Drones in Manufacturing: Opportunities and Challenges

Omid Maghazei
Chair of Production and Operations Management (POM)
Department of Management, Technology, and Economics (D-MTEC)
ETH Zurich, Switzerland
omaghazei@ethz.ch

Abstract

Over the past decade, the applications of drone technology have proliferated in various industries. This dissertation sets out to investigate the opportunities and challenges of drones in manufacturing industries from an operations management (OM) perspective. This dissertation consists of four papers. The first paper explores the applications of drones in manufacturing and proposes a typology of drone applications. The second paper narrows down the scope to examine potential applications and the benefits and challenges involved in the petrochemical industry that has shown particularly high potentials for the use of drones. The third paper focuses on the adoption process of drones in Geberit and IKEA and highlights where, why, and how drones can be used in operations settings. The fourth paper builds a virtual simulation model and explores the potential of automatic drones in factory inspection operations. This dissertation contributes to the existing literature on advanced manufacturing technologies (AMT) by introducing the new case of drones. This dissertation has rich contributions to practice. First, it provides a systematic approach to identifying drone applications, benefits, and challenges in manufacturing settings and provides a useful starting point for companies evaluating the adoption of drone technology in their factories by elucidating the factors that should be known and planned before implementation. This dissertation benefits from both *explorative* and *experimental* research approaches. To the best of the author's knowledge, this dissertation offers one of the first systematic and rigorous analyses on drone technology from an OM perspective.

Keywords
Drones, Operations Management, Technology Management, Industry 4.0, and Manufacturing.

1. Introduction
Unmanned aerial vehicles (UAVs)—popularly known as drones—have a long history of development, primarily for military applications. Over the last two decades, breakthrough advances in drone technology (Floreano and Wood, 2015), as well as in components, and other technologies used in drones, have enabled transforming drone technology from a military tool to a commercial product. Despite their great potentials, the adoption rate of drones in *manufacturing* industries has been rather limited.

At the start of this doctoral research in 2016, to the best of the author's knowledge, the only application of drones in the manufacturing industry was concerned with inspection and monitoring in outdoor environments of oil, gas, and petrochemical plants, particularly for the inspection of flaring stacks (sUAS News, 2014). Yet, consulting and financial service companies and investment banks released optimistic estimates in 2016 for the future of drone technology as an industrial tool (e.g., Allianz, 2016; Goldman Sachs, 2016; Mazur and Wiśniewski, 2016). Drones also explicitly appeared for the first time in Gartner's Hype Cycle for Emerging Technologies in 2016, which mapped drones at the early phase of the *peak of inflated expectations* (Forni and Meulen, 2016) (see Figure 1).

Figure 1. Gartner's 2016 Hype Cycle for Emerging Technologies (Forni and Meulen, 2016)

Despite witnessing the growth of drone applications in various sectors such as agriculture, construction, and mining, as well as market estimates on the potential of drones as industrial tools, the manufacturing industries had a relatively slow adoption rate of drone technology, particularly in the beginning of this research project in 2016. This research project set out to explore the potential of drone technology in manufacturing industries from an OM perspective.

2. Summary of the papers included in this dissertation

This dissertation consists of four papers. The scope of the papers included in this dissertation is illustrated in Figure 2 and is detailed in Table 1.

