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Drones in manufacturing: exploring opportunities for research and practice

Although the industrial application of drones is increasing quickly, there is a scarcity of applications in manufacturing. The purpose of this paper is to explore current and potential applications of drones in manufacturing, examine the opportunities and challenges involved and propose a research agenda.

By Omid Maghazei and Torbjørn Netland

Recent advancement in technologies challenge the way companies manufacture and deliver products. One of the promising technology is the unmanned aerial vehicle (UAV), which is commonly known as a drone. A breakthrough in the use of drones in industry occurred in 2006 when the US Federal Aviation Administration issued the first commercial drone permit. Since then, interest in the professional application of drones has grown rapidly. In 2018, the research and advisory company Gartner Inc. described drones as an "emerging technology that will become a source of competitive advantage over the next decade" (Panetta, 2018). Over the past decade, the capability of drone technology has improved, its price has plummeted and its availability has greatly increased. Nevertheless, drones have hardly found any profitable applications in manufacturing. Why? There is a rich research on the technical capabilities of drone technology, but much less research on the practical application of drones in industry.

The current industrial applications of drones are mainly in the outdoors. Manufacturing operations, on the contrary, are almost exclusively indoors. In manufacturing facilities, drones compete with conventional technologies that can be mounted to fixed installations (such as floors, pillars, walls or ceilings) or moving installations (such as cranes, conveyors or vehicles). While outdoor drones can use conventional global positioning systems (GPS) for localization, positioning, and routing, indoor drones require complex technologies, such as laser rangefinders (e.g. simultaneous localization and mapping (SLAM)), ultra-wideband radio signals (a form of "indoor GPS"), or more expensive technologies, such as motion capture systems (e.g. Khosiawan and Nielsen, 2016). Safety, noise and privacy also remain of

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considerable concern. Moreover, doors, cables, cranes, equipment and people limit the maneuverability of drones, and the confined spaces in manufacturing facilities can create turbulence. However, indoors also have advantages. Indoor settings are not subject to governmental legislation regarding open air flight (Floreano and Wood, 2015) and weather conditions are irrelevant.

This study aims to bridge the gap between the current capabilities of drone technology and its potential applications in manufacturing, as well as to set the stage for the future of drones in manufacturing. We enter the field informed by the knowledge from the rich literature on advanced manufacturing technology (AMT).

Theoretical background

An AMT is a computer-based technological innovation used in manufacturing processes (Udo and Ehie, 1996; Gouvea da Costa and Pinheiro de Lima, 2008). AMTs include a range of modern technologies used in manufacturing, such as computer numerical control (CNC) machines, industrial robots, flexible manufacturing systems (FMS), automated storage and retrieval systems (AS/RS), radio frequency identification (RFID), additive manufacturing ("3D printing") and automatic guided vehicles (AGV), among others (Jonsson, 2000; Boyer et al., 1997). Although the application of drones in manufacturing has not received much attention in the operations management literature, the application of comparable manufacturing technologies has of course been studied. The drone technology can be classified as an AMT.

Drones as an advanced manufacturing technology

An AMT application can be "stand alone" or it can be linked or integrated with other technologies (Meredith and Suresh, 1986; Small and Yasin, 1997; Small, 2007). Most current drone applications are stand-alone designed to do a specific task. Examples include the inspection of hard-to-reach equipment using video and thermal cameras in the oil and gas industry, aerial photogrammetry for developing three-dimensional modeling during factory planning and delivering spare parts during maintenance operations (see Barth and Michaeli, 2018; Maghazei and Netland, 2018; ZF Friedrichshafen AG, 2018). Linked AMTs conduct their own tasks, but also communicate and coordinate with other technologies. An example of a linked drone system is applications used in inventory cycle counting to automatically update inventory records in a warehouse management system. Integrated AMTs are dependent on the tasks of other technologies. Only very few current drone applications qualify as integrated AMTs.

