloading"[vi]
A1		„if it is a smaller part then just in the automatic small parts warehouse"[vii]
A1		„rest is automated, so then the parts are then somehow automatically going with a storage and retrieval device into the warehouse, on conveyor belts and are
A1		"With large load carriers, there's of course some soil or block storage"[ix]
A3	Buffering	"stock is buffer for me"[x]
A9		"this is then put on an intermediate buffer"[xi]
A9		"usually this is then stored by the buffer surface directly into the shelves"[xii]
A2	Transportation	"Transport in the broadest sense of course, too" [xiii]
A9		"transport of pallets, of stored pallets, mainly pallets, into the warehouse"[xiv]
A2	Release from Stock	"releasing from stock" [xv]
A1		"only when they are needed"[xvi]
A8		"a demand coming"[xvii]
A1	Checking	"would be interesting to know, because in terms of area, is very large of course, that one says, ok, what is my filling level degree"[xviii]
A9		"that you can hover drones over the vehicles" [xix]
A1	Parking space	"it is just not exactly measured with the parking spaces, that you can say, what is my current situation there"[xx]

Table 4.30 *Quotations of automotive experts on implementation of drones in 'storing' (4.2.1.4), Source: The author*

Respondents		Most relevant quotations of automotive experts on tasks for drones in 'Storing'
A2	Allocation	"optimization of parking space allocations through the detection of vacant parking spaces" [i]
A4	Sensorics+ Temperature	"Sensors, [...] for logistics, this is quite relevant, as are temperatures in the warehouse"[ii]
A2	Scanning	„check for completeness, even in high shelves and warehouse structures"[iii]
A7		"perform scanning, also again compare the actual status with the target level on a regular basis"[iv]
A5		"Search for lost load carriers in intralogistics"[v]
A3		"first find the box in the AKL" [vi]
A4		"theft protection" [vii]
A6	Process focus + not drones	"should [...] focus more on my process, knowing where to stand, and making the process robust, then I do not need to fly through a corridor afterwards" [viii]
A	No tasks	the experts A5, A6, A7, A9, A10 see no tasks for drones in logistics operations of

Table 4.31 *Quotations of automotive experts on performance measures in 'storing' (4.2.1.4), Source: The author*

Respondents		Most relevant quotations of automotive experts on performance measures in 'Storing'	
	A1	Quality	„the typical topic, do I make some damage anywhere"[i]
	A4		"wrong storage, wrong labels" [ii]
	A9		"the subject wrong delivery" [iii]
	A2	Utilisation	„Utilization of warehouse structures"[iv]
	A10		"storage filling level"[v]
	A4		"expanse and height" [vi]
	A6	Time	"days of inventory"[vii]
	A1		"of course it is important that we have low, shorter lead times" [viii]
	A8		"fastness of some re-supply" [ix]
	A1	Stock reduction vs Days of inventory	"as few stocks as possible" [x]

Table 4.32 *Quotations of automotive experts on potentially changed performance measures in 'storing' (4.2.1.4), Source: The author*

Respondents		Most relevant quotations of automotive experts on potentially changed PM in 'Storing'	
	A2	Stock	„stock transparency if you like"[i]
	A4		"name error-based KPIs [...] this topic permanent inventory"[ii]
	A7	Error rate	"you would probably significantly improve the error rate should-stand and actual stand"[iii]
	A10	Transparency+ stock and capital	"A certain degree of transparency always has a certain [...] opportunity to reduce inventories and thus to reduce the capital commitment"[iv]
	A10	Supply security	"would improve security of supply so at a bottom line then"[v]
	A2	Utilisation	"utilization of the storing structure" [vi]
	A2		"by the space allocation I get more in, so I can better use the area I have and am more cost-efficient on the way"[vii]
	A6		"the area requirements are getting bigger because the variance increases, because the set building is increasing, and because we consume more and more
	A7		"you would increase the capacity of the storing device because then you would do the job of scanning and checking"[ix]

Table 4.33 *Quotations to automotive experts on logistics operations in 'picking and sequencing' (4.2.1.5), Source: The author*

Respondents		Most relevant quotations to automotive experts on logistics operations in 'picking and sequencing'
A4	Delivery to picking line	"delivery, parts are brought to a person or brought to a zone where a sequencer picks"[i]
A7		„in the supermarket is indeed a sequencing of the variance of the parts and if a […] container is picked empty, because everything is installed, then that is
A5	Picking+ Sequencing	„there shopping carts are put together"[iii]
A6		"sets formed"[iv]
A7		"the pure picking process" [v]
A5		"so to speak smaller pre-assembly activities"[vi]
A7		"the worker then runs through the supermarket and then picks the vehicle
A8	Provision	„provision for onward transport"[viii]
A4	Sequencing	"brings the parts in the right order"[ix]
A5		"sequenced scopes provided in a shopping cart"[x]
A7	Delivery	„delivery to the place of installation is directly related to the sequencing actually"[xi]

Table 4.34 *Quotations of automotive experts on implementation of drones in 'picking and sequencing' (4.2.1.5), Source: The author*

Respondents		Most relevant quotations of automotive experts on tasks for drones in 'picking and sequencing'
A4	Data gathering	„not collecting a lot of data that can help us get better in the process"[i]
A4	Sensors	"temperature"[ii]
A4		"air moisture"[iii]
A4		"dust exposure"[iv]
A3	Picking+Grabbing	"a drone could also pick parts tomorrow, that means, if they had a magnet attached"[v]
A3		"if it had a grabber"[vi]
A9		„in the field of small parts"[vii]
A7	Additional	"at first in the additional delivery process though"[viii]
A4	No tasks	„the parts I want to sequence are either stored on shelves or distributed at ground level" [ix]

Table 4.35 Quotations of automotive experts on performance measures in 'picking and sequencing' (4.2.1.5), Source: The author

			Most relevant quotations of automotive experts on PM in 'picking and sequencing'
Respondents	A4	Quality + Errors	"sequencing errors"[i]
	A9		"missing parts, and the second is [...] wrong picking"[ii]
	A10		"do not have 100% control" [iii]
	A2	Throughput	"employee activities no longer occur"[iv]
	A2		„parallelization of the processes is possible, that means, I could process more orders"[v]
	A8	Picking rate	"picks per hour"[vi]
	A1		"Classic [...] is always the picking performance - let me say now - relevant in the system, how many parts can I pick somewhere per time unit"[vii]
	A3	Times	"F-Times"[viii]
	A7	Utilisation+ Variants	"how many variants does a part have"[ix]
	A2	Costs	"Cost reduction, of course, by eliminating manual tasks"[x]

Table 4.36 *Quotations of automotive experts on potentially changed performance measures in 'picking and sequencing' (4.2.1.5), Source: The author*

			Most relevant quotations of automotive experts on potentially changed PM in 'picking and sequencing'
Respondents	A3	Time	"how much time do you need to complete a certain process" [i] (A3)
	A7		„is not stopped on its own way, can be there much faster, that does not hang in traffic"[ii] (A7)
	A10		"much faster than any other option that I know today to deliver goods to the line"[iii] (A10)
	A2	Quality + delivery	„for which sequence is to create, are fetched accurately, so basically quality, quality of delivery"[iv] (A2)
	A9		"avoiding misallocated components" [v] (A9)
	A2	Throughput	"in accompanying processes of this activity" [vi] (A2)

Table 4.37 *Quotations of automotive experts on logistics operations in 'delivery to line' (4.2.1.6), Source: The author*

	Most relevant quotations of automotive experts on logistics operations in 'delivery to line'		
Respondents	A6	Overall	"really great potential" [i]
	A8	Transport	„out of our staging areas with our tugger trains and forklifts, um, transport systems up to the spot" [ii]
	A3		"vanquish just a distance between A and B"[iii]
	A4		„classic loading process, um, the truck then goes over to the factory or from the warehouse [...] to the assembly area, where it has to go, [...] and is then unload
	A4		„there again turned on a tugger train, so then almost a tractor and three small trailers behind it"[v]
	A9		"manual supply of the individual, ähm, of the individual shelves with KLTs or then also um, via forklift then with larger components"[vi]
	A1		"they are then brought to the line or to the installation site by corresponding employees or on AGVs, driverless transport systems"[vii]
	A10		„travel the distance, from the warehouse, from the point of origin to the place of demand"[viii]
	A10		"today usually is highly manual"[ix]
	A1	Allocation	"then just there provided, mostly in small shelving systems which are then there on the line"[x]
	A2		"where value creation happens"[xi]
	A8		"locally the parts change, or the container change"[xii]

