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Managing the drone revolution: A systematic literature review into the current use of airborne drones and future strategic directions for their effective control

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A R T I C L E I N F O

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A B S T R A C T

Commercial and private deployment of airborne drones is revolutionising many ecosystems. To identify critical issues and research gaps, our systematic literature review findings suggest that historic issues such as privacy, acceptance and security are increasingly replaced by operational considerations including interaction with and impacts on other airspace users. Recent incidents show that unrestricted drone use can inflict problems on other airspace users like airports and emergency services. Our review of current regulatory approaches shows a need for further policy and management response to both manage rapid and efficient drone usage growth, and facilitate innovation (e.g. intraurban package delivery), with one promising strategic response being low altitude airspace management (LAAM) systems for all drone use cases.

1. Introduction

Remote technology and automation have been present for centuries, giving human operators safety from harm and enabling new task functionality (increasing capability of individual operations and capacity of the system). Early examples include fireships, a maritime drone, which were used in navies to destroy other ships remotely. In World Wars 1 and 2, airborne drones were used to disrupt airspace above cities, drop ordinance on enemy territory and as target practice for pilots. Railways have for some time used drone (non-crewed) locomotives to support driver occupied locomotives.

While drones have had a long history in military deployment, their increasingly widespread use in non-military roles requires consideration (e.g., Hodgkinson and Johnston, 2018). Though current usage is limited whilst the technology is in the development phase, as they possess significant potential versatility drones may transform the way that logistics services are provided. Their use no doubt will lead to the achievement of new business, social, environmental and other goals (Atwater, 2015). However, it also creates a potentially disruptive scenario as their usage expands out of control and causing problems for other parts of the economic system, as illustrated in the rapidly growing literature presented in this paper.

Interestingly, during the COVID-19 crisis drone potential has been further harnessed, using the people free nature of the technology to modify current service delivery to improve safety and capacity levels, including the delivery of face masks to remote islands in Korea and prescription medicines from pharmacies to retirement villages in Florida. It could be argued that COVID-19 has increased technological advancement in many areas and that perhaps drones represent a revolution in how we transport goods and potentially even ourselves (however that is analysis for a future paper).

In that sense, it is important to note that the use of drones in larger commercial applications is also growing (see, e.g. Bartsch et al., 2016), with their deployment in remote work leading to significant cost reductions and capability enhancements (such as in mining, engineering and transport network management contexts and agricultural scanning). Their ability to view large areas at a low cost from altitude provides new viewing aspects and new data acquisition ability (or existing data can be sourced at a large scale at a lower cost) to make decisions and manage operations more effectively. Similarly, airborne photography has entered a new stage of development with operators, both large and small, able to give consumers new imagery that had previously been in the domain of birds only. Besides, the recent spurt of the retail sale of drones for recreational and small-scale commercial purposes has pushed airborne drones into the entertainment space.

However, there is a range of other potential uses. Experience in

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delivering medical supplies in remote African areas gives a potential preview of their role in urban parcel/package delivery, radically changing the way small deliveries are made in urban areas. Commercial and policymaking efforts are turning to contemplate this future and how airborne drones may need control in such uses. This may have significant impacts, not only on delivery cost but on urban congestion and traffic management issues – should they replace land-based journeys. Being in urban areas, implementation issues will arise that require consideration, given the greater risks involved.

While there have been earlier reviews (e.g. a techno-ethical one, Luppicini and So, 2016), the commercial use of drones is yet to be written about in any significant volume in the management literature. Preliminary issues like privacy/security received the required attention, given the potential for drones to peer (visually or audially, and intentionally or not) into areas that were previously easy to guard. With increased use, the focus has moved to the engineering literature where a range of computer, materials and design issues are being discussed. Recently, the management literature has begun to case study how drones are used in current commercial contexts, and more importantly, has begun to consider the broader role that drones may play in the logistics industry. What is missing, in our view, is a clear understanding as to where to next, given that increased use cases and traffic volumes might not only significantly disturb other airspace users but also bring the drone ecosystem itself to a standstill (uncontrolled chaos scenario). We aim to investigate whether the emerging body of literature can provide sufficient answers and solutions or at least trending ideas on how to provide drone use with a framework that allows this evolving industry to continue growing at a rapid pace and also to innovatively disturb traditional business models in an economically ordered and safe manner.

This paper reviews the extant literature on the potential implementation of drones into the economic system and specifically how the implementation and ongoing use may be managed. Section 2 outlines our methodology for conducting the systematic review. Section 3 then presents our bibliometric results and discusses the issues being reported in the literature and highlights the four main use cases for drones (based on a content analysis of the reviewed papers) that we see being discussed. Section 4 examples current regulatory steps and then conclude in Section 5 with some discussion and identification of future research avenues, including the need for greater regulation of the drone ecosystem at the macro level and the potential for low altitude air management systems (LAAM).