Physical vs analytical capabilities of advanced manufacturing technologies

AMTs can be classified according to their physical and analytical capabilities (e.g. Bessant and Buckingham, 1989; Kotha and Swamidass, 2000; Kotha, 1991; Steenhuis and Pretorius, 2016). The physical capability of an AMT is its ability to conduct physical tasks. For example, RFID readers and sensors have relatively low physical capabilities and CNC machines, conveyor systems, AGVs and industrial robots have relatively high physical capabilities. Following Kotha (1991) and Kotha and Swamidass (2000), we define the analytical capability of an AMT as its ability to process data. What separates high from low analytical capability is not necessarily associated with tedious programming but is decided by the degree of data processing during use. For example, a simple special-purpose CNC machine has a high programming setup, but the machine usually simply runs its program during use and is therefore an AMT with low analytical capability. An advanced FMS, however, needs high analytical capability to synchronize the real-time flows between machining processes, machine tools and materials.

The capabilities of AMTs are improving quickly due to the advancement of complementary technologies such as sensors, robotics, cloud computing, big data and analytics, to name a few (Guo and Qiu, 2018; Frank et al., 2019). Such technological advancements are improving both the physical and the analytical capabilities of AMTs.

The separation of analytical capabilities vs physical capabilities of AMTs makes intuitively sense for drone systems. Using the separation of analytical capabilities vs physical capabilities, we derive a conceptual framework from the AMT literature (Figure 1). The combination of low and high for these two capabilities suggests that AMTs can be classified into four different types, respectively, low-low, high-low, low-high, and high-high configurations of analytical vs physical capabilities.

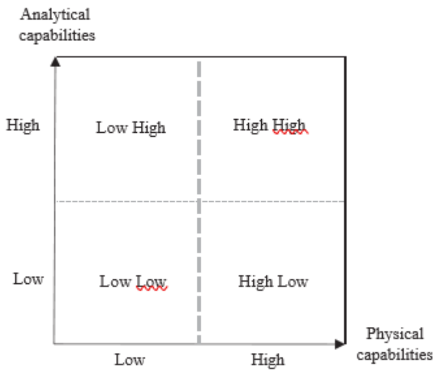

Figure 1. Classifying AMTs as a combination of physical and analytical capabilities

A conceptual framework explains graphically “the main things to be studied” and can “evolve as the study progresses” (Miles et al., 2014, p. 20).

Research methodology

Due to the novelty of drone applications in manufacturing, there is little empirical evidence in the operations management literature. Qualitative research is “particularly oriented toward exploration, discovery, and inductive logic,” which allows us to determine the emergence of meaningful categories or dimensions (Patton, 2015, p. 64), and to establish a knowledge base for the phenomenon studied (Karlsson, 2016; Patton, 2015). We selected the qualitative research method of interviewing experts (Bogner et al., 2009), which has been used extensively in industrial sociology, educational research, policy research and political science (Meuser and Nagel, 2009), but less so in the operations management literature. Interviewing experts is an appropriate and complete method in research that aims to reconstruct explicit expert knowledge (Pfadenhauer, 2009). We followed the general advice regarding the analysis of qualitative data in operations management (Meredith, 1998; Ketokivi and Choi, 2014).

Findings

Industrial applications of drones

Based on our data reduction structure for the industrial applications of drones (e.g. Gioia et al., 2013; Ramus et al., 2017), we offered theory-informed generalizations of activities that a drone can provide: see, sense, move and transform. We derived the four aggregate dimensions by elaborating on the relations between concepts through further abstraction. For instance, we aggregated all the application areas of drones in relation to visual capabilities into "see."

"See" is the capability of collecting visual data, often in the forms of images and videos. In the manufacturing industry, example is the visual inspection of equipment, such as gas flare, silos, etc.

"Sense" is the capability of collecting data and transforming it into the other forms of data or structured data (i.e. information) without performing additional physical operations. Some relevant example in manufacturing include the following: the thermal inspection of equipment, machines, chimneys and stacks.