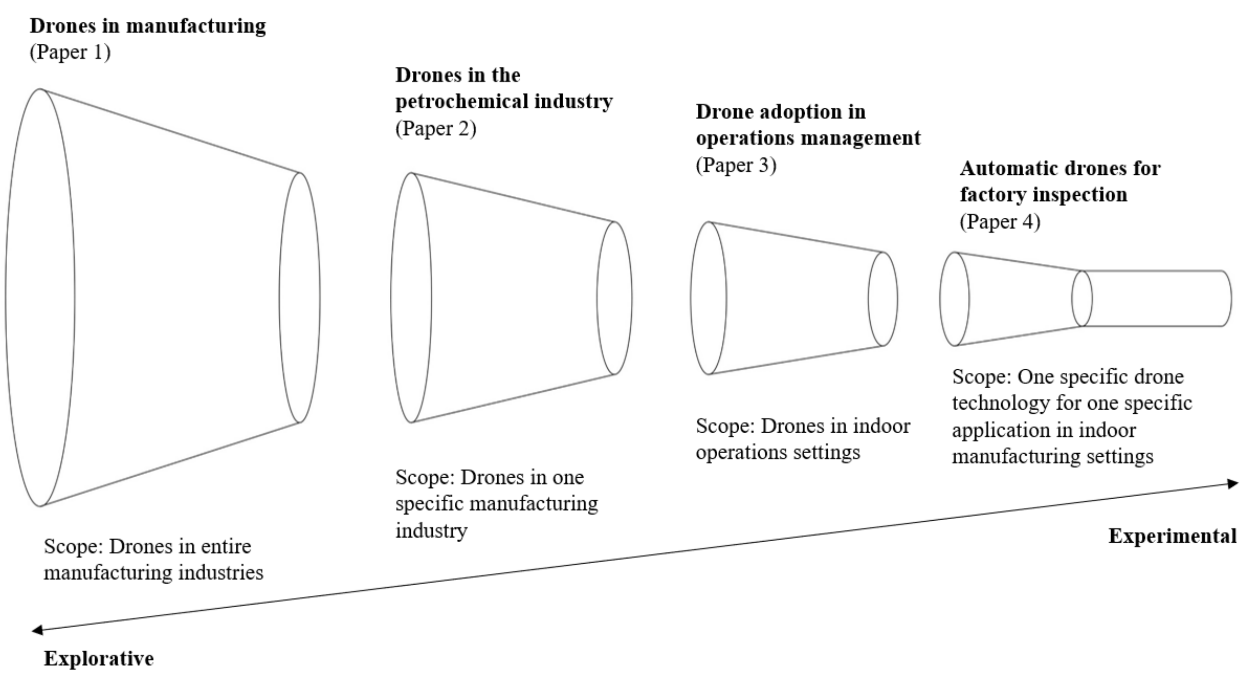


Figure 2. The scope of papers included in this dissertation

Table 1. Overview of the papers

	Paper 1	**Paper 2**	**Paper 3**	**Paper 4**
Title of the paper	"Drones in manufacturing: Exploring opportunities for research and practice"	"Exploring the value of drones in petrochemical plants: Implications for the management of emerging technologies in process industries"	"Emerging technologies and the use case: A multi-year study of drone adoption"	"Automatic drones in manufacturing: Evidence from field research with simulation"
Short title	"Drones in manufacturing"	"Drones in the petrochemical industry"	"Drone adoption in operations management"	"Automatic drones for factory inspection"
Authors	Omid Maghazei, Torbjørn Netland ETH Zurich	Omid Maghazei ETH Zurich	Omid Maghazei[1], Michael Lewis[2], Torbjørn Netland[1] [1]ETH Zurich, [2]University of Bath	Omid Maghazei, Dirk Frauenberger, Tobias Thalmann, Torbjørn Netland ETH Zurich
Research objectives	Exploring applications, benefits, and challenges of drones in the manufacturing industry	Exploring applications, benefits, and challenges of drones in the petrochemical industry	Studying the adoption of drone technology in operations management	Analyzing the potential of automatic drones in indoor manufacturing settings
Methodology	Interviewing experts	Value-focused thinking	Longitudinal case study	Virtual simulation
Main data	66 interviews	49 interviews	24 interviews, 1 focus group	Simulation model in Gazebo
Supplementary data	Attendance at drone exhibitions	Attendance at petrochemical fairs, site visits	Observation sessions, informal interviews, archival documents	Factory layout and machine measurements
Industrial partners	-	-	Case companies: Geberit, IKEA. Drone vendors: Flyability, Verity, Hardis	Geberit
Key contributions	Developing the typology of drone applications	Identifying the applications, benefits and challenges of drones in a specific process industry	Proposing a "use case-driven" framework for the adoption of drones in operations management	Identifying the technological and operational challenges of using automatic drones for factory inspection
Status of the paper	Published in the *Journal of Manufacturing Technology Management*, 2019	To be submitted to *Production and Operations Management* (*POM*) in 2022; early version presented at EurOMA 2018	Accepted in the *Journal of Operations Management* (*JOM*), 2022	Published at the proceedings of Advances in Production Management Systems (APMS), *IFIP Advances in Information and Communication Technology*, 2021
Contributions of Omid Maghazei	Major contributions to literature review, research design, data collection, data analysis, writing of the manuscript	Sole authored	Major contributions to literature review, research design, data collection, data analysis, writing of the manuscript	Frauenberger and Thalmann developed the simulation under my supervision. Major contributions to literature review, research design, writing of the manuscript