Table 4.38 *Quotations of automotive experts on implementation of drones in 'delivery to line' (4.2.1.6), Source: The author*

	Most relevant quotations of automotive experts on tasks for drone in 'delivery to line'		
Respondents	A5	Post-delivery + special parts	"such an express delivery or such a special delivery, if sometimes material has gone out" [i]
	A4	Post-delivery	"Post-delivery processes when errors occur" [ii]
	A8	Non-series	„maybe in the non-series material supply of any gloves or shoes"[iii]
	A4	No tasks	„in both cases, the goods being transported, ähm, are too heavy to be transported with the technical possibilities of a drone" [iv]

Table 4.39 *Quotations of automotive experts on performance measures in 'delivery to line' (4.2.1.6), Source: The author*

Respondents		Most relevant	quotations of automotive experts on named PM in 'delivery to line'
	A2	On-time delivery	"On-time delivery, which of course is [being] at the right time in the right place" [i]
	A5		"cycle time, the cycle time is indeed a key figure I have to adhere to"[ii]
	A8		"that this comes on time, so in this case not the duration but the time window, when this is provided" [iii]
	A10		"also a big topic in the area is traffic"[iv]
	A3	Supply security	"Actually, the primary concern is security of supply"[v]
	A10		"topics such as transport load, transport frequencies" [vi]
	A1	Inventory	to "minimal inventory on the line"[vii]
	A2	Speed and costs	„if I save time, of course, I'll cut the costs"[viii]
	A4		"if I could just fly across ways, then I would be faster in the subsequent
	A4	Efficiency	"That's a significant improvement in efficiency"[x]
	A10		"So there are usually fixed circuits, that we drive and they are just not very flexible and therefore little demand-oriented. And every time I'm less demand-oriented, it means I'm inefficient"[xi]

Table 4.40 *Quotations of automotive experts on changeable performance measures in 'delivery to line' (4.2.1.6), Source: The author*

Respondents		Most relevant	quotations of automotive experts in changed PM in 'delivery to line'
	A2	Speed	"happens faster, because I can use drones and unload transport units faster, so to speak" [i]
	A7		"make any decisions a little bit later"[ii]
	A7		"have a very fast delivery process"[iii]
	A7		"instead of half an hour, we only have to plan with 10 minutes" [iv]
	A8		"fast re-supply"[v]
	A10		"brings time and speed and also brings degree of automation"[vi]
	A2	Utilisation	"utilization of the routes"[vii]
	A10		"also imagine that the 3rd dimension simply relieves the infrastructure" [viii]
	A9		"you could represent differently with the need [...] for these industrial trucks or the orbital period"[ix]
	A7		"Long-distance JIT or JIS"[x]

Table 4.41 *Quotations of automotive experts on future “infrastructural” changes (4.2.2.1), Source: The author*

Most relevant quotations of automotive experts on future “infrastructural” changes			
Respondents	A4	Air corridors	“creating corridors in the air that we are allowed to use for such air cargo”[i]
	A6	Corridors+ grids	“what does not work is grid-level. I do not want to fly over a grid, that's naive”[ii]
	A6		„I want to be able to get up and down, I do not want to have to make holes in my bars tomorrow. I want a flexible factory“[iii]
	A7		„up there they are not competing for the same roads, intersections, roads. And then you can fully exploit the advantage, and with that we can rethink our
	A1	Process+ Zones	“we need zones where this is loaded”[v]
	A1	Process+ carriers	“carriers must be adapted“[vi]
	A6		“the load carrier, as it is today, is actually a miserable load”[vii]
	A2		„storage structures would have to be reconsidered”[viii]
	A2	Process+ accessibility	“to change many details in the processes so that e.g. an accessibility for the drone is given”[ix]
	A8		“easy accessibility and visibility of parts, which are to be transported”[x]
	A6		„today [...] think about preserving these corridors in new factories“[xi]
	A4	Process+ Structural changes	“[...] would have to go more towards the area and keep the space above shelves and [...] production lines for drones”[xii]
	A9		“would have to arrange perhaps structural actions within the plant [...], and then there is always the question of whether it is worthwhile or not”[xiii]
	A1	Data protection	“data protection. Often you have cameras under the systems, even if there are none underneath, [...] people do not see that from the bottom”[xiv]

Table 4.42 *Quotations of automotive experts on future “management system” changes (4.2.2.2), Source: The author*

Most relevant quotations of automotive experts on future “management system” changes			
Respondents	A3	Drone delivery concept	“My process is not safe somewhere, if the drone can pick something and land somewhere and deliver something, but also do not let the conditions around out of sight”[i]
	A1	Drone delivery supply map	„can map the entire supply chain” [ii]
	A6	Central vehicle management	“the vehicle must also be managed”[iii]
	A6		„no matter what kind of transport takes place in the factory, you need an idea how to regulate transport and traffic in your factory tomorrow“[iv]
	A7		“not just do this one process, but we have to implement a combination of many processes”[v]
	A8	Change of flow	“there one has to think about, if this goes towards masses, then you have to fly car-sets for 1000 cars”[vi]

Table 4.43 *Quotations of automotive experts on required automation towards autonomy (4.2.2.3); Source: The author*

Most relevant quotations of automotive experts on required level of autonomy			
Respondents			
	A5	Autonomy	"always has to be there and look after during the remote control"[i] (A1)
	A1		„to get permission easier to operate systems really autonomously, or let's say, let's say automated in the first step"[ii] (A1)
	A4		„when we talked about drones, we always talked about autonomous control"[iii]
	A2		„relate it more about the use case, so to the task and not the size" [iv] (A2)
	A8		"the reproducibility of the entered flight path" [v] (A8)
	A7		"at some point then maybe even so intelligent, that if my way is blocked, then I am looking for another way"[vi] (A7)
	A3	Drones+ Actuating elements	„drones would actually have to be flying robots equipped with camera and gripping elements today, in addition to flying and transporting, they also carry out handling activities"[vii] (A3)
	A6		"needs a secure fit for carried load" [viii] (A6)

Table 4.44 *Quotations of automotive experts on development of more efficiency (4.2.2.4), Source: The author*

Most relevant quotations of automotive experts on development of more efficiency			
Respondents			
	A2	Battery	"To be better used, a longer battery life would be desirable"[i]
	A2		"the pure performance, so what can a drone lift" [ii]
	A4		"so if I now put the drone on the dock three to four times per shift, that would never work" [iii]
	A1	Payload	"payload is always an issue, be it with any sensors, or with parts that you take, so that's always the question. The more the better of course, but that's clear, that the system has limits"[iv]
	A5		"need there to a one on one reference so to say [...], since the load factor is so low, I need so many drones for somewhere a supply of x components, that then this is not efficient anymore"[v]

Table 4.45 *Quotations of automotive experts on required acceptance (4.2.2.5), Source: The author*

Most relevant quotations of automotive experts on required change of mindset			
Respondents			
	A1	Process+ Social mindset	„the technology has to be present in the people and they have to see what is possible with it"[i] (A1)
	A1		"a bit more accepted"[ii] (A1)
	A3		„the topic of works council is not to be underestimated on such things"[iii] (A3)
	A1	Process+ job profiles	"then again also means that I [need] a brand-new Job profile, a whole new job"[iv] (A1)
	A2	Process+ employee	"I have to have fewer employees there to avoid this legal situation with the endangerment of employees"[v] (A2).