"Move" is the ability of a drone system to grasp and carry objects or perform physical operations (e.g. spraying). A typical example in manufacturing consists of intra-logistics operations, such as delivering light components, spare parts or tools especially during maintenance operations.

"Transform" is the ability of a drone system to collect data and transform them into information while performing physical operations (e.g. carrying objects). It combines the capabilities of see, sense and move. Current examples of "transform" in industry are scarce, but a few promising pilot studies are underway. For instance, a drone system with a camera can simultaneously inspect equipment and perform simple repair operations using mounted tools (e.g. patching, painting and sealing).

Building on the theory-informed classification of AMTs in Figure 1, we can now use the empirical findings to propose a typology of drone applications in manufacturing. It is illustrated in Figure 2. Seeing is a low analytical and low physical capability. Sensing involves a high analytical capability and low physical capability. Moving represents high physical capability and low analytical capability. Transforming requires high analytical and high physical capabilities. We use this typology to discuss the current state of drone applications in manufacturing, propose a research agenda, and propose implications for practitioners.

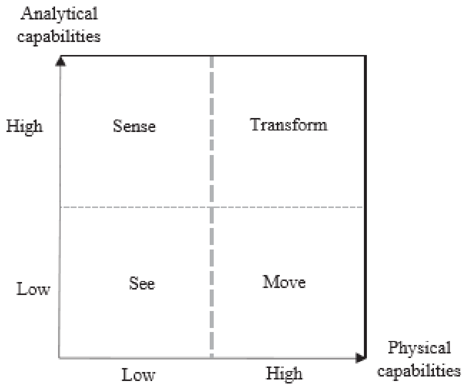

Figure 2. Typology of industrial drone applications

Potential benefits of drones

We asked all interviewees about the potential benefits of using drones in manufacturing. Although the real benefits are related to specific-use cases and contexts, the data analysis showed that the potential benefits fell into five broad categories:

(1) cost savings;

(2) task speed;

(3) safety improvements;

(4) efficient data collection; and

(5) public relations (PR) and marketing.

Regarding an extreme non-manufacturing example, one interviewee reported that in an inspection project on one of the biggest oil platforms in the North Sea, the introduction of drones reduced a 700 person-days inspection of 14 objects to 28 person-days.

A related potential benefit is the increased speed of performing tasks. Another example is the use of drones for the inventory management of bulk raw material, in which light detection and ranging (LiDAR) scanning with drones can increase the speed and efficiency of inventory counting compared with handheld scanners.

Safety improvement was the most frequently mentioned benefit of drones. According to the president of a global drone association and the CEO of a drone start-up, “Dull, dirty, and dangerous, those are the jobs that drones improve on.”

A fourth benefit is that drones can increase data collection efficiency and assist acquisition of data that has not been collected before. For example, one interviewee explained, “A drone can get high quality, more consistent, and repeatable datasets, and that’s important because if you inspect the same structure many times, you see trends.” This capability is particularly promising in maintenance operations in process industries.

A fifth and more subtle benefit of drones is their use in PR stunts. A few recent examples of press coverage for drones are reports of applications used in cycle counting in Mercedes warehouses (e.g. Banker, 2016), intra-logistics applications in ZF Friedrichshafen (Dellinger, 2018) and inspections of hard-to-access equipment in a Ford factory (Hatt, 2018), the Pilsner Urquell brewery (Margaritoff, 2018) and Royal Dutch Shell's oil and gas facilities (Castellanos, 2018).

Challenges for drone applications

We identified some challenges and drawbacks related to the use of drones in manufacturing.

The most frequently mentioned constraint in current situation is battery technologies. The limited battery capacity implies that drone users must balance flight endurance with payload. As of 2019, commercially available industrial drones have a flight time between 2 and 25 min. After the mission, the batteries must be replaced or recharged. Recharging often takes 45 min or longer.

Other challenges include indoor navigation, reliable data transfer and communication, danger of explosion, safety mechanisms and noise.