2. Methodology

Originally developed in the medical literature the systematic literature review (SLR) has been used as a methodology in a range of management papers. In the transport literature it has been deployed in areas such as supply chain (e.g. Perera et al., 2018) and in aviation management (e.g. Ginieis et al., 2012; Spasojevic et al., 2018). Whilst not a strict laboratory controlled study (Ginieis et al., 2012), they do give researchers and practitioners a flavour for the extent and coverage of the literature, and some vision as to where and by whom it is being generated and what it covers.

Drones have received literary attention for some time, primarily in legal/ethical, engineering and computer science fields. For this paper, we have focussed on management literature, given our interest in investigating drone management and related issues. Importantly, we ignore any military/defence use of drones to focus only on civilian applications. While ground-based and maritime drones are also present in the literature (Pathak et al., 2019), the term 'drones' is now widely understood to refer to airborne ones, upon which we focus.

For our search, we developed a search string in Scopus composed of a keyword search for 'drone*'. We added synonyms like 'unmanned aviation', 'unmanned aircraft*', 'unmanned aerial vehicle*', 'UAV', or 'remotely piloted aircraft*', which yielded 65,953 documents. We then restricted the results to the Scopus allocated subject areas of 'Business, Management and Accounting' (which includes a variety of areas such as innovation, strategy or logistics and supply chain management), or 'Economics, Econometrics and Finance' (yielding 1567 documents). Further, we restricted results to articles (published and in press), conference papers or book chapters (1133 documents), and we restricted the search to articles published in the last five years only, since the beginning of 2015 (519 documents). Finally, we limited results to the English language (505 documents).

Using Covidence (an online tool that aids in the faster review of documents through work flowing the review process and collaborative review), we analysed and filtered these articles. This was due to a variety of reasons. Initial screening results showed that for a substantial portion of the papers, drones are not the core focus of the paper and are merely an enabling device for the key topic of the paper, such as strategies for disseminating technology products into the construction sector (Sepasgozar et al., 2018). Where drones were more significant, some articles were operationally (e.g. Zhou et al., 2018) or engineering focussed (e.g. Chen et al., 2017) with no substantial management consideration. Other articles were excluded as they were not relevant, including other uses for the word 'drone/s' (e.g. bees or employees) or UAVs (e.g. corporate finance terms). Articles without full text were also eliminated. Article content was further reviewed through Covidence, and the final sample of 133 articles was derived. Results were then analysed with Excel and Bibexcel (Persson et al., 2009).

3. Results

The identified papers are a population of different paper types. Some represent operational use case studies. Others are engineering focussed but are contemplative of future management endeavours. There are papers written from other (non-drone) perspectives that provide useful insight into drone deployment more generally. And in addition to bibliographic results, we found that use cases of drones to be a worthy area for discussion, as well as the current issues being experienced, which have expanded past historic issues to cover new ones that had not been encountered.

3.1. Bibliographic results

The following are selected results of our review. As illustrated in Fig. 1, publications related to drone management (including case studies of their use) have been increasing.

Table 1 provides a summary of the published sources relates to our 133 reviewed drone papers. What is evident is that a few sources account for a significant number of publications on drone management in the investigation period. Also evident is a very long tail of single publication sources. What Table 1 also demonstrates is that drone management is still heavily domained in the technology and engineering literature.

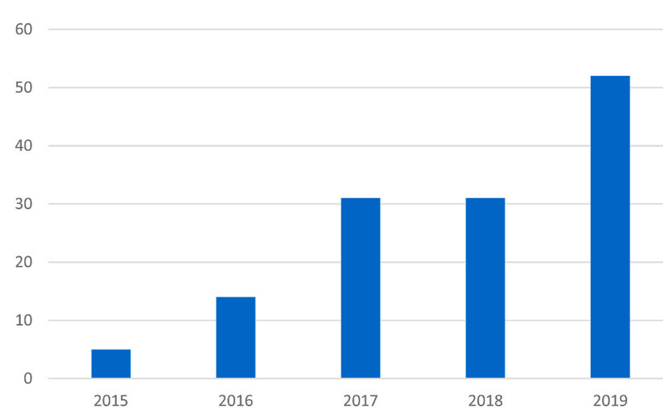

Fig. 1. Publication year.

Table 1
Listed publication sources.

Number of publications	Sources
6	Journal of Advanced Transportation
	Technology in Society
4	ENR (Engineering News Record)
	International Journal of Recent Technology and Engineering
3	Applied Geography
	Computer Law Security Review
	ICTC 2019 - 10th International Conference on ICT Convergence: ICT Convergence Leading the Autonomous Future
	International Journal of Intelligent Unmanned Systems
	Journal of Humanitarian Logistics and Supply Chain Management
	Knowledge Based Systems
	Science and Engineering Ethics
	Studies in Systems, Decision and Control
	Technology Analysis and Strategic Management
2	11 unique sources (including the Journal of Air Transport Management)
1	64 unique sources

However, other types of journals are still present to cover specific drone issues (e.g. security and mining reclamation). As the management of drones appears to be very much about micro-level management instead of macro-level management, it is perhaps natural that technology, engineering and related literature are the major publication areas for drones to date.