Table 4.46 *Quotations of automotive experts on regulation guidelines (4.2.2.6), Source: The author*

Most relevant quotations of automotive experts on safety and sequrity			
Respondents	A1	Safety	"just let something fall down in case of doubt or fall down yourself if it does something" [i]
	A4		"The subject of security, goods could fall from the sky" [ii]
	A1		"that you are not somehow flying against an existing obstacle" [iii]
	A2		"Additional security feature, so that I really have person-security with me" [iv]
	A2		"or I have different sensors or scanner systems on it, right up to redundant systems" [v]
	A3		"Security aspects, maybe you can manipulatethese things" [vi]
	A4		"I believe that drones have to put a lot of emphasis on sensors - like safety sensors - something like impact detection or early sensors" [vii]
	A6		"now to find a technical solution that I can work under the suspended load" [viii]
	A5		"somehow I have to wear a helmet etc" [ix]
	A1	Data protection	"Data protection. Often you have cameras under the systems" [x]
	A1	Noise reduciton	"Become quieter" [xi]
	A4		"I think they have to be a lot quieter so that this is bearable for employees" [xii]
	A7		"those which can carry usually make noise accordingly" [xiii]
	A8	Downwinds	"Wind nuisance" [xiv]

Table 4.47 *Quotations of automotive experts on legal changes and regulation requirements (0), Source: The author*

Most relevant quotations of automotive experts on legal changes and regulation requirements			
Respondents	A1	Process regulation	"also with the authorities' sides, that they then allow appropriate concepts"[i]
	A2	Legal framework	"great enabler for the topic drone is really still the legal framework"[ii]
	A5		„all legal precautions would have to be taken, so that I can then fly indoor with this drone, that means I would have to create corridors"[iii]

Table 5.48 *Quotations of automotive experts key statements on class rating 'Goods receipt' (5.5), Source: The author*

Most relevant Quotations of automotive experts key statements on numeric rating 'Goods receipt'		
Respondents	A1	"rather smaller solutions because it is indoor" [i]
	A1	then "it is just spatially limited" [ii]
	A3	"somewhere on a hall a drone landing pad on top"[iii]
	A1	"currently due to the spatial restriction"[iv]
	A3	"imagine the fixed wing drones just outside of halls"[v]
	A5	"with these fixed-wings, with those I can actually do nothing from intralogistics perspective" [vi]

Table 5.49 *Quotations of automotive experts' key statement on class rating in 'Storing' (5.5), Source: The author*

Most relevant quotations of automotive experts' key statement on numerical rating in 'Storing'		
Respondents	A1	"can turn on the spot, then [...] [they] do not have to fly a big turn somewhere"[i]
	A5	"is just too high the airspeed that I have here [...] that I can fly around somewhere indoor-like in the hall"[ii]

Table 5.50 *Quotations of automotive experts' key statement on class rating in 'Picking and Sequencing' (5.5), Source: The author*

Most relevant quotations to drone rating in Picking and Sequencing		
Respondents	A1	"if rotor-bound systems in the hall at all, small light systems" [i] (A1)
	A10	"on factory grounds I would not even see the fixed-wings here" [ii] (A10)
	A2	"here one can bridge larger distances with these drones, but at the same time you can stop" [iii] (A2)
	A4	"Regardless of the technology carrier, it is very unlikely that a drone would be used there" [iv] (A4)
	A5	„have actually provided pick robots for these topics" [v] (A5)

Table 5.51 *Quotations of automotive experts' key statement on class rating in 'delivery to line' (5.5) , Source: The author*

Respondents		Most relevant quotations to proposed drone classes in 'delivery to line'
	A1	"with small and light parts perhaps also small and medium is adequate" [i]
	A4	"so regular delivery of load carriers, I see everywhere a 5, that does not work" [ii]
	A10	"the smaller the better" [iii]
	A19	"suitable to travel longer distances, so I would not have the need here in the factory" [iv]
	A8	"a use of a drone [...] - because of the structural characteristics, so as I said, there is the only the re-supply of missing parts, broken parts or individual parts stop - I can imagine almost nothing there"[v]

APPENDIX H, PUBLIC PRESENTATION SLIDES

VIVA 2021: Sebastian Hartl 5th March, 2021

VIVA 2021: Sebastian Hartl

A Framework for the implementation of drones in German automotive OEM logistics operations

University of Portsmouth / ESB Reutlingen
Doctorate of Business Administration
Cohort 2016

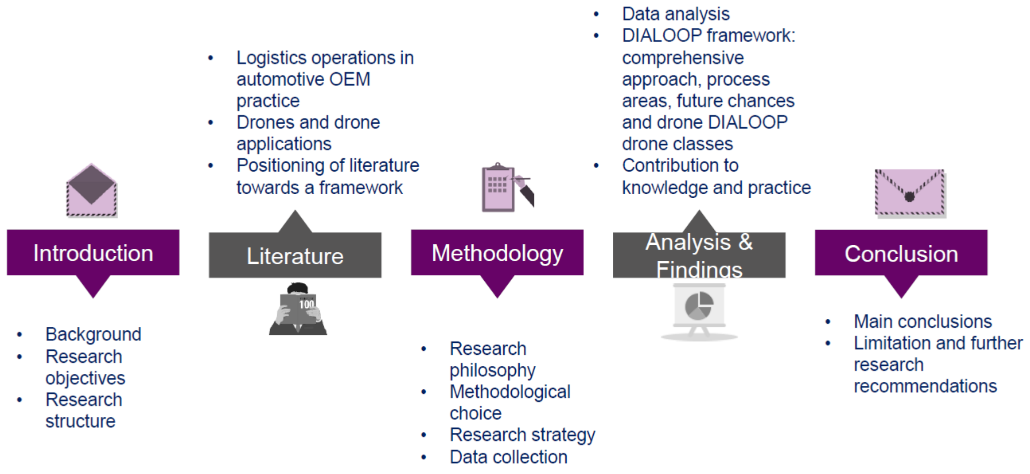
"Drones overall will be more impactful than I think people will recognize, in positive ways to help society"

- Bill Gates -

1

VIVA 2021: Sebastian Hartl 5th March, 2021

Agenda following the structure of the thesis



UNIVERSITY OF PORTSMOUTH ESB BUSINESS SCHOOL REUTLINGEN UNIVERSITY

2

INTRODUCTION

Background

Research objectives

Research structure

Problem background and research motivation

Background on automotive OEM logistics operations

- Trends towards **modular production** increase
- **New technologies** and changing environments
- **Horizontal limits** in the plant environment
- Increasing **complexity** of the manufacturing environment
- Autonomous guided vehicles (AGV) currently used, lead to **denser traffic in plants**

Background on drones

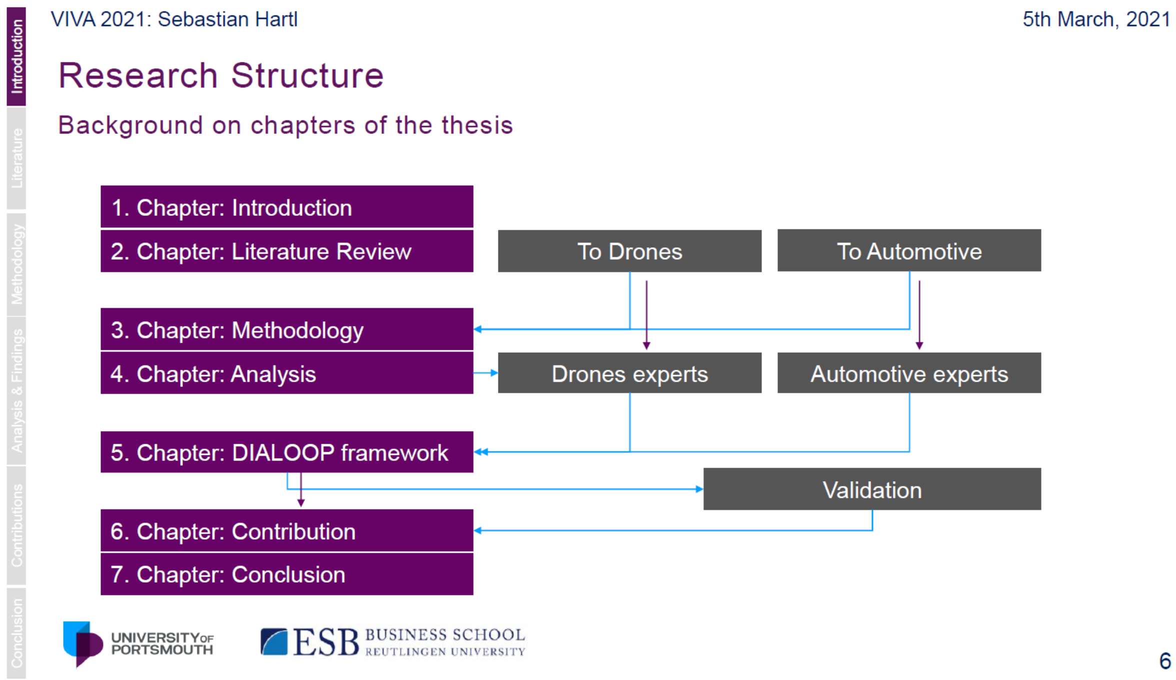
- Drone usage and development **focused on long-range deliveries**, subject to numerous **legal regulations** as well as to considerations of **safety and security**
- First approaches towards drone usage in other manufacturing environments
- Multiple use cases and drone types **offer different chances** for specific areas