Most current drone applications are manual pilot operations that are flown within the line of sight. The alternatives are automatic or autonomous flights. Manual operations require alert and skilled pilots. In long operations, pilot fatigue can quickly become a source of human error. The gates, doors, etc. in factory environments are challenging to navigate even by experienced pilots. Automatic and autonomous flights require a continuously maintained navigation infrastructure. In both cases, drone flights need to be reliable and safe, especially around people.

Skilled drone pilots must be able not only to fly drones safely but also must have a deep understanding of the tasks and missions involved. Human issues such as workers' knowledge and technical experience, training and involvement in planning are key determinants for the success of technology adoption (Chung, 1996; Walton, 1987; McCutcheon and Wood, 1989; Pagell et al., 2000). Other challenges of adopting drones are related to developing a convincing business case that provides an acceptable return on investment. This is similar to the debate on measurable benefits of adopting AMTs in manufacturing industries (Swink and Nair, 2007; Udo and Ehie, 1996). On one hand, it is difficult to specify the potential savings that drones can provide in manufacturing. The costs, on the other hand, are visible to everyone. Furthermore, organizations that plan to invest in drone operations face the "make-or-buy" dilemma. The data collected in the interviews indicated that this decision should depend on the availability of internal and external skills and the sensitivity of both the processes and the data. An additional challenge concerns dealing with the data that are collected. In many firms, drones are only a small part of their "digital transformation."

Although the number of drone applications is increasing, the regulations concerning their use is lagging. A main benefit of using drones in indoor applications is that the regulations are more relaxed compared with outdoor applications. The licenses (or the lack of them) define how, where and what applications the manufacturer can use drones. As in many emergent technologies, it has been difficult to regulate drones, which is because of the rapid improvement of the technology, safety and security issues, the lack of clarity of who should draft the regulations and the lack of knowledge about many real applications (Khanna, 2018).

Many members of the public have negative perceptions of drones as a new technology. People are concerned about the safety of drone technologies, the intimidating appearance and noisiness of drones and the invasion of personal data. In a case in Australia, drones were used to monitor staff behavior, but the practiced was stopped because it violated workers' privacy (Opray, 2016). In operations that use heavy drones or payloads, safety concerns are justified.

Interestingly, only two of our 66 interviewees mentioned price as a drawback. This finding was surprising. Only few years ago, price would have been a major challenge. The recent affordability of drone technologies is because of the mass production (Khanna, 2018).

Discussion

Current state of drones in manufacturing

In 2018, there were few established applications of drones in manufacturing. Many companies are now experimenting with the use of drones in different applications, and a few manufacturers have already begun to use drone applications in warehouse operations and inspection tasks. Nevertheless, there is a significant potential for further drone applications.

The majority of the current applications of drones are the "see" and "sense" types. Many manufacturers employ at least one drone enthusiast who brings his or her interest and expertise to producing aerial photos and videos of the facilities. These applications are inexpensive and simple, and they do not require specialized drone technology or consultation. For manufacturers with large facilities, tanks, etc. that require regular inspections, the next stop is to consider whether drones could replace manual inspections. These "see" capabilities could be enhanced to "sense" capabilities by integrating advanced sensors and software. Standard video cameras could be replaced by thermal cameras to detect heat loss from machines and buildings.

It is harder to improve the physical capabilities of drones than it is to improve their analytical capabilities because of their physical limitations, especially their payload and battery capacity restrictions. In "move" or "transform" tasks, which require high physical capabilities, drones are typically inferior to tools, sensors or cameras. "Move" operations, such as intra-logistics and part delivery applications, are rare, and their use is practical only in small, light, and urgent "emergency" deliveries. Indoor applications are more difficult to justify. "Transform" operations are rare not only in manufacturing but also in all industries.

A research agenda

Our insights suggest that by 2025, drones will be applied in many manufacturing plants. This should provide a rich opportunity for empirical research in this area.