In terms of author contribution and potential thought leadership, there are 408 unique authors of the analysed papers, representing a wide and varied number of contributors. Of these, one has produced five publications (Hwang, J), one has made four publications (Liu, Y), three have made three publications (Abaffy, L, Kim, H and Zhang, X) and 16 have produced two publications. Aside from a number of author pair or group combinations in clearly linked publications from the same research activity, there does not appear to be any significant grouping/clustering of authors as is evident in other systematic reviews of other topics.

Similarly to authors, contributing institutions are wide and varied in range, with those with three or more contributions shown in Table 2. Again, a long tail of institutional contribution is present, with some institutions having more concentrated contribution. Note that for these institutions, contribution may be planned but is more often unplanned, with different faculties (e.g. engineering and health) making independent, uncoordinated contributions to the literature. Inspection of the contributing departments reveals substantial contribution from engineering and computer science disciplines or institutes of that nature.

Country contribution is shown in Table 3. Top 10 contributing countries and regions. The US, China, Australia and South Korea are significant contributors. Continentally (see Table 3.), while Asia and North America are significant (to be expected based on the country results), the diverse efforts of European countries are also evident given Europe's substantial contribution.

Our analysis of author keywords (543 keywords) revealed similarly wide and varied results, reflecting the wide range of contexts of research focus, as shown in Table 4. Making allowance for similar keywords (e.g. drone delivery and drone-delivery), 442 unique keywords were identified. Excluding keywords used only once (386 keywords) and excluding 91 drone referential keywords that are not descriptive of an issue (e.g. drone, drones, UAV, UAVs, unmanned aerial vehicles), these keywords were identified multiple times. Key issues relating to privacy, security, acceptance and management are evident.

Table 2
Institution contribution.

Affiliated publications	Institutions
6	Sejong University
4	Beihang University
	Griffith University
	Monash University
3	Kyungheee University
	University of Guelph
	University of Massachusetts Amherst

Table 3
Top 10 contributing countries and regions.

Country	Affiliated publications	Regions	Affiliated Publications
USA	58	Europe/USA	58
China	25	East Asia	27
Australia	22	China	25
South Korea	21	Australasia	22
India	17	South Asia	19
Italy	11	Europe related	9
France	10	Middle East, North America, SE Asia	6
Germany	8	South America	4
United Kingdom	7	Africa	1
Canada	6		

We note that papers from earlier in the literature focus on conceptual issues such as privacy and security and have stood as a warning scene for industry to ensure that these concerns are addressed, and that policy makers will be alert to them. However, and concurrent with greater usage and chance to study this usage, papers later in the date range show a clear trend towards the consideration of more commercial aspects of drone adoption including how they are operated and used.

For example, the keyword 'privacy' appears in 2016 (four articles), 2017 (two articles) and 2019 (three articles). 'Regulation' appears in 2016 (2 articles), 2018 (one article) and 2019 (2 articles). The keyword 'ethics' appears in articles in 2016 (one article) and 2019 (two articles). However, 'drone delivery' is top of mind in the research community, quickly followed by how drones are going to navigate their way around. Of the drone delivery keywords, 13 of these (more than 80 percent) were published in 2019 indicating its rather recent focus in the literature, which is consistent with the drone use case discussion presented in section 3.3.

Table 4
Keyword analysis.

Count	Keyword
16	Drone delivery (including food, parcel or generic)
9	Path planning/routing,
	Privacy
5	Regulation
4	Routing
3	Behavioural intentions
	Logistics
	Ethics
2	Age
	Attitude
	Gender
	Data protection
	Humanitarian logistics
	Policy
	Data protection
	Lifecycle
	Humanitarian logistics
	Obstacles Avoidance
	Surveillance
	Desire
	Disaster management
	Optimisation
	Monitoring
	Multi-UAVs

3.2. Present and emerging issues in civilian drone usage results

In this section, we discuss some of the content of these papers. Operating in new spaces, in a third (vertical) dimension and proximity to other users, drone use is expected to have a significant impact on the quality of life, health, social and economic well-being (Kyrkou et al., 2019). However, this potential disruption will, being a technological development (Kwon et al., 2017), create issues and problems that require management to minimise negative impacts (as well as to maximise positive potential). Notably, however, our review indicates that these security, privacy and acceptance concerns, whist significant and relevant, are not as dominant as they have been in previous periods – with the use of drones in various ecosystems providing an opportunity for researchers to examine their introduction and impact on those with whom they interact.

Security management remains a critical issue. Invasion (intentional or not) of sensitive airspaces, like airports (Boselli et al., 2017) and power stations (Solodov et al., 2018) have the potential to and do cause costly disruption (e.g. the near-total closure of Gatwick Airport and disruption to fire and emergency services work in Tasmania in 2018). Safety is a perennial issue though automation may support improved physical safety outcomes (Torens et al., 2018). Privacy issues remain a concern, particularly from drones that can capture imagery, particularly those that are used close to private personal space such as homes and apartments (Daly, 2017; Aydin, 2019), or as drones are used in new ways, including research approaches (Resnik and Elliott, 2018). Drone users, particularly recreational ones, do not have an understanding of the privacy requirements that they are subject to (Finn and Wright, 2016). Therefore, a regulatory response is likely to be required. Ethical issues around the use of drones for surveillance purposes are also present (West and Bowman, 2016). Other amenity issues, such as the impact of noise, are also under consideration (e.g. Chang and Li, 2018).