Academia

- **Limited literature towards drone implementation** in manufacturing logistics
- Limited literature towards drone implementation **especially in automotive OEM logistics**
- **No existing framework** of drone implementation, of approach, or of potentials

UNIVERSITY OF PORTSMOUTH   ESB BUSINESS SCHOOL REUTLINGEN UNIVERSITY


Introduction
Literature
Methodology
Analysis & Findings
Contributions
Conclusion
VIVA 2021: Sebastian Hartl
5th March, 2021
Research question & Research Objectives
“Can drones be implemented in automotive original equipment manufacturers (OEM) logistics operations and how can this be achieved?”
RO1
Define automotive OEM logistics operations and performance measures
RO2
Classify drones to explore their application in automotive OEM logistics operations
RO3
Explore the preconditions under which drones can meet current the requirements of automotive OEM inhouse logistics operations and identify related performance measures
RO4
Establish a framework for the implementation of drones in automotive OEM logistics operations
RO5
Validate the framework, including the content that reflects present-situation, transient conditions and assessments within automotive OEMs
UNIVERSITY OF PORTSMOUTH
ESB BUSINESS SCHOOL REUTLINGEN UNIVERSITY
5


Introduction
Literature
Methodology
Analysis & Findings
Contributions
Conclusion
VIVA 2021: Sebastian Hartl
5th March, 2021
Research Structure
Background on chapters of the thesis
1. Chapter: Introduction
2. Chapter: Literature Review
To Drones
To Automotive
3. Chapter: Methodology
4. Chapter: Analysis
Drones experts
Automotive experts
5. Chapter: DIALOOP framework
Validation
6. Chapter: Contribution
7. Chapter: Conclusion
UNIVERSITY OF PORTSMOUTH
ESB BUSINESS SCHOOL REUTLINGEN UNIVERSITY
6

LITERATURE

Logistics operations in automotive OEM practice

Drones and drone applications

Positioning of literature towards a framework

Logistics operations in automotive OEM practice

Fundamental influences on logistic operations in automotive OEMs

Research is **about technology integration:** addresses current fundamental influences ahead of basis logistic theory or optimisation methods

Thesis scope **focusses on possible combination of new drone topic to existing automotive landscape**

European Build-to-order

Change from a push to a pull process **requires flexibility in production lines and a reduction in lead times**. (Mondragon, Lyons, Michaelides, & Kehoe, 2006)

Mass customisation

Requires to solve the problem of **frequently conflicting goals**, such as high variety, low price, short delivery time and space limitations, at the same time (Emde & Gendreau, 2017)

Industrie 4.0

As an overall paradigm has **many drivers**, like agility, customisation, need for accuracy or efficiency **yet is facing barriers** including financial matters, lack of management support or change mentality (Ghadge, Er Kara, Moradlou, & Goswami, 2020)

Modular and smart manufacturing

Requires adequate logistic; "**enabling technologies […] are more likely to obtain greater opportunities**" (Büchi, Cugno, & Castagnoli, 2020, p.8)

Autonomous ground vehicles

Can be expanded into 3D space and reduce traffic in manufacturing plants (Fornasiero et al., 2018)

UNIVERSITY OF PORTSMOUTH   ESB BUSINESS SCHOOL REUTLINGEN UNIVERSITY

Logistics operations in automotive OEM practice

Results on process areas & Performance measures

Results of investigation on (downstream) process areas for the research

Goods receipt | Storing | Picking&Sequencing | Delivery to line

Performance measures from automotive process areas in relevance for this research

Strategic-level ↔ **Operational-level** ↔ **Novel Operational-level**

Strategic-level:
- Efficiency
- Effectiveness
- Differentiation

Operational-level:
- Reliability
- Time
- Quality
- Costs
- Productivity
- Flexibility

Novel Operational-level:
- Scalability
- Reconfigurability
- Reliability
- Safety
- Resource efficiency
- Modularity
- Decentral controllability

Key authors
- Dörnhöfer (2016),
- Boysen et al. (2015),
- Kern et al. (2017),

- Dörnhöfer, Schröder, & Günthner (2016),
- Marchesini & Alcântara (2016),
- Furmans, Seibold, & Trenkle (2019)

Drones and drone applications

Current application, classification of drones and characteristics

Current drone applications

- Drones focus on **fast long range delivery and surveillance**
- First application **pilots in smart cities**, like medical device transportation
- **Single sources to intralogistics** focus on drone implementation to safe cost as a matter of delivery-time reduction

Definition and classification of drones

- **Multiple classifications** on size and weight or drone type (wing type)
- Size classifications **do not match the regulations** of the German government with having 25kg upper limit
- Type-based classification **can be combined** with size classification

Benefits and Challenges of drones

- **Rotor-based drones could be preferred, hybrid drones could also be applied, less implementation of fixed-wing drones expected**

Key authors
- Hassanalian & Abdelkef (2016),
- Custers (2016),
- Olivares et al. (2015)
- Dobrindt (2017),
- Hassanalian & Abdelkef (2017),
- Maghazei & Netland (2019)

Positioning of literature towards a framework

Influential of manufacturing-logistic based frameworks

(Ghalayini & Noble, 1996)
Dual perspective "Vision and Market"
Using **decision parameters,** performance measures change

Klingebiel (2006)
Focusses on BTO process, **strategic** thinking, **AS-IS** analysis, **identification of field of actions** and relevant process

Marchesini & Alcântara (2016)
5-step framework, to guide implementation of logistic activities in key business processes

Gladysz & Santarek (2015)
Strategic matters, **evaluation matrix for technology** integration, **process area** rating, **AS-IS** and **TO-BE** comparison

Dörnhöfer (2016)
Strategic and operations connection, automotive focus, combination of process areas and **performance measures**

Vidal Vieira et al. (2017)
Structural approach: Established towards strategy, process areas with logistic operations and measures

Concept of the DIALOOP framework

UNIVERSITY OF PORTSMOUTH
ESB BUSINESS SCHOOL REUTLINGEN UNIVERSITY

Positioning of literature towards a framework

Proposed concept of DIALOOP framework

Concept of the DIALOOP framework

- Provides a multi-step framework approach
- Provides an AS-IS and TO-BE comparison
- On basis of logistic operations and performance measures
- Ensures combination of strategic and operational application on this specific drone implementation topic
- Combined with proposed drone classes for the use in automotive OEM practice

The DIALOOP framework after structural influences from literature:

1. **A strategy-based multistep structure**
2. **A detailed matrix of logistics operations**
3. **A detailed matrix of performance measures**
4. **An outline of the effects of the future changes**

UNIVERSITY OF PORTSMOUTH
ESB BUSINESS SCHOOL REUTLINGEN UNIVERSITY

Concluding the literature

Main observations summarized

The following observations are made that outline the research gaps, which this thesis aims to fill:

Observation 1: There are only few sources on automotive OEM logistics operation
→ Research contributes on **current operations in up-to-date process areas** as well as existing performance measures in automotive OEM logistic operations

Observation 2: Lack of literature on drones in automotive OEM logistics operations
→ Research aims to identify logistic operations **where drones can be implemented** as well as performance measures that could be affected

Observation 3: Lack of a framework for drones in automotive OEM logistics operations
→ Research addresses the gap of a framework to **support greater understanding** what might lead to **greater acceptance of drones**. Added to the framework a specific classification can add to knowledge and implementation

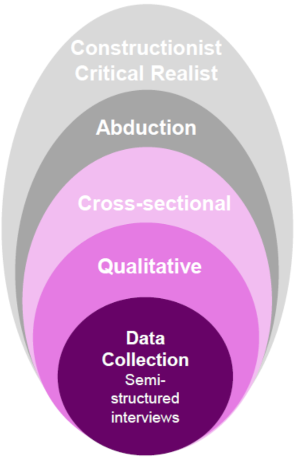
UNIVERSITY OF PORTSMOUTH ESB BUSINESS SCHOOL REUTLINGEN UNIVERSITY

METHODOLOGY

Methodological explanation

Data collection

Research "Onion" as basis for methodology explanation



own illustration based on Saunders et al. (2009)

Constructionist/ Critical Realist

- Constructionist: the **individual interviewees create meaningful information** based on their **knowledge and experience** gained in a shared professional context
- Critical Realist: **puts its focus on understanding, describing and interpreting** the social world and individual and collective experience while assuming that there is a common reality

Abduction

- **Using theoretical knowledge** on logistic operations and **extend this by drone technology** in a conceptual framework