2.1 Summary of Paper 1: "Drones in manufacturing"

The application of drones in manufacturing is in its infancy but is foreseen to grow rapidly over the next decade. The purposes of Paper 1 are to explore current and potential applications of drones in manufacturing, examine the opportunities and challenges involved, and propose a research agenda. The paper reports the results of an extensive qualitative investigation into an emerging phenomenon, informed by the literature on AMTs.

Paper 1 uses *interviewing experts* as an appropriate and complete research method to reconstruct explicit expert knowledge through a structured procedure (Meuser and Nagel, 2009; Pfadenhauer, 2009). Data collected from in-depth interviews with 66 drone experts representing 56 drone vendors and related services are analyzed using an inductive research design.

This paper makes a distinction between analytical and physical capabilities of drones, and based on this, proposes a typology of drone applications in manufacturing (see Figure 3). A drone's physical capability is defined as *the ability to conduct physical tasks*, and its analytical capability is defined as *the ability to process data* (cf. Kotha, 1991; Kotha and Swamidass, 2000), with each capability classified as "low" or "high." A drone with low analytical capability only captures input data without processing it, whereas a drone with high analytical capability converts the input data to other forms of data or information. A drone with low physical capability is unable to perform any physical operation other than flying, whereas a drone with high physical capability has the ability to execute physical tasks or to perform a physical operation in addition to flying. The typology categorizes four types of applications into "see," "sense," "move," and "transform."