The issue of drone acceptance therefore by the public remains an issue, though different parts of the community are more accepting than others (Anania et al., 2019; Sakiyama et al., 2017; Rengarajan et al., 2017). Some literature (e.g. Boucher, 2016; Khan et al., 2019) notes that an outcome of this acceptance debate is that drones are being developed to be accepted, taking into account, instead of enforcing, acceptance of drones by the public, showing the role that 'social license' (Gunningham et al., 2004) plays in the acceptance debate. Drones require societal trust (Nelson and Gorichanaz, 2019). The demilitarisation of drones has facilitated trust (Boucher, 2015), and positive media attention to non-controversial use cases has been shown to have had a positive impact on acceptance (Freeman and Freeland, 2016).

The first stages of research into specific consumer reaction to drones have begun to bear fruit. Studies have shown how media positioning frames consumer and public responses to drone technology (Tham et al., 2017). Recent work indicates that consumers may respond positively to drones. The technological aspects of drones have been identified to form a relationship with consumers through changing perceptions of risk, functional benefits and relational attributes (Ramadan et al., 2017). Drones provide a psychological benefit to consumers and generate positive intentions to use drones (Hwang et al., 2019a). Perceptions of environmental benefits suggest favourable consumer perceptions of drone use (Hwang et al., 2019b). A study of motivated consumer innovations suggests that dimensions of functional, hedonic and social motivatedness are key drivers of attitudes towards consumption using drones (Hwang et al., 2019c). Innovativeness is noted as an attraction of drone food delivery services for consumers, with younger and female consumers more likely to be attracted by drones (Hwang et al., 2019d). Managing perceived risks associated with drone deliveries is a necessary task for foodservice delivery operators (Hwang et al., 2019e). In marketing, aerial drone photography is being well received by targets who respond positively to their inclusion in campaigns/advertisements given its cognitive stimulation (Royo-Vela and Black, 2018). Use of drone imagery in this manner is, therefore expanding (Stankov et al., 2019).

Operational management issues have begun to come to the fore with some studies beginning to examine drone maintenance regimes (Martinetti et al., 2018), battery life management/charging and efficient performance characteristics (Goss et al., 2017; Pinto et al., 2019). Importantly, with the move towards logistics, other questions are being raised, including how to optimise delivery strategies (e.g. El-Adle et al., 2019). Initial analysis indicates combined truck and drone delivery systems are a more efficient method of logistics delivery systems than current approaches (Ferrandez et al., 2016; Chung, 2018; Carlsson and Song, 2017; Liu et al., 2018), Wang et al. (2019). However serial delivery systems may be more efficient still (Sharvarani et al., 2019b) and overall delivery considerations need further analysis, such as preparation time for deliveries which are different between truck vs. drone delivery (Swanson, 2019). Further research in different urban contexts may yield different results (e.g. dense urban areas with higher density and shorter trip distances). Take-off and landing management processes (Gupta et al., 2019; Papa, 2018a, 2018b; Papa, 2018a) and ground handling operations (Meincke et al., 2018) are also evident in the literature. Using longer-range drones for civilian purposes is beginning to be discussed (more so of remotely piloted drones instead of automated ones) (Tatham et al., 2017a) and the development of specific, commercial drone aviation parks for large drones has been completed (Abaffy, 2015a,b).

Initial strategic impacts are receiving literary attention. Drones are driving entrepreneurial activity (Giones and Brem, 2017). Magistretti and Dell'Era (2019) show that operators use four main types of technology development strategies when using drones: focus (adding drones to current operations), depth (expanding current operations more fully), breadth (expanding operations across new offerings) and holistic (developing wholly new operations or approaches). Both Kim et al. (2016) and Meunier and Bellais (2019) note that drone technology leads to spillover effects in other sectors. Hypothecations of societal impacts of future drone issues are also being made (Rao et al., 2016). Consideration of their use in extra-terrestrial environments is also contemplated (Pergola and Cipolla, 2016; Roma, 2017).

In the next section, we analyse drone use through several revealed use cases.

3.3. Primary use cases

A valuable part of our review and a key finding is our contribution to understanding how drones are deployed. A large proportion of reviewed articles are (usage) case studies rather than a systematic analysis of an issue. Through these papers, we can highlight that there are presently four primary categories: monitoring/inspection and data acquisition, photography, logistics (including passenger), and recreation. Even accounting for the lag between events and their academic publication, we view that the categories below are reflective of unpublished but current use types.

3.3.1. Monitoring, inspection and data collection

With lower capital costs and greater capabilities, drones can capture existing data in new ways, or capture uncollected data for new analysis. Industrial users are taking advantage of the new opportunities being offered by the technology to do things in new ways, for the same or better outcome.

