POLITECNICO DI MILANO

School of Industrial and Information Engineering

Master of Science in Management Engineering

APPLICATIONS OF DRONES IN LOGISTICS:

A LITERATURE REVIEW

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ABSTRACT

Purpose - This paper reviews scientific publications regarding the applications of drones in logistics activities. The themes covered space from their employment in peculiar tasks, like inventory controls or last-mile delivery, to transversal topics, like fleet management or environmental sustainability. Given the growing interest in the utilization of this technology in civil operations, this review is intended to highlight the main opportunities and challenges specifically related to the logistics field.

Design/methodology/approach - The review is based on 76 papers, published in the last decade in 26 international peer-reviewed journals or proceedings of international conferences, retrieved from bibliographic databases. These contributions were analyzed and categorized according to the themes tackled, following a three-phase approach.

Findings - The application of drones in logistics is gaining increasing interest both from firms, which are testing and prototyping many different solutions, as well as from scholars, as shown by the rising amount of publications from 2017 onwards. The number of contributions around this topic is very huge and it will undoubtedly increase even further in the next years. However, it seems to be missed a study that jointly covers many different applications of drones in logistics, since each paper focuses on a very limited range of them. Examining the literature, it is evident the great potential of this technology employment in logistics applications, although it is currently leverage only in specific niches, due to the numerous technical and "business" challenges.

Originality/value - To the extent of the author's knowledge, this paper is the first one that, in a unique literature review, tries to address all the possible applications of drones in logistics. Considering the heterogeneity and breadth of the potential opportunities, it could be difficult for novices to clearly identify them and understand their potentiality. Therefore, this review could help the spread and access to the necessary information for practitioners who want to approach the theme, thanks to the embedded work of categorization and synthesis.

Keywords - Logistics, Drones, UAVs, Inventory Controls, Handling, Monitoring, Last-mile, Innovativeness, Fleet management, Environmental impact, Humanitarian Logistics.

Paper type - Literature review

SOMMARIO

Scopo – Questo report esamina le pubblicazioni scientifiche riguardanti le applicazioni dei droni nelle attività logistiche. I temi trattati spaziano dal loro impiego in attività particolari, come il controllo dell'inventario o la consegna dell'ultimo miglio, a temi trasversali, come la gestione della flotta o la sostenibilità. I temi trattati spaziano dal loro impiego in compiti particolari, come il controllo dell'inventario o la consegna dell'ultimo miglio, a temi più completi e trasversali, come la gestione della flotta o la sostenibilità ambientale. Dato il crescente interesse per l'applicazione di questa tecnologia nelle operazioni civili, la presente rassegna intende evidenziare le principali opportunità e sfide specificamente legate all'ambito logistico.
Metodologia – Il report si basa su 76 articoli, pubblicati nell'ultimo decennio in 26 riviste internazionali o atti di conferenze internazionali, recuperati da database bibliografici. Questi contributi sono stati analizzati e classificati in base ai temi affrontati, secondo un approccio trifase.
Risultati - L'applicazione dei droni nella logistica sta suscitando un crescente interesse sia da parte delle imprese, che stanno testando e prototipando diverse soluzioni, sia da parte degli accademici, come dimostra il crescente numero di pubblicazioni scientifiche sul tema a partire dal 2017. Il numero di contributi su questo tema è enorme e sicuramente aumenterà ancora di più nei prossimi anni. Tuttavia, sembra mancare uno studio che copre congiuntamente molte e diverse applicazioni dei droni nella logistica, poiché ogni documento si concentra su una gamma molto limitata di essi. Esaminando la letteratura, è evidente il grande potenziale dell'impiego di questa tecnologia per la logistica, anche se, al momento, si sta sfruttando solo in nicchie specifiche, a causa delle numerose sfide tecniche e manageriali.
Originalità – Dopo un'approfondita ricerca, si evince che questo lavoro è il primo che cerca di affrontare, in un'unica rassegna della letteratura, tutte le possibili applicazioni dei droni nella logistica. Considerando l'eterogeneità e l'ampiezza delle potenziali opportunità, potrebbe essere difficile, per chi si avvicini a questi temi per la prima volta, identificarle chiaramente e comprenderne le potenzialità. Pertanto, questo report potrebbe aiutare la diffusione e l'accesso alle informazioni necessarie per i professionisti che vogliono avvicinarsi al tema, grazie allo sforzo fatto di categorizzazione e sintesi.
Parole chiave - logistica, droni, UAV, controlli di magazzino, *handling*, monitoraggio, ultimo miglio, innovatività, gestione della flotta, impatto ambientale, logistica umanitaria.
Tipo di contributo - Rassegna della letteratura

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1 INTRODUCTION

In the last years, thanks to the impressive technological development, drones have been employed in an increasing number of industries and in heterogeneous applications. However, their first appearance dates back to the nineteenth century, when the Austrian soldiers used unmanned balloons filled with explosives to attack Venice in 1839. In fact, an Unmanned Aerial Vehicle (UAV) could be simply defined as “any aircraft operating or designed to operate autonomously or to be piloted remotely without a pilot on board” (EU, 2019). The military sector began to employ extensively drones after the Second World War, using them not only as flying remote-controlled weapons, but also as spy aircrafts, which allowed monitoring enemies’ moves quick and effectively, without risking the pilot life. Hence, over the course of the Vietnam War (1955-1975), the US army mainly utilized drones as a medium to gather data. The use of drones has been confined to the military sector until 2005 when, after the Katrina Hurricane, they helped during the rescue operations. The following year, the Federal Aviation Administration (FAA) emanated the first commercial drone license, paving the way for civil applications and the broad adoption of this technology. In fact, also looking at the following figures and data, it is evident how huge and fast the phenomenon of drone diffusion is.