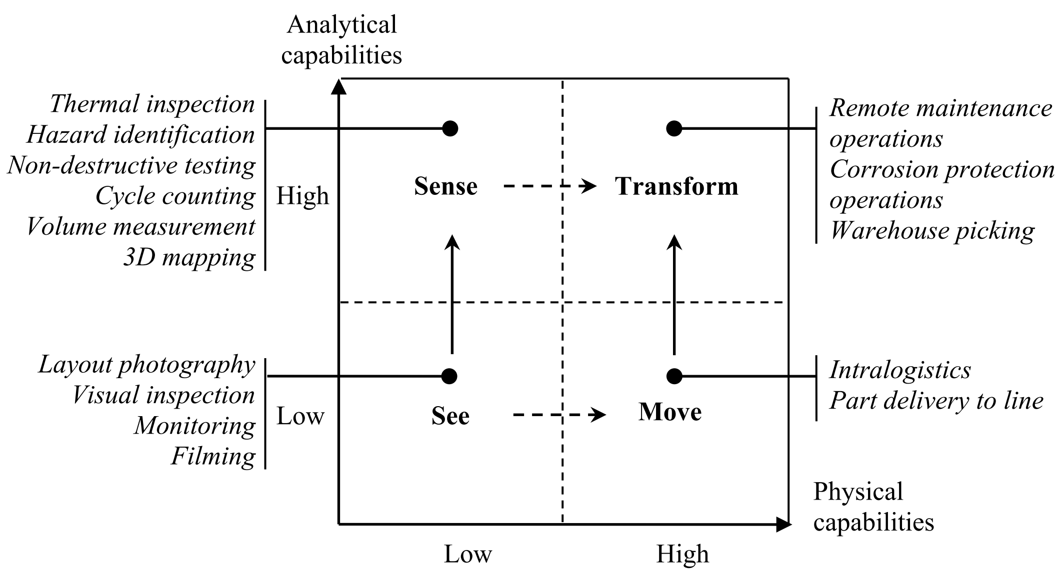


Figure 3. Typology of industrial drone applications

Paper 1 also summarizes the benefits and challenges of using drones in manufacturing industries. Although the real benefits are related to specific use cases and contexts, the findings show that the potential benefits can be classified into five broad categories: cost savings, task speed, safety improvements, efficient data collection, and public relations (PR) and marketing. Five generic categories of challenges and drawbacks related to the use of drones in manufacturing are also classified as technological, operational, organizational, legislative, and societal.

The proposed research agenda in this paper offers a guide for future research on drones in manufacturing and assists in the establishment of a new stream of literature on the topic. Guidance on current and promising potentials of drones in manufacturing is also provided to practitioners. Particularly interesting applications are those that help manufacturers "see" and "sense" data in their factories. Applications that "move" or "transform" objects are scarcer, and they make sense only in special cases in very large manufacturing facilities.

2.2 Summary of Paper 2: "Drones in the petrochemical industry"

The applications of drone technology are increasing quickly in many industries, and evidence shows that the petrochemical industry represents high potentials for the use of drones. The existing literature on the management of technology shows that there is little research on the adoption and implementation of early-stage and emerging technologies in process industries to start grappling with the analysis of drone technology in the petrochemical industry. This research set out to explore *what* applications drones can offer to the petrochemical industry, and *why* or *why not* drone technology should be adopted in this industry.

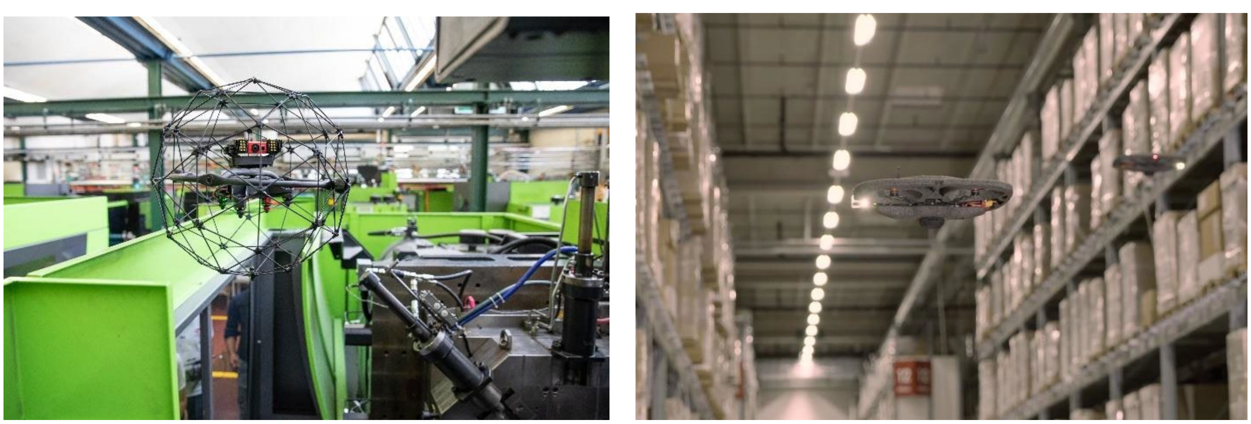
To study drones in the petrochemical industry, *value-focused thinking* was used (Keeney, 1994, 1996; Keeney and McDaniels, 1992). To do so, 49 senior managers from 17 petrochemical plants that are mostly located in the Middle East were interviewed. Insights from 13 drone vendors and service providers that specialize in oil, gas, and petrochemical industries were also used to complement the analysis.

The applications of drones in the petrochemical industry can be classified into six main categories: 1) HSE, 2) inspection, 3) maintenance, 4) project and construction, 5) security, and 6) warehouse. The main benefits of drones include boosting the performance of petrochemical plants through cost reduction, increasing safety, and improving security and environmental measures. The main challenges of using drones in the petrochemical industry can be classified into technological, operational, and organizational.