Network management businesses, e.g. pipelines or energy transmission (Li et al., 2018), road maintenance (Abaffy, 2015a,b) and railway operation (Vong et al., 2018) have swapped costly inspection teams with drones. Some inspection drones have real-time analysis capability and quickly report issues and objects for investigation back to the base rather than involving separate analysis stages. These users mainly deploy drones on their specific network geographies (within a set meterage from the network line) however, in positioning to and from their inspection areas, they may traverse open airspace. These network geographies are often in public spaces and given that powerlines (and sometimes rail/road networks) are placed over private properties via easements, management of drone airspace use is important.

Agricultural (and related) industries are inquisitive when it comes to learning more about the land they manage and naturally have looked at drone technology to capture new information (Weersink et al., 2018). Farming has had a recent history of using satellite information to identify crop health issues, using data collected to more efficiently target the application of fertilisers and pesticides. More recently, drones have acquired this information (Na et al., 2017). This has financial implications, but also environmental impacts, as reduced inputs lead to reduced negative impacts for the same output. Similarly, mining operations have used drones to remotely manage and optimise different elements of their production process (Wendland and Boxnick, 2017), including monitoring stockpiles of ore and leeching pads for maintenance issues and analysing blast ore before its processing (Bamford et al., 2017), accessing waterbodies in hazardous/remote locations to facilitate sampling for environmental management (Banerjee et al., 2018; Langhammer et al., 2018) and imaging mines for rehabilitation (Moudry et al., 2019). The construction industry uses drones in planning construction sites cheaper than other means (such as helicopters) and at lower risk to staff (Abaffy and Sawyer, 2016; Li and Liu, 2019) and hazardous industrial plants use drones to monitor gas production (Kovacs et al., 2019). Importantly for all of these industries, use of drones takes place largely in the airspace above the mining or farming areas and may have minimal impact on other users (notwithstanding that mining and farming areas are generally quite distant from urban areas).

Drones are also used by government and regulatory agencies for surveillance purposes and to monitor compliance. The technology has, for instance, been used in New South Wales to monitor land clearing, both to ensure that permits are complied with and to check if illegal land clearing has taken place. In hard to access areas, air pollution monitoring has been undertaken with drones (Alvear et al., 2017). Drones were used to assess urban damage in the aftermath of floods, hurricanes and even the 2011 Fukushima nuclear reactor disaster (Hultquist et al., 2017). Drones are also used to assess compliance with rehabilitation performance (Johansen et al., 2019), and just this year have seen use in shark monitoring trials at beaches. Emergency services are making more use of drone technology. While some of this use has overlap with logistics (refer below), using drones in search and rescue is a logical move to increase the capability of rescue activities (Lygouras et al., 2017; Kamlofsky et al., 2018). Despite the disruptive potential noted above, the monitoring use of drones is useful to fire management (Athanasis et al., 2019) and surf lifesaving (Lygouras et al., 2017) teams. Drones see use in humanitarian relief uses (Bravo et al., 2019; Carli et al., 2019). The use of drones for security monitoring is also increasing (Anania et al., 2018; Sakiyama et al., 2017). Sensitive but large area enterprises such as forestry or solar cell farms can monitor and inspect remotely with drones (Xi et al., 2018; Saadat and Sharif, 2017). These uses are often performed over public and private property and therefore impact a range of other users. However, they are also supported by regulatory requirements and are often undertaken for public purposes and so might be more accepted by the general public.

3.3.2. Photography/image collection

Photography is another special form of data acquisition. While monitoring/inspection uses by industry might also use photographic means to acquire data, this is to convert visual imagery into data to support decision making. However using photos solely for aesthetic value has become an important use of drones in its own right, mainly for personal use (such as the documentation of a person's special event), but also increasingly for commercial use such as sporting events or in marketing campaigns (e.g. Royo-Vela and Black, 2018; Stankov et al., 2019). Being able to fly has been a dream of (some) humans since time immemorial, and use of drones to capture imagery from birds-eye-views is attracting substantial interest from some quarters.

Use of drones for this purpose is somewhat ad-hoc, and in a large number of cases involves the use of public space as users document their weddings, family events, naturescapes or other events (either themselves or through a commercial operator). However some uses (e.g. farmers taking drone photography of their farm operations) take place entirely over the privately owned property of the drone operator, and some of the aforementioned events happen over publicly but remote land that is not intensively used like urban public land. For sporting events, such as football matches, golf tournaments and car races, use is largely confined to space above the event and closely managed by the event manager to maximise the photographic potential of the event and avoid event disruption.

3.3.3. Recreation

Drones as recreation is a new use, though mimics things like remote-controlled cars which have provided people with entertainment for many decades. The explosion of recreative use shows how popular the phenomenon is, as people take advantage of the third dimension for leisure, which for a long time has been a luxury only enjoyed by those who could fly (in various forms) or partake in risky sports. Drones are being used, e.g. in tourism activities (Song and Ko, 2017), and there are even competitive drone racing tournaments (Barin et al., 2017). Drones are also being used as three-dimensional art installations to generate linked visual structures with no other purpose than entertainment (China Global Television Network, 2019).