Cross-Sectional

- Based on the **nascent research topic** and fast-moving drone environment

Qualitative

- Nascent research topic does **not provide numerical data**

Data collection, Semi-structured interviews

- Follow an **interview guide** but also have the **possibility for further discussion**

Data collection

Information to the interviews, sampling strategy and sample size

Interviews

Two sets of pilot interviews

- **2x2 pilot interviews** with colleagues

Two main set of interviews

- **9 automotive experts**
- **9 drone experts**

+

One set of validation interviews

- **3 validating automotive** experts (from previous set)

Sampling strategy

- **Purposive sampling** applied
- Looking for experts that **provide richest data**
- **Automotive experts: focus on logistic operations** and also innovation or even drone experience
- **Drone experts: focus on experts that use drones** in logistic operations (both automotive and non-automotive)
- **Minimum of 3 years** related experience

Sampling size

- Automotive: population of **about 100 experts** relevant in German automotive OEMs (experience and company organisation charts as guidance)
- Drones: population of **about 30 experts** (experience on conference speakers and LinkedIn)
- 1 expert was excluded in each set

Automotive expert 10 did not meet 3 years of minimum experience

Drone expert 6 did not reply to a mistake in the consent form

DATA ANALYSIS & FINDINGS

Drone experts

Automotive experts

DIALOOP framework

Research overview on interviews, analysis and findings

Main areas of interviews

Automotive Expert interviews

- Introduction, background, **expert level**
- **Logistics operations** from the interviewee's perspective
- Interviewee's understanding of drones
- **Use of drones** in the interviewee's process area and in logistics operations + performance measures possibly influenced by drones
- Relevant **future developments** (=current challenges and negative aspects of drone implementation

Drone expert interviews

- Introduction, background, **expert level**
- Expertise in existing **classifications of drones**
- Opinion on the **DIALOOP drone classes**
- **Characteristics** of, and possible main applications, for different drone types
- **Future developments** regarding a drone application in automotive OEM logistic operations

UNIVERSITY OF PORTSMOUTH ESB BUSINESS SCHOOL REUTLINGEN UNIVERSITY

Interview results: drone experts

Aim of a classification & Mentioned classifications

Results to importance of an aim of a classification

- Highlight mentioned towards the **aim of a classification**
- A **multi-step** framework approach
- A **matrix-based** classification must be the result
- Combine **two different classification criteria**
- Experts highlight the importance of deriving influencing factors (future developments) regarding implementation

Results to mentioned classifications

- **Take-off weight** > Leading classification
- **Type** > Leading classification
- European Union > Framework needs to be aligned with EASA framework
- Purpose and mission > Matches with central purpose definition with the framework
- Commercial/private use > Research purely commercial nature
- Indoor and outdoor use > Logistic operations occur both indoor and outdoor

Interview results: drone experts

Analysis of different types of drones

Rotor-based drones

Advantages:

Flight characteristics, construction, **manoeuvrability**; **vertical take-off and landing**, speed, flexibility and precision

Disadvantages:

Energy efficiency, **boost and weight ration** very poor

Fixed-wing drones

Advantages:

Flight characteristics; **Long flights** and fastness, high energy **efficiency**, reliability

Disadvantages:

Take-off and landing, **infrastructural needs**, loss of flight time as a result, construction with high payload **very large**; not suitable for current indoor environment

Hybrid drones

Advantages:

Combination of **vertical take-off and landing** with **fast gliding** flights, speed and flexibility, lower energy consumption

Disadvantages:

Complexity in construction, **higher weight and higher costs**, change from flying to hovering consumes **massive amount of energy** and is not possible very often

Interview results: automotive experts

Process areas & Potential of drones

Definition of process areas

- Process areas **match with the literature**
- there are single highlights **towards a continuous processes**

Potentials of drones in process areas: processes and performance measures

- **Potentials are given**, yet **some experts are sceptical** and emphasise a focus towards process optimisation without drones
- **Multiple potentials were identified**, that, in combination with drone classes, led to usable results (compared to the drone expert's opinions to that drone class capabilities)
- Potentials of drones are **both information and transportation based,** yet
- **more transportation tendencies** are seen towards the line (area of use)

Interview results: automotive experts

Automotive experts followed the DIALOOP structure and used the drone classes

Use of the proposed DIALOOP framework as interview guidance

Interview questions followed the structure of the proposed DIALOOP framework: from **general strategic questioning** through the processes: **focussing on logistic operations and performance measures** and then thinking **about the implementation of drones**

- Overall strategic thinking
- Followed the "process area differentiation" - thinking
- After giving their own expertise of knowledge the experts used a **supportive paper** of the proposed DIALOOP drone classes
- Automotive experts reached similar results as the drone experts

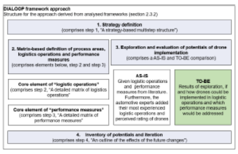
The **DIALOOP framework and the drone classes appeared to be very applicable** for the automotive experts. Besides this results mainly the validation confirmed the results from the interviews towards the usability of the DIALOOP framework

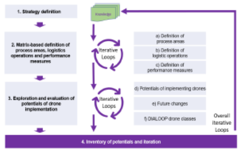
DIALOOP framework: elements derived from the interviews

Overall combination of literature and interview results

The DIALOOP framework to be developed should encompass:

1. **A strategy-based multistep structure**
2. **A detailed matrix of logistics operations**
3. **A detailed matrix of performance measures**
4. **An outline of the effects of the future changes**





DIALOOP framework based on literature

- Overall **strategic thinking**
- Aligned with frameworks from literature
- Combines **strategic and operational use**
- **Combines** current possibilities (matrix) with existing hurdles/challenges (future developments)

DIALOOP framework approach graphical design

- Aligns with basis steps from literature framework concept
- Applies matrix structure that **follows process area thinking**
- Highlights importance of **AS-IS and TO-BE comparison** regarding drone implementation

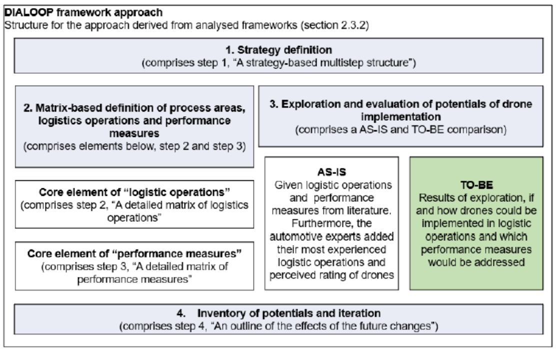
Final DIALOOP framework approach after validation

- Highlights importance of **iterative application**
- Values the possibility to **step in or out** at any time
- Adds **DIALOOP drone classes** as applicable support
- Emphasises starting-point on strategic level

DIALOOP framework: elements derived from the interviews

Comprehensive approach to using the DIALOOP framework

- The comprehensive approach derived from literature **acknowledged by the interviewees**
- Main part is the **DIALOOP framework structure itself**
- Interviews also **added a first application** to the findings of the thesis
- Thesis contains AS-IS and TO-BE parts in separate tables for further detail



Introduction Literature Methodology Analysis & Findings Contributions Conclusion

DIALOOP framework: elements derived from the interviews

Potentials of drones in process areas

Goods receipt

- Drones can generally be used, predominantly **information-based** tasks
- **Speed** and **throughput** as well as **quality** aspects can be addressed by drones

Storing

- Logistics operations for drones are **information-based** + potential drone uses identified as of a **supportive** character
- **Speed**, **utilisation** and **quality**, also strongly related to **transparency**

Picking&Sequencing

- Potential use scenarios for drones in **both information-gathering and transportation**, especially in **emergency cases**
- Performance measures affected by drones pertain to **quality** and **throughput** as well as **time** aspects

Delivery to line

- Potential operation are **urgent delivery** of supply, **resupply**
- Performance measures influenced by drones are **speed** as well as the **utilisation of transport routes**

Besides possible drone implementations and performance measures influenced by drones respectively there were also experts that **did not see any potentials for drones** and mentioned **further future developments and changes** instead

UNIVERSITY OF PORTSMOUTH ESB BUSINESS SCHOOL REUTLINGEN UNIVERSITY

26

Introduction Literature Methodology Analysis & Findings Contributions Conclusion

DIALOOP framework: elements derived from the interviews

Relevant future changes

The element of future development and changes combines **constraints and negative thoughts on drone implementations** that occurred in the interviews with **further comments and recommendations** by the expert

The following elements were identified:

- Infrastructure
- Drones Management
- Automation
- Efficiency
- Acceptance
- Legal Action
- Safety and Security
- Platform development (only drone expert)

Negative aspects of drones or unmatching logistic operations could hereby be addressed in future research or practice.