By exploring the value of drones in petrochemical plants, this paper contributes to the broader literature on the management of technology in OM scholarship by highlighting the dynamics of adopting drones in supportive operations of process industries. This study also has practical contributions regarding the applications, benefits, and challenges of using drones in the petrochemical industry, which can be extrapolated to other process-oriented settings.

2.3 Summary of Paper 3: "Drone adoption in operations management"

How does a company take advantage of disruptive "Industry 4.0" technologies, such as drones? Drones were not developed to solve traditional operational problems, they lack a clear business case, and they can have low acceptance with frontline workers due to privacy, safety, and noise concerns. This paper is grounded in the AMT literature that suggests three set of success factors for technology adoption: (1) economic and strategic factors, (2) operational and supply chain factors, and (3) organizational and behavioral factors. This paper mainly draws on two longitudinal case studies of drone applications in Geberit for inspection operations and IKEA for inventory counting. Figure 4a shows an example of Flyability drone operation in Geberit conducting thermal inspection of an injection molding machine and Figure 4b shows an example of Verity autonomous drones reading barcodes in an IKEA warehouse.



a) Flyability drone flying over an injection molding machine in Geberit (Photo: Geberit)

b) Verity drone flying in an IKEA warehouse (Photo: IKEA)

Figure SEQ Figure * ARABIC 4. Examples of drone operations in the case companies Geberit and IKEA

This paper explores how drone technology transitioned from first ideas to, albeit early, implementations at scale in daily operations. This paper documents an ongoing "struggle" between technological maturity and meaningful operational value when faced with hyped technologies. A key finding is the critical role of the "use case"—a concept commonly used in information systems research but underdeveloped in operations management.

2.4 Summary of Paper 4: "Automatic drones for factory inspection"

This paper focuses on analyzing the use of drones with higher levels of automation in Geberit using the *virtual simulation* method. Virtual simulation is an established method in industrial engineering, OM, and management sciences as a good choice when field implementation is costly, risky, or impossible (Davis et al., 2007; Shafer and Smunt, 2004). Figure 5 shows screenshots of drone flights in the Gazebo simulation environment.

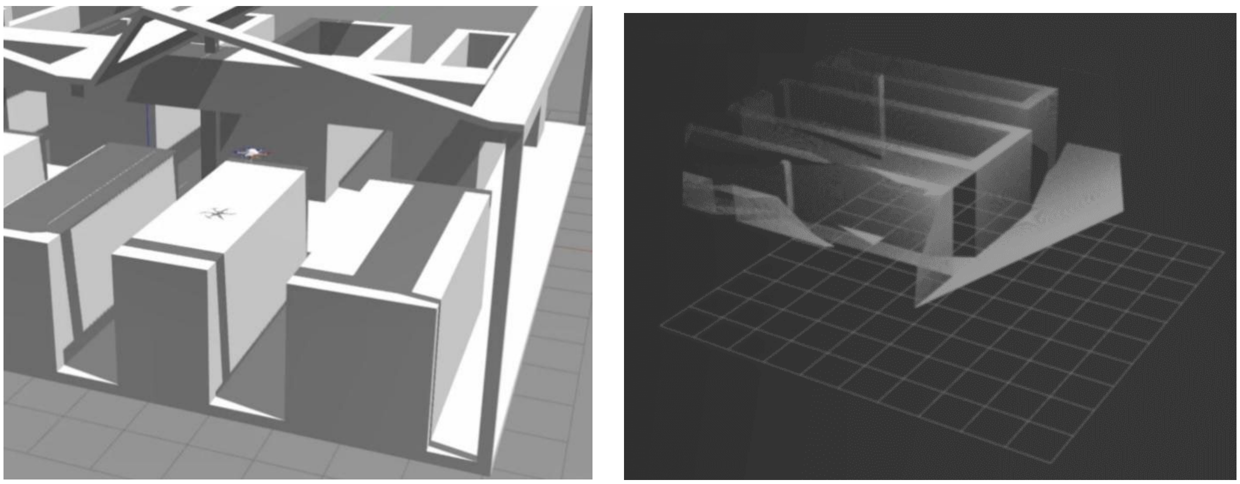


Figure 5. The left picture shows the AscTec Firefly drone on top of an injection-molding machine, and the right picture shows the coverage of the drone sensor.