The expansion into recreative space is perhaps linked to the increasing acceptance of drone technology by the public as people become more familiar with the technology and begin considering their potential uses for it. Most recreative use is over public spaces such as parks and other such spaces with some of it in non-urban areas being conducted over farmland and naturescapes (either owned or not by the drone operator), though is limited by the low complexity of drones available to use for this purpose.

3.3.4. Logistics

Perhaps most interesting, and most in need of management consideration is using drones for logistics purposes. In its very early days, this use case has perhaps the most significant potential for disruption. Current discussion contemplates that their use will enhance supply chain efficiency and effectiveness (Druehl et al., 2018). Indeed, currently inside warehouses, logistics firms are using drones to manage inventories (Xu et al., 2018). Externally, drones have been used for medical supplies (Prasad et al., 2018; Tatham et al., 2017b) and organ deliveries (Balakrishnan et al., 2016) in different contexts so far, but with trials for aerial pesticide application (Zheng et al., 2019) and food deliveries currently underway, their use in broader delivery services (e.g. Drone-as-a-Service Asma et al., 2017, Kang and Jeon, 2016 Shahzaad et al., 2019) may lead to substantial shifts in delivery service execution. Prospective applications also include postage/package delivery, with interest being shown by major logistics firms (Connolly, 2016) and the potential for other drone facilitated household services (e.g. dry-cleaning collection/delivery). But we are sure that this is just the tip of the iceberg of opportunity for drones in the logistics space. Indeed, the potential for personal logistics (i.e. humans) is also a goal of some operators (Lee et al., 2019) which would call for significant regulatory oversight (especially safety). Large scale industrial applications are also being investigated (Damiani et al., 2015). The list of potential uses is extensive, and the development of drones in this way is likely to be revolutionary however initial findings are suggesting that they may only be feasible in congested urban areas (Yoo and Chankov, 2018).

The above use classes show the wide spectrum on which drones are used. Clearly, both the literature and observations of trends outside the literature show that these uses will expand. Several questions in many contexts are open for academic exploration at this time, and a few that are of interest to us we will present here (though our specific areas for further research for our paper topic we will discuss at the end of this paper). In the future logistics space, an important question we believe will arise is who owns drone fleets? Will drones be owned by individuals (e.g. mobile phones and private cars) or will they be owned by fleet management/delivery companies and used in an on-demand manner (as common in traditional wet leased air freight operations; e.g. Merkert et al., 2017)? A drone premium is likely to be chargeable given the convenience and time-saving factors but who will ultimately pay this premium? Will it be added to the delivery cost of goods and services (as in the current postage cost model) or will goods providers decide to use drones for competitive advantage and absorb the cost as part of their cost structure (offsetting delivery cost savings)?

But the key question on our minds for the remainder of this paper is the management of the significant volume of traffic that these movements will create. Increased and increasing use will be more invasive of airspace than current usage, which if not managed appropriately, and if not managed for community standards (within the license to operate), may lead to rejection of the technology and the benefits that they are purported to bring.

4. Managing the drone revolution – current regulatory approaches

We have alluded to the specific issues that drones will present above. Solodov et al. (2018) describe a range of particular drone threats, in the forms of surveillance, smuggling, kinetic (i.e. collision), electronic and distraction. Solutions to these threats include both non-destructive means (such as software intervention, UAV vs UAV, ground-based capture/interference and bird-based methods) and destructive (including electromagnetism, lasers, firearms, and missiles (Solodov et al., 2018). Some airports are working to manage drones in their airspace (e.g. Sichko, 2019; Mackie and Lawrence, 2019). Many of these methods are reactive or defensive. Instead, more proactive and preventative methods of management would be warranted. Current regulatory approaches are looking to assign responsibility to the operator, which is, in reality, a concern for both consumer and operator (Liu and Chen, 2019).

But further management of lower airspace is a growing area of policy consideration. Across the globe, laws and regulations will need to be created to manage drone impacts. Jurisdictions across the world are examining the drone use and building regulatory environments around them. Chen (2016) identified that the legal and regulatory framework in the US needs reform to facilitate commercial purposes. Integration of drones into the presently regulated airspace (particularly in urban areas and areas of higher sensitivity) is seen by industry to be a likely policy outcome (Torens et al., 2018). Various consistent jurisdictional approaches to this regulation are under development, some of which appear consistent with that envisaged by Clarke (2016), and the European approach is said to focus on the operation of the flight, rather than the aircraft itself (Hirling and Holzapfel, 2017). This might be described as an approach to softly regulate the industry as it presently stands to allow for safe participation. These regulatory measures significantly increase the requirements of operators to build cultures of safety into their operations. This approach bears a resemblance to other transport sectors (i.e. non-drone aviation, railways and road vehicle operations) which require pilot/driver licensing and firm accreditation. Regulators worldwide are looking to manage the drone itself (weight and size) who flies the drone (both organisationally and personally), how they fly it (height, day/night, speed, visual line of sight), where they fly it (restricted areas, near people, near private space) and other factors (such as the number of simultaneous drones operated) (Civil Aviation Safety Authority, 2019).