The section to future development can be seen as guidance or a back-log for future implementations.

UNIVERSITY OF PORTSMOUTH ESB BUSINESS SCHOOL REUTLINGEN UNIVERSITY

27

DIALOOP framework: elements derived from the interviews

DIALOOP drone classes

Main statements

- Conceptual framework from literature
- Adjustment of small class to up to 4kg following the interviews
- EASA framework leading and matching with final DIALOOP framework classes
- No adjustments from the validation

Finally **drones** are separated in nine classes:

- **three types x three sizes each**

Conceptual classification

Rotor-based	Fixed-Wing	Hybrid	Max. Takeoff-weight
DC* 1-R	DC 1-F	DC 1-HT	small [<2kg]
DC 2-R	DC 2-F	DC 2-HT	medium [<10kg]
DC 3-R	DC 3-F	DC 3-HT	large [<25kg]

*DC = DIALOOP Class

EASA Framework

Max. Takeoff-weight	Classes	Operation. Subcategory
<250g	C0	A1: fly over people
<900g		
<4kg		A2: fly close to people
<25kg	C3	A3: fly far from people
	C4	

Adjustment through interviews to 4 kg (section 5.4)

Extra classes enable subdivision of EASA sub-categories (C3,C4)

No adjustments from validation (section 5.6)

Resulting DIALOOP drone classification after analysis

Rotor-based	Fixed-Wing	Hybrid	Max. Takeoff-weight
DC* 1-R	DC 1-F	DC 1-HT	small <4kg
DC 2-R	DC 2-F	DC 2-HT	medium <10kg
DC 3-R	DC 3-F	DC 3-HT	large <25kg

DIALOOP framework: elements derived from the interviews

Contemporary perspective & Validation

Contemporary perspective on drone potentials using the DIALOOP framework during the interviews

Automotive experts were **guided by the DIALOOP drone classes** (as non-drone experts) and reached almost **similar understanding** like the drone experts opinion on the abilities of the drone classes (only as a perceived rating)

- **Rotor-based** drones seem to have **most fit** in the research area
- **Hybrid drones** with a perceived moderate fit
- **Fixed-wing drones** could be implemented especially in large space/range (car storage, supplier integration)

Validation of the DIALOOP framework

- Experts highlight the **feasibility of a computer tool**, were parameters are precise and locally connected
- Emphasise the importance of using the DIALOOP framework with **strategy as a beginning**
- Highlight the importance of an **iterative application** and praise possibility to **exit towards other technologies**

Contributions

Contribution to theory

Contribution to practice

Contribution to theory

Automotive OEM logistic operations and applicable performance measures

Findings to process areas

- Goods receipt, storing, picking & sequencing as well as delivery to line are **still applicable and relevant** for the thesis

Performance measures

- Basic measures emphasised in the interviews, such as **throughput, time, quality, costs** and **security of supply** have matches particularly in logistics literature
- Experts **did not propose to use the measures efficiency, effectiveness and differentiation** when thinking about drones
- Logistics experts among the interviewees **did mention only few newly developed performance measures**

UNIVERSITY OF PORTSMOUTH ESB BUSINESS SCHOOL REUTLINGEN UNIVERSITY

Contribution to theory

Logistics operations suitable for, and performance measures affected by, drone application in automotive OEMs logistics operationson

Goods receipt

- Most of the **drone-based operations align with literature**
- Performance measures addressed by drones **correspond to the basic measures**, i.e., time, quality, costs and reliability

Storing

- Logistics operations potentially executed by drones are **predominantly information based, yet also delivery of parts** and emergency part delivery were identified

Picking & Sequencing

- Logistic operations suitable for drone implementation are **predominantly of a transportation character** (picking, handling, parts emergency process), but data collection, an information-oriented process, is also included

Delivery to line

- Results show a clear focus on **urgent or error post-deliveries**
- Potential to improve performance measures relating to **speed, automation** and the **utilisation of limited space**

Drone experts' evaluation

- **Matched** with automotive expert's drone opinion
- **Rotor-based drones offer very good fit** to OEM intralogistics processes and performance measures
- **Moderate fit is offered by hybrid drones**, if complexity and high costs can be overcome
- **Fixed-wing drones offer limited fit**, yet are situated in the context of supplier integration

>> It has been shown so far that **drones can be implemented in automotive OEM logistics operations and can affect performance measures** based on the perceptions of the interviewees

UNIVERSITY OF PORTSMOUTH | ESB BUSINESS SCHOOL REUTLINGEN UNIVERSITY

Contribution to theory

DIALOOP drone classification for the use in automotive OEM logistic operations & future developments and changes

DIALOOP classification

- **Accuracy and usability of the DIALOOP classification** was confirmed by drone experts
- The **applicability of the classification was discussed, and tested**, by several automotive experts
- Classification now **offers a practice-oriented** boundary in the small-drone area of automotive intralogistics
- Framework structure **offered the automotive experts a useful guidance** in thinking about existing processes, operations, measures and the application of drones

Future developments and changes

- Research **investigated influential development and future changes** with a potential impact on drone implementation
- Drone experts and automotive **experts highlighted similar developments and changes**
- Experts highlight the **need of hierarchical differentiation** which shows the causal interrelations

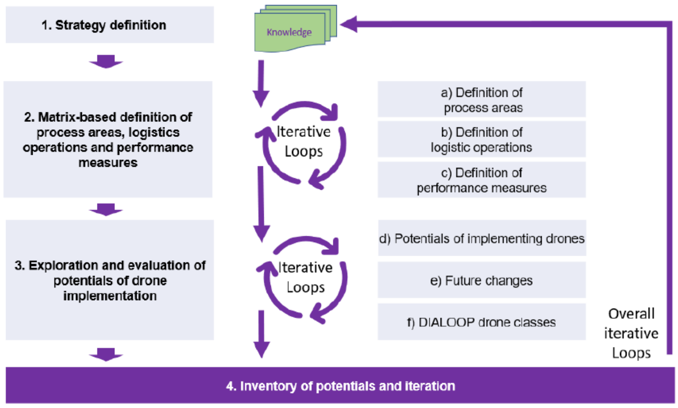
UNIVERSITY OF PORTSMOUTH | ESB BUSINESS SCHOOL REUTLINGEN UNIVERSITY

Contribution to theory

DIALOOP framework for the implementation of drones in automotive OEM logistics operations

Elements

- DIALOOP **comprehensive approach** developed
- Core structure allows the framework to be used to **compare the as-is state to a potential to-be state**
- DIALOOP **drone classes aid the user of the framework** in selecting a drone type suitable to the logistics operation
- **Future development** section contains potentially significant influence on the implementation of drones



UNIVERSITY OF PORTSMOUTH ESB BUSINESS SCHOOL REUTLINGEN UNIVERSITY

Contribution to practice

An applicable framework

- Provides the practitioner with a **guideline needed to navigate the steps toward drone implementation in intralogistics** operations
- Iterative approach **offers multiple entry points**, such as strategy or logistics operations
- **Does not block out alternative ways** toward optimisation other than drone technology
- Higher **awareness of drone technology** towards implementation possibilities
- Framework user can take the developments and changes into circumspect consideration and future-oriented planning
- **Includes also "soft factors"** like acceptance or activity towards changing job profiles
- The framework could help policy-makers to **create further, more practice-oriented regulations**

- Offers a guideline for practitioners to **explore opportunities to increase competitiveness through drone technology** solving numerous problems

UNIVERSITY OF PORTSMOUTH ESB BUSINESS SCHOOL REUTLINGEN UNIVERSITY

Introduction | Literature | Methodology | Analysis & Findings | Contributions | Conclusion

VIVA 2021: Sebastian Hartl

5th March, 2021

CONCLUSION

Main conclusions

Limitation and further research recommendations

36

Introduction | Literature | Methodology | Analysis & Findings | Contributions | Conclusion

VIVA 2021: Sebastian Hartl

5th March, 2021

Main conclusion

DIALOOP classification

- Classification confirmed as **suitable for distinguishing drone types** and classes in a way that is relevant to automotive intralogistics
- DIALOOP classification is **industry specific** and, at the same time, in agreement with non-industry-specific legal classifications
- DIALOOP classification is **useful and applicable**

DIALOOP framework

- It was shown that **drones can be a valuable addition** to the existing operational setting
- This research has shown that **drones can be implemented in several processes** in each process area
- **Performance measures were identified** as relevant as they may be affected by drone implementation
- **Drone applications can add value** if applied in specific operations, which can be identified using the DIALOOP framework

UNIVERSITY OF PORTSMOUTH

ESB BUSINESS SCHOOL REUTLINGEN UNIVERSITY

37

Limitations

- Limiting factor for this research was the **German automotive Diesel emissions crisis**
- The **number of interviewees** especially in the validation interviews due to the pandemic, respectively the breadth of knowledge of the experts could be more specific on drones
- **Corona pandemic** may have reduced willingness to participate and therefore more validation interviews
- The **existence of German work councils or culture** in general may limit the application of the research at hand and the transferability of the insights
- The framework development did not include a differentiation of **all the different process variants** in the intralogistics of car manufacturers

Further research recommendations

UNIVERSITY OF PORTSMOUTH

FEEDBACK.