The results demonstrate that the virtual simulation helped Geberit evaluate the potential of automatic drones for thermography inspection and could quickly be adapted for different use cases and scenarios. The potential implementation of automated, routine thermal inspection of injection-molding machines could help increase productivity at Geberit. Geberit could discover heat losses and irregularities earlier than it can at present, which could (1) reduce the defective parts produced or improve the material quality of products, (2) increase machine uptime, (3) reduce maintenance time (e.g., by decreasing the time to search for undetected heat losses, sources of oil leakages, and defective band heaters, isolations, and cooling systems), and (4) reduce energy costs. Geberit managers estimated the potential savings in maintenance costs alone at CHF (Swiss franc) 24,000 annually. Given that the technology would be available, safe, and cost-efficient to implement and operate, this makes a positive business case for automated drone flights for inspection.

3. Contributions

Table 2 summarizes the contributions of the papers of this dissertation.

Table 2. Summary of the contributions of the papers of this dissertation (direct contributions are marked with an X, while indirect contributions are marked with an X in parentheses)

Contributions	Paper 1: "Drones in manufacturing"	Paper 2: "Drones in the petrochemical industry"	Paper 3: "Drone adoption in operations management"	Paper 4: "Automatic drones for factory inspection"
1. Discussing the differences between drones and other AMTs	x		x	

2. Proposing a typology of drone applications in manufacturing industries	x			
3. Summarizing the opportunities of drones in manufacturing industries	x	(x)	(x)	(x)
4. Summarizing the challenges of drones in manufacturing industries	x	(x)	(x)	(x)
5. Exploring the potential of drones in a specific process industry		x		
6. Exploring the potential of drones in operations settings	(x)		x	(x)
7. Evaluating the potential of drones with higher levels of automation in factory inspection operations				x
8. Proposing a "use case-driven" framework for the adoption of drones in operations management			x	
9. Bringing together insights from drone developers and drone users		(x)	x	x

3.1 Contribution 1

This dissertation shows that drones could be defined as constituting a new form of AMT to increase business performance in specific manufacturing industries. However, a review of the extant literature on AMTs shows that drones exhibit distinct characteristics during the adoption process because of three main factors. First, this is due to the very different provenance of such technology (i.e., developed for military and leisure applications). Second, drone functionality in terms of flying capability, different analytical and physical capabilities, versatility (i.e., being mounted with various sensors), mobility (e.g., being a portable and flexible tool), and variety of automation level (from manual to fully autonomous operations) has made a clear distinction between drone technology and other AMTs. Third, drone technology is still emerging, and its capabilities are advancing, which releases new potentials and applications that can outcompete its analogs in manufacturing settings.

3.2 Contribution 2

In this dissertation, the typology of drones in manufacturing industries classifies applications based on the physical and the analytical capabilities of drones. An original and theory-informed typology for drone applications is a timely contribution to the nascent literature. This typology could be used to map the tested or currently in-use drone applications in a few manufacturing companies, showing that the typology has a face value.

3.3 Contribution 3

Drones offer various opportunities to different kinds of manufacturing industries to improve their business performance. For example, the drones' flying capability that allows access to hard-to-reach areas can lead to improvements in terms of cost, quality, safety, or time of access in specific use cases. Drones can reduce the cost of access by offering a more economical alternative to expensive means of access and transport, such as helicopters. Drones can improve the quality of access by allowing aerial overviews of areas that are blind spots, such as pipe racks. Drones can increase the safety of access compared with risky alternatives, such as rope access. Finally, drones can decrease the time of access compared with time-consuming alternatives, such as scaffolding.