The approach by regulators in most jurisdictions so far to grow regulation with the industry, instead of trying to foresee the future and regulate that, is one that may (and are indeed intended to) be designed to support entrepreneurship, innovation and economic growth (Chisholm, 2018).

However, despite the above, it is clear that even in jurisdictions that are well advanced in terms of established drone governance frameworks, more regulation will no doubt be required. The above framework does not cover the full regulatory gap between current drone use and the non-drone airspace. Operators seeking to operate outside of the limits of the above regulation will arise and require further management. Drone automation will mean that pilot intervention to manage the drone in the event of abnormal operations will be impossible. However, there will remain human-controlled drones (including remote ones) such as for recreation or ad-hoc, customised usage. Manned and unmanned drones will have to operate together, and both modes will involve new levels of complexity, particularly as drone numbers increase. Questions will arise about how to manage drones across the industry, where individual adoption by firms will more than likely require harmonised regulation to support supply chain efficiency (Druehl et al., 2018; Foina et al., 2015). And different operators will run subnetworks with different path optimisation plans (Liu et al., 2019; Jeong et al., 2019). With the substantial increase in flying, in both time and frequency terms in particular, drones are going to have a far more significant impact than the current regulatory impact can manage.

5. Managing the drone revolution – where to from here?

Given the relatively low level of literary consideration, the opportunities for interesting research into the control and macro-management of drones are significant, wide and varied. However, in the context of this paper, the primary area for further research that we see as relevant is how the new drone management ecosystem is to be managed in the macro sense. There are still a raft of challenges to be overcome (Zhou et al., 2018), however with the prospect that drone flight will be as normal as car trips, and that they will play a role in 'smart' cities (Mohamed et al., 2018), how to ensure that this new system is not only safe but also productive is essential.

An Internet-of-Drones (Edwin et al., 2019) is a very potential future. Research into the use of flying ad-hoc networks to monitor and manage deviant drone behaviour (Bahloul et al., 2017; Barka et al., 2018, Karthikeyan and Vadivel, 2019) are in progress, as are geofencing (Boselli et al., 2017) and signal jamming (Chowdhury et al., 2017) that act on the navigation systems within drones to prevent drone incursion into restricted areas. Though to implement some of these preventative technologies, it is, of course, necessary that the relevant drones have navigation technologies installed to be acted upon by the countermeasures, which for a substantial number of retail drones is not the case. For those that do have navigation technology, research efforts are quite extensive into developing algorithms and programs to facilitate orderly inter-drone coordination like network registration processes (Agron et al., 2019) incorporating obstacle detection, (Zheng et al., 2016; Zhu et al., 2017; Choutri et al., 2019; Abdullah et al., 2019), separation processes and collision avoidance (Tan et al., 2017; Nysetvold and Salmon, 2019) the impact of weather on drone performance (Vural et al., 2019), completion of common tasks (Zhuravska et al., 2018; Abraham et al., 2019; Fesenko et al., 2019; Zhu and Wen, 2019), inter-drone information security (Abughalwa and Hasna, 2019) and operation in GPS poor areas (Siva and Poellabauer, 2019), though many of these are conceptual and theoretical deployment (e.g. Kim and Kang, 2019). Connecting independent networks of drones (that are expected to exist in the future) is yet to appear in the literature, though some elements of this are developing such as using drones as nodes of a multi-drone communication network (Kuleshov et al., 2018; Smith et al., 2018; Xiao and Guo, 2019). Though note, these methods are only for local drone coordination of the drone and static obstacles (e.g. buildings) or a few connected drones or drone micro-management – systems and processes being developed to impact the drone from the drone's perspective. However, more thinking about drone macro-management and their broader interaction with the environment needs progression, particularly how to manage drones and their collective impact on the remainder of society so that this impact is positive.

Industry is turning towards this question with operators looking to develop more complex management systems. It is likely that (as for aviation generally) each operator will look to develop a customised way of managing drones to suit their operations, such as for search and rescue systems (Mohsin et al., 2016; Mondal et al., 2018), complex distribution networks (Shavarani, 2019) or routings with ad hoc targets (Suteris et al., 2018) which will no doubt be complex given the use of the third dimension (Pandey et al., 2018). The concept of an overarching coordinating network is gaining traction in industry and government - NASA is, for instance, looking to integrate UAS into the national airspace system (Luxhøj et al., 2017; Matus and Hedblom, 2018; He et al., 2019). Conversely, the industry has a different view. Logistics and technology firms such as Amazon and Google are looking at using drones in their parcel delivery systems and firms such as Uber are looking to introduce point to point passenger drone services. Small scale trials are underway in various locations globally, where industry is developing their navigation systems to manage drone delivery. Industry is making the argument that they would be able to self-regulate their drones with these systems, designing them to communicate between drones of different operators and centralised processors. These systems would look to simultaneously program the most efficient routes for deliveries (taking into account, mitigate and avoid collisions and incursions that may cause damage not only to other drones but also to other non-involved parties).