40

ENDNOTES, GERMAN ORIGINALS TO ENGLISH QUOTATIONS

[1] „Frage ist, worauf die Klassifizierung letztendlich abzielt" (D7)
[2] „man hat am Ende halt dann eine x-teilige Matrix und nicht nur ein Kriterium" (D4)
[3] „muss zwangsläufig auf eine Kombination aus verschiedenen Klassifizierungen hinauslaufen" (D9)
[4] „wollen eine Drohne nicht implementieren, um eine Drohne zu implementieren sondern einfach weil wir ein Problem des Kunden damit lösen wollen" (D4)
[5] „muss zwangsläufig auf eine Kombination aus verschiedenen Klassifizierungen hinauslaufen" (D9)
[6] „geht's ja zum einen nach Verwendungszweck und Gewichtsklasse hauptsächlich" (D1)
[7] „die bestehenden Klassifizierungen ergeben sich ja letztlich ein bisschen aus dem Luftrecht" (D9)
[8] „Wenn man vom Bodenrisiko zum Beispiel wieder an die Frage rangeht, kann es sein, dass man eher nach Gewicht gehen sollte" (D7)
[9] „Gesetzgebung, die jetzt quasi in der Pipeline ist, die wird sich sehr stark nach dem Risiko orientieren, die diese Drohne auf die Umwelt hat, und da wird das Gewicht wahrscheinlich keine große Rolle mehr spielen" (D10)
[10] „je kleiner je leichter die Drohnen sind umso weniger reguliert sind Sie, umso schwerer sie werden umso strenger werden die Auflagen" (D1)
[11] „man kann halt über das Gewicht natürlich letztlich immer streiten" (D9)
[12] „Unterscheidung zwischen eben Fixed Wing – Systemen, den Rotary und den Hybrid-Systemen" (D3)
[13] „über die Mission und die Art des Betriebs klassifizieren" (D9)
[14] „Sensortragende Systeme, ähm, dann Logistik und Transportsysteme die irgendwelche Lasten von A nach B transportieren, und dann so im oberen Ende dann so Mann-tragenden Systeme" (D5)
[15] „die Unterscheidung zwischen kommerzieller und ähm privater Nutzung" (D1, D3, D4, D8)
[16] „bei etwa 10.000 Euro gesetzt also alles was nördlich ist würden wir als reines Profiequipment zählen" (D10)
[17] „eigentlich zwischen Systemen für den Inneneinsatz und Systemen für den Außeneinsatz. Das ist eigentlich für uns die wichtigste Unterscheidung" (D3)
[18] „Transportflügen Outdoor, von Dringteilen, von Ersatzteilen" (D4)
[19] „könnte […] vorstellen, dass im Logistikbereich vor allem Multirotorsysteme sich durchsetzen werden aufgrund der Flexibilität" (D1)
[20] „sehr präzises Fliegen, mit Fliegen auf der Stelle" (D4)
[21] „Infrastruktur die am Boden vorhanden ist, kann relativ schlank gehalten werden" (D7)
[22] „der ewige Handel, den man da halt führen muss" (D10)
[23] „Effizienzsteigerung der Plattform, dass die also länger und schneller oder beides fliegen" (D10)
[24] „tatsächlich irgendwie Hochregale abfliegen, Barcodes scannen" (D1)
[25] „die sind auch recht zuverlässig und auch das recht ähm günstig im Wartungsfall" (D2)
[26] „Start und Landung" (D1)
[27] „ein Tilt-Wing multiples Gerät kann selbst senkrecht starten, geht dann in den Gleitflug über und kann dann auch wieder senkrecht landen" (D5)
[28] „vor allem in die Richtung geht, dass die Drohnen speziell für eine bestimmte Aufgabe entwickelt werden" (D1)
[29] „die Strecken schneller überbrückt werden" (D7)
[30] „niedrigerem Energieeinsatz als mit Multirotoren" (D8)
[31] „muss größere Bereiche schaffen, in denen sie abfliegen und arbeiten können" (D1)
[32] „unter Berücksichtigung von entsprechenden Sicherheitsauflagen" (D8)
[33] „auch Möglichkeiten, wie Drohnen mit anderen Drohnen oder einer Art zentralem System zur Verwaltung des Drohnen-Luftraums interagieren können" (D2)
[34] „hier ist so eine Forschungsplattform, die fliegt, und die hat Interfaces, macht damit was ihr wollt"
[35] "gibt ja viele, die diesen Ansatz fahren, auf eine ganz spezifische Problemstellung eine Drohne zu entwickeln oder eine anzupassen" (D1)
[36] „wenn es komplexere Umgebungen werden, muss das Problem gelöst werden" (D1)
[37] „ich kauf mir ja nicht eine Drohne, damit ein Mann das Ding dann irgendwie belädt und ein anderer das steuert, da kann dann einer das Teil auch direkt von A nach B tragen" (D10)
[38] „wenn wir da jetzt Faktor 10 schaffen mit einem Energiespeicher mit elektrischem oder elektrochemisch […] Speicherung der elektrischen Energie mit Akkus" (D9)
[39] „geht das Spiel wieder von vorne los, wie viele Batterien kann man tragen, und wie ist das noch in einem Verhältnis zueinander" (D10)
[40] „Menschen müssen sich also an die Drohnen am Himmel gewöhnen" (D2)
[41] „Mehr Pilotprojekte" (D3)
[42] „einheitliche einfachere regulatorische Rahmenbedingungen" (D5)
[43] „allein durch die rechtliche Situation, kann man sagen, dass eine kleinere Drohne oftmals schneller eine Genehmigung bei kritischen Infrastrukturen sozusagen stattgegeben wird" (D7)
[44] „die Zukunft der Drohnen wird wie heute Handys oder Smartphones sein" (D2)

[45] „Intralogistik beginnt […] ab dem Wareneingang (A1)
[46] „klassischer Wareneingang" (A2)
[47] „haben verschiedenen Lagerstrukturen" (A2)
[48] „entweder sortenrein das Material an die Linien bringen oder halt in Sequenz" (A10)
[49] „wir machen Leergutsteuerung nach dem kürzesten Lieferanten, der das Teil im VW Konzern braucht (A3).
[50] „Wareneingang ist ja eigentlich, ich sag mal, nur ein Gefahrenübergang" (A3)
[51] „Entladung eines LKWs und das Abstellen der Ware auf irgendwelchen Kontrollpunkten (A4)
[52] „das Gewicht der Ladungsträger einfach schlichtweg viel zu hoch" (A4)