3.4 Contribution 4

The challenges of using drones could be classified into technological, operational, organizational, legislative, and societal and mental challenges. The main *technological* challenges involve the current battery limitations of drones, causing constraints in payload and flight time, the reliability of drones during system failures and the risk of explosion in hazardous areas are other technological challenges. The main *operational* challenges include reliable data transfer and compatibility with infrastructure. The main *organizational* challenges include training pilots, developing know-how and organizational routines for drone flights. The *legislative* challenges mainly address privacy regulations. Finally, the *societal and mental* challenges are concerned with trusting drone flights in terms of reliability and safety and managing likely anxieties and pressures on personnel.

3.5 Contribution 5
Using emerging technologies in process industries has scarcely been the subject of research in OM scholarship. In this dissertation, the potential of drones has been studied in a specific category of process industries—the petrochemical industry. "While the process industry realizes a considerable portion of GDP in many countries, operations management (OM) research has traditionally paid very little attention to this large group of industries" (Donk and Fransoo, 2006, p. 211). This dissertation contributes to this deficiency in OM scholarship by highlighting the management of emerging technologies such as drones in process industries.

3.6 Contribution 6
Evidence shows that using drones indoors poses more technological (e.g., navigation), operational (e.g., noise), and organizational (e.g., investment justification) challenges than doing so outdoors. In this dissertation, to study the potential of drones in indoor settings, a research project was established with Geberit and IKEA to present case evidence of opportunities and hurdles in adopting drones in operations settings.

3.7 Contribution 7
The development of automatic drone technology can be a game changer for the applicability of drones in indoor manufacturing. This dissertation contributes to the assessment of using automatic drones in factory inspection operations through a virtual simulation method. Virtual simulation models enable playing with automatic drones, defining and evaluating different trade-off scenarios, and investigating the hurdles of using automatic drones in indoor settings.

3.8 Contribution 8
Operations managers have long been engaging in technology management. However, in the era of "Industry 4.0," they are now being asked to explore, assess, pilot, and scale fast-changing and potentially disruptive technologies before certainty in the business case. Given the ambiguous nature of this managerial challenge, this dissertation contributes theoretical and practical insights. Although the classic technology adoption models of the AMT literature would generally suggest that drones should not have been piloted as often as they are, this dissertation shows that hyped "Industry 4.0" technologies like drones—supported by a thriving vendor ecosystem—are developing into viable business cases through piloting of use cases. This dissertation also provides cautionary points for TM researchers to be sensitive to the technologies' development stage.

3.9 Contribution 9
Studying emerging technologies needs to bridge insights from the developer and the user perspectives in order to align the developments with real needs. Combining insights from both drone technology developers and drone users is a crucial step for an early analysis on an emerging technology, which avoids providing one-sided, either overly optimistic or pessimistic results on technological capabilities and unrealistic application areas.

4. Conclusion
To the best of the author's knowledge, this dissertation presents the first academic analysis of potential drone applications in manufacturing from an OM perspective. This dissertation has analyzed the potentials of drone applications in manufacturing industries as constituting an AMT. The results show that drone technology has quite distinct characteristics and that drone adoption processes exhibit relatively new opportunities and challenges compared with other AMTs. This research has focused primarily on the capabilities of drones and the applications areas in manufacturing industries, as well as on the benefits and the hurdles involved. Next, it has narrowed down the scope to a specific manufacturing industry and then to applications in operations settings.

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Biography

Omid Maghazei (Ph.D.) is currently a postdoc and senior researcher at the Chair of Production and Operations Management (POM) at the Department of Management, Technology, and Economics (D-MTEC) at ETH Zurich, where he earned his doctoral degree in 2021. In his research, he collaborates with leading industrial companies such as IKEA and Geberit to empirically study emerging technologies like drones in operations management. Since December 2020, he is also project manager in Eur3ka project funded by the European Union's Horizon 2020 Research and Innovation program, which addresses manufacturing repurposing operations during emergencies.