A competing view is considering whether drones should be integrated into the overall air transport management system (Zhang et al., 2018) and managed using many of the same tools and mechanisms deployed by regular aircraft such as identification and collision avoidance systems (Lin, 2019). There is a view that far more oversight of the sector will be required to ensure that safety conditions can be met, and that airborne drones cannot operate separately to large aircraft with which drones will share airspace. A system through which this control can be exercised is being called by airspace management technology developers 'low altitude airspace management systems (LAAM)'. LAAM as currently envisaged may replicate the control mechanisms used for general and civil aviation flights. Still, importantly each of these different types of flights, drone and non-drone, will know about all other flights in making flight planning and execution decisions. They will be able to communicate with drones and record their position and use within the network. Other features might also be incorporated into LAAM, including the ability to issue instructions to drones (for say crash avoidance) or the ability to enforce geofencing boundaries to prevent drone incursion into specified issues. They may be able to aid in congestion management, to ensure that all drones can achieve their missions within reasonable parameters and may include mechanisms to facilitate flight planning and operations, consistent with current air and rail control management systems. Real-time management of issues would be an essential feature of LAAMS (Zheng et al., 2016). To us, the debate over centralised or distributed airspace management is quite interesting, not only for the impact that it may have on airspace management for drones but also the precedents it may make for other sectors. The impact of such coordination systems on public drone acceptance would also be of interest for researchers to address considering the involvement of government in such regulation may be trusted more than that of the private sector.

From an engineering and technical perspective, the areas of research that are required are almost endless, as new systems are scoped, designed and developed to integrate within the current regulatory environment and aviation control systems. But from our perspective, that of management, there are a few key areas of research that stem from the question of LAAM implementation. Firstly, the need for LAAM and what they are to do needs better articulation from those who would be impacted by it.

As noted, key potential future users of such systems are discussing their need, but further consultation is required to detail precisely what is needed. There are significant policy and commercial/regulatory discussions, but from an academic perspective, this discussion will provide useful insight into a range of issues. An immediate area to investigate are the perspectives of current recreational and commercial users and their reaction to such a possible integration into LAAM and determining what they may like to see for themselves if LAAM is implemented. Current regulations enforce rules on operators which may not be required with a LAAM. Besides, research into prospective users and their preliminary strategies, pricing and other decisions that firm such as logistics ones will make when using the network. Consideration of overall supply chains and the changes that drones may bring in the context of LAAM, helping to not only enable but cheapen the use of drones and impact a range of upstream and downstream elements. Retail precincts may be impacted by yet more package delivery. Warehouses may look quite different from what they do now. Drones may replace hydrocarbon fuel consumption with electric fuel consumption. They may also remove trucks from roads, particularly urban delivery ones. And individual supply chains and travel patterns may change as drones become part of everyday life.

Other transport management specific questions remain to be answered, as highlighted in the literature. Delivery substitution decisions will also be of interest to academia. Cost will be a driver of these changes, but other factors such as service quality and the types of services offered will become a focus area. Optimal drone network designs will be an interesting avenue of discussion (e.g. Pulver and Wei, 2018) which will vary depending on the purpose of the drones employed. Optimising how truck and drone fleets interact may be a useful transitive measure to help improve delivery time and efficiency (Freitas and Penna, 2018). Consideration of other delivery mechanisms is also worth researching, such as replacing the truck with a parent drone (Kim and Awwad, 2017). Medical deliveries will need higher prioritisation on the network to ensure their rapid delivery from the donors to the operating theatres where they are needed, or transit points through which they will need to travel (Balakrishnan et al., 2016). So some form of prioritisation matrix will be required.

A key limitation of our approach and any literature review more principally is the lack of full comprehensiveness as literature in the relevant subject area is a proliferating (past the cut-off date and the publication of the paper) and b) not confined to academic outputs (i.e. those indexed in SCOPUS). During our grey literature review, we noticed a recent surge of consultancy reports on drone use cases in the context of urban air mobility (UAM) as a new mode of transportation (e.g. Baur et al., 2018 (Roland Berger); Booz Allen Hamilton, 2018; Grandl et al., 2018 (Porsche Consulting); Thomsen, M., 2017 (Airbus)) which suggests that academic papers covering this topic will follow. Indeed, Fu et al. (2019) is a first in a potential series of such papers and has been included in our review.

In summary, our literature review results suggest that security, privacy and acceptance concerns, whist significant and relevant, are not as dominant as they have been in previous periods – with the use of drones in various ecosystems providing an opportunity for researchers to examine their introduction and impact on those with whom they interact. We conclude that further work is needed to understand potential impacts of drone usage (e.g. fatalities due to accidents), subsequent potential risk trade-offs and adjustment/formulation of new regulation (Hirling and Holzapfel, 2017), The safety/cost trade-off will be an important one to contribute to the setting of appropriate safety rules that facilitate the industry without constraining it unnecessarily, including the development of low altitude airspace management systems to support the increased deployment.

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