[53] „wenn ich mir vorstelle, dass ich im Jahr 2019 oder im Jahr 2020 eine Drohne nehmen soll um festzustellen wo der LKW ist oder wo meine Ladung ist, dann hab ich eigentlich vorher ein anderes Problem, das ich nicht beherrscht“ (A6)
[54] „was ist da angeliefert worden, auf Vollständigkeit geprüft wird“ (A2)
[55] „wie pünktlich ist die Ware“ (A10)
[56] „Transportieren im weitersten Sinne natürlich auch“ (A2)
[57] „die Drohne spät nachts oder eben zu betriebsfreien Zeiten nochmal durch die Halle durchfliegen“ (A5)
[58] „Optimierung von Stellplatz Zuweisungen durch die Erkennung von freien Stellplätzen“ (A2)
[59] „dass man auch da dann ähm Drohnen über die Fahrzeuge schweben kann” (A9)
[60] „sollte ich mich eher auf meinen Prozess konzentrieren, dass ich weiß, wo ich mich hinstelle, und den Prozess robust machen, dann brauch ich nicht anschließend durch einen Korridor fliegen“ (A6)
[61] „wichtig ist natürlich, dass wir geringe, geringere Durchlaufzeiten haben“ (A1)
[62] „möglichst wenig Lagerbestände” (A1)
[63] „Auslastung der Lagerstruktur“ (A2)
[64] „schneller mit der Drohne unterwegs vs. den klassischen Transporteinheiten“ (A3)
[65] „wäre das ja auch schon eine Effizienzsteigerung“ (A7)
[66] „der reine Pickprozess” (A7)
[67] „die Teile die ich sequenzieren möchte die sind entweder in Regalen eingelagert oder ebenerdig verteilt“ (A4)
[68] „keine 100% Kontrolle” (A10)
[69] „Parallelisierung der Prozesse ist möglich, das heißt ich könnte mehr Aufträge bearbeiten“ (A2)
[70] „wieviel Zeit brauchst du, um einen gewissen Vorgang zu machen“ (A3)
[71] „Vermeidung von falsch zugeordneten Bauteilen“ (A9)
[72] „in Begleitprozessen dieser Tätigkeit” (A2)
[73] „wirklich ein Wahnsinns großes Potenzial” (A6)
[74] „aus unseren Bereitstellflächen raus mit unseren Routenzügen und Staplern, ähm, Transportsystemen bis vor Ort“ (A8)
[75] „die Fahrstrecke zurücklegen, vom Lager, vom Auslagerungspunkt hin zum Bedarfsort“ (A10)
[76] „so eine Eilanlieferung oder so eine Sonderanlieferung, wenn mal Material ausgegangen ist“ (A5)
[77] „Nachlieferungsprozesse, wenn Fehler auftreten“ (A4)
[78] „in beiden Fällen ist die Ware, die transportiert wird, ähm, zu schwer um aktuell mit den technischen Möglichkeiten einer Drohen transportiert zu werden“ (A4)
[79] „Termintreue, das es natürlich zur richtigen Zeit am richtigen Ort ist“ (A2)
[80] „dass das also pünktlich kommt, also in dem Fall nicht die Dauer, sondern da reichen die Zeitfenster, wann das bereitgestellt wird“ (A8)
[81] „Themen wie Transportauslastung, Transportfrequenzen” (A10)
[82] „schneller passiert, weil ich Drohnen einsetzen kann und sozusagen Transporteinheiten schneller entladen kann“ (A2)
[83] „auch vorstellen, dass die 3. Dimension einfach die Infrastruktur entlastet“ (A10)
[84] „ich will ja hoch und runter können, ich will ja nicht morgen Löcher in meine Gitter machen müssen. Ich will ja eine flexible Fabrik“ (A6)
[85] „viele Details in den Prozessen so ändern, dass eine z. B. Zugänglichkeit für die Drohne gegeben ist“ (A2)
[86] „gesamte Lieferkette abbilden können“ (A1)
[87] „nicht nur diesen einen Prozess machen, sondern wir müssen eine Kombination vieler Prozesse umsetzen“ (A7)
[88] „die Reproduzierbarkeit des eingegebenen Flugwegs“ (A8)
[89] „eher auf den Anwendungsfall beziehen, also auf die Aufgabe und nicht auf die Größe“ (A2)
[90] „braucht einen sicheren Formschluss zur Ladung“ (A6)
[91] „also wenn ich die Drohne jetzt pro Schicht drei bis viermal auf die Ladestation schicke, das würde niemals funktionieren“ (A4)
[92] „die reine Performance, also was kann eine Drohne heben“ (A2)
[93] „die Technologie muss präsent werden bei den Leuten und die müssen sehen, was damit alles möglich ist“ (A1)
[94] „"jetzt eine technische Lösung zu finden, dass ich unter der schwebenden Last arbeiten kann"
[95] „großer Befähiger für das Thema Drohne ist da wirklich noch die rechtlichen Rahmenbedingungen“ (A2)
[96] „bei den Drohnen sind wir schon technisch auf einem Level, was deutlich mehr ermöglichen würde als das was wir aktuell machen” (D7)
[97] „geht’s ja zum einen nach Verwendungszweck und Gewichtsklasse hauptsächlich“ (D1)
[98] „eher kleinere Lösungen, weil es ist Indoor“ (A1)
[99] „bei diesen Fixed Wings, mit denen kann ich aus der Intralogistik heraus eigentlich garnichts anfangen“ (A5)
[100] „kann auf der Stelle drehen, dann muss ich keine große Kurve irgendwo fliegen“ (A1)
[101] „auf Werksgelände Inhouse würd ich die hier wieder garnicht sehen die Fixed Wings“ (A10)
[102] „auch unabhängig vom Technikträger ist es sehr unwahrscheinlich ist, dass da eine Drohne eingesetzt würde“ (A4)
[103] „je kleiner desto besser“ (A10)
[104] „bei kleinen und Leicht-teilen reicht auch vielleicht Small oder Medium“ (A1)
[105] „besser geeignet, um größere Entfernungen zurückzulegen, also den Bedarf hätte ich jetzt hier im Werk nicht“ (A10)
[106] „reguläre Anlieferung von Größladungsträgern seh ich überall eine 5, das funktioniert nicht“ (A4)
[107] „vom Aufbau her passt das ja schon und ist ein Vorgehen, was man wählen kann“ (V1)
[108] „dass man beginnt mit einer Lösung und dann versucht ein Problem zu finde“ (V3)
[109] „finde vor allem den Ansatz interessant mit Strategie zu beginnen“ (V3)
[110] „So ähnlich gehen wir ja auch bei FTS Prozessen vor“ (V1)
[111] „passt das sehr von der Vorgehensweise her, also von der methodischen Vorgehensweise her. Das ist sehr in Ordnung was sie da gemacht haben“ (V2)
[112] „weil Logistik sind ja immer das richtige Teil zur richtigen Zeit am richtigen Ort“ (V2)
[113] „willst du den Prozess weg haben vom Werksgelände eigentlich, weil er Platz braucht ohne Ende” (V1)
[114] „das sind viele Faktoren, weil so ein Prozess so viele Prämissen hat. Das kann natürlich beliebig viele Kombinationen einzelner dieser Prämissen dafür sorgen, dass es plötzlich relevant wird“ (V1)

[115] „zum Beispiel ein ganz großes Ding auch Richtung Qualität“ (V2)
[116] „find ich gut, verstehe ich auch, ist in Ordnung, ja.“ (V2)
[117] „vor allem das Acceptance und Safety and Security, das ist natürlich ganz nah beieinander“ (V3)
[118]„die aktuelle Gesetzgebung macht eine wirtschaftliche Anwendung eben unwahrscheinlich schwierig“ (V3)
[119] „das würde passen. Da würde man wahrscheinlich gefühlt vielleicht so ein bisschen parallel fahren“ (V1)
[120] „dann spring ich nochmal zurück. Wobei man das ja mit deinem Loop erklären würde, wenn der da auch zu tragen käme“ (V1)
[121] „bis ich irgendwie sage ich bin fertig und viertens kommen dann meine Potenziale irgendwie raus“ (V2)
[122] „vielleicht auch mal schauen, wo bietet denn die Drohne eigentlich auch die Chance mich von der bestehenden Prozesswelt vielleicht auch ein Stück weit zu lösen“ (V3)
[123] „auch die Frage stellen, wo hätte ich vielleicht in der bestehenden Welt vielleicht revolutionäre Ansätze für Prozesse einfach durch diese Vorteile die die Drohne bietet“ (V3)
[124] „Prämissen, die dafür sorgen, dass verschiedene Prozesse für verschiedene Bauteile erforderlich sind“ (V1)
[125] „deswegen würde man hier unter der Überschrift Pilot oder Enabler […] eine Proof of Concept würde man mal testen” (V1)
[126] „würde […] dann am Ende das Ding wieder nutzen – also einen Loop machen und dann die Zahlen ermitteln, die man dann künftig braucht“ (V1)
[127] „man muss dann ja schon konkret überlegen, wo möchte ich denn rein“ (V2)
[128] „halte es für unglaublich falsch […] mit einer Lösung anzufangen und ein Problem zu suchen” (V3)“
[129] „performance measures hätte nicht mehr die Bedeutung, die es aktuell hätte“ (V3)
[130] „wäre dann wahrscheinlich viel stärker im Fokus als Potenziale und Kosten und Leistungskennzahlen“ (V3)