Operations management scholars could extend the literature on the evaluation, implementation and measuring effects of adopting drones in manufacturing. As a starting point in particular, scholars can build frameworks for supporting "make-or-buy" decision-making. Industrial engineering scholars could study specific-use cases and develop design guidelines for different applications. The theoretical literature on AMT is a valuable starting point. For instance, reviewing AMT literature shows the potential of survey research to determine the industries that are more likely to benefit from each type of applications, as well as elaborating on the contingency factors (such as proximity to know-how, size of the companies and organizational culture) that influence drone adoption in manufacturing companies.

There is also much work to be done in the engineering sciences and in product development regarding the application of drones in manufacturing. The most promising technological research in terms of manufacturing applications is the development of automatic drones. Replacing manual work by a piloted drone produces only marginal benefits. Replacing manual work by automatic drones is a much better business proposition. The next step after automatic flight is autonomous flight by artificially intelligent drones that make decisions in changing environments (Floreano and Wood, 2015). Autonomous micro aerial vehicles is another research area with promising potentials in manufacturing operations (Kumar and Michael, 2012).

People know that drones collect data and can potentially film them while they are working, which poses serious questions about personal data protection rights. In addition, drones and robotics in general evoke the fear that people will lose their jobs to machines (Stewart, 2015). In short, drones involve a trust problem that is more serious than that involving many other AMTs. To establish trust for drone applications in manufacturing, past studies on AMT advice managers to develop an innovation-supportive culture that supports experiments with new technologies (Khazanchi et al., 2007). Because drones are quite different from other "grounded" AMTs, socio-cultural and behavioral aspects of drone implementation represents a particularly promising research area.

Implications for practice

Drones are a new form of AMT that will be applied in many manufacturing industries, especially in large, technology-intensive facilities in process industries. The overview of current use cases shown briefly above could provide manufacturers with a perspective on what is possible today. An important point is that current drone applications are mainly "see" and "sense" types of applications.

Where should manufacturers start? As the arrows shown in Figure 3 indicate, manufacturers could start with simple experiments related to the "see" capabilities. From there they could move to "sense" applications, "move" applications or both. However, the transition to "move" applications is currently the most challenging. By following this advice, manufacturers could start running experiments with off-the-shelf drone technologies. Such actions could foster learning and champion drone technology through familiarization and promotion (Dimnik and Johnston, 1993; Kolb, 1976). That would help in discerning opportunities and challenges, as well as justifying investment (Boyer, 1999; Kolb, 1976). As suggested in previous work on AMT, learning from the experiences of other manufacturing companies can help managers avoid common mistakes and assist them during the planning phase of a drone program (Sohal, 1996). Manufacturers that have gained experience in using drones in “sense” or “move” tasks could consider further integrating technology to make their drones capable of performing “transform” tasks.

Conclusion

In the present study, we explored the current and potential uses of drone technologies in manufacturing. We proposed a typology of drone applications, discussed the related benefits and challenges and recommended a research agenda.

We conclude that drones are on the verge of being adopted for use in many manufacturing industries. Particularly promising and cost-efficient 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. Our findings show that drones could have higher potential in process industries than in discrete manufacturing.

Despite the great amount of technological development during the past decade, there are still technological, organizational and regulatory challenges to the implementation of drones. Drones will not revolutionize manufacturing alone, but they have the potential to radically improve the efficiency of certain tasks in manufacturing. In 2025, drones are likely to be a much more common sight in manufacturing facilities than they are today.

Questions

1. **What are the management problems that the article examines? Please give a brief but accurate description of each problem. List all the problems you found in the article. You can extend the list, taking into account your own experience and knowledge.**
2. **Suggest how the conceptual framework matrix of analytical and physical capabilities can be applied to the different types of drones. Support your ideas with a comprehensive description of the possible applications of drones.**
3. **Explain the way (general logic) in which each of the benefits of drones identified in the article can be achieved, or how it will impact on the company's key performance indicators.**
4. **Imagine that you are a manager responsible for the development of production systems in a company. What lessons would you draw from reading this article? Give at least 4 lessons.**