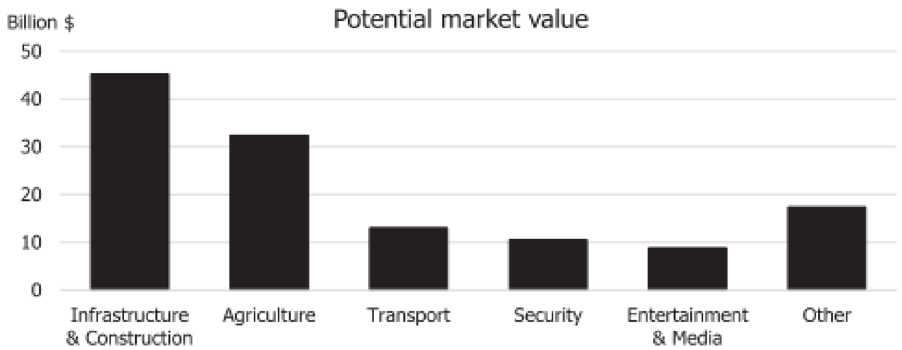


Figure 1: Potential drone market value (Otto et al., 2018)

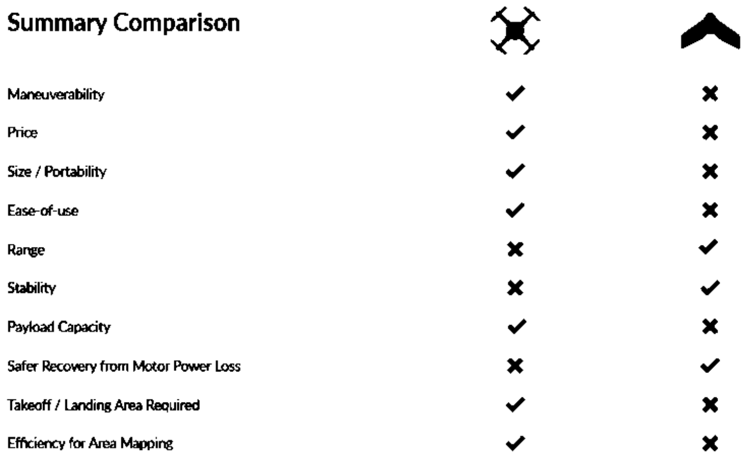
Figure 2: Drone diffusion by continent (DroneDeploy)

Additionally, DroneDeploy (DroneDeploy, 2018), the leading cloud software platform for commercial drones, affirms that their worldwide usage in the biennium 2016-2018 has surprisingly increased from 5 to 30 million acres covered, and the number of countries that saw their usage rose from 130 to 180. Moreover, the data regarding the expected growth of the market are even shinier: a 15% CAGR increase in the period 2019-2024 ("Mordor Intelligence," 2019). DroneDeploy identifies three key factors affecting differences in drones' adoption among countries: economical, cultural frictions (for instance South Africa or Canada) and normative.

Moreover, it is important to highlight that there are many different types of drones, which could be grouped according to different criteria. Alwateer (Alwateer, Loke, & Zuchowicz, 2019) affirms that the different classification dimensions have a great impact on drones' performances, in terms of speed, payload, endurance, traveled distance, service type, and location type. Classifications usually base on:

- The **space of action**, which could be aerial, maritime or terrestrial. Although the most diffused drones are the aerial ones, for some operations diverse drone typologies are combined together to leverage their peculiar characteristics and overcome the distinctive drawbacks.

- The **configuration**, which could rotary wing (fixed central body plus several propellers) or fixed-wing (they have a fixed-wing for each part of the central body). The first group of solutions ensures easier maneuverability and allows to vertically land/take-off, which is an important feature for instance in indoor spaces. Instead, the other group is recommended for those operations that require higher stability or battery performance.



Summary Comparison		
Maneuverability	✔	✖
Price	✔	✖
Size / Portability	✔	✖
Ease-of-use	✔	✖
Range	✖	✔
Stability	✖	✔
Payload Capacity	✔	✖
Safer Recovery from Motor Power Loss	✖	✔
Takeoff / Landing Area Required	✔	✖
Efficiency for Area Mapping	✔	✖

Figure 1: Comparison fix vs rotary-wing, DroneDeploy

The autonomy, namely the freedom from external control or influence (e.g. human operator). "How autonomous a drone is must always be a measurement of how independent the platform and its workflow are. A truly autonomous drone would decide on destination and route as well as control in the air" ("Droneii," 2019). It is important to distinguish the term "autonomy" from the one of "automation", which applies instead to the mechanical elements, embedded in the drone, that reduce the operator efforts and tasks.

- A single or Multi-UAV environment. The network architecture ensures greater scalability and multitasking abilities but embeds a higher management complexity.

2 METHODOLOGY OF THE LITERATURE REVIEW

This review covers scientific contributions of the last 10 years. Indeed, the academic interest in drones' applications in logistics is rather recent. To perform this work, I restored to a three-step methodology. Step 1 consisted of paper selection, step 2 in the analysis of the literature, finally step 3 was framework creation.
Figure 4 clarifies the overall methodology used and it illustrates the sub-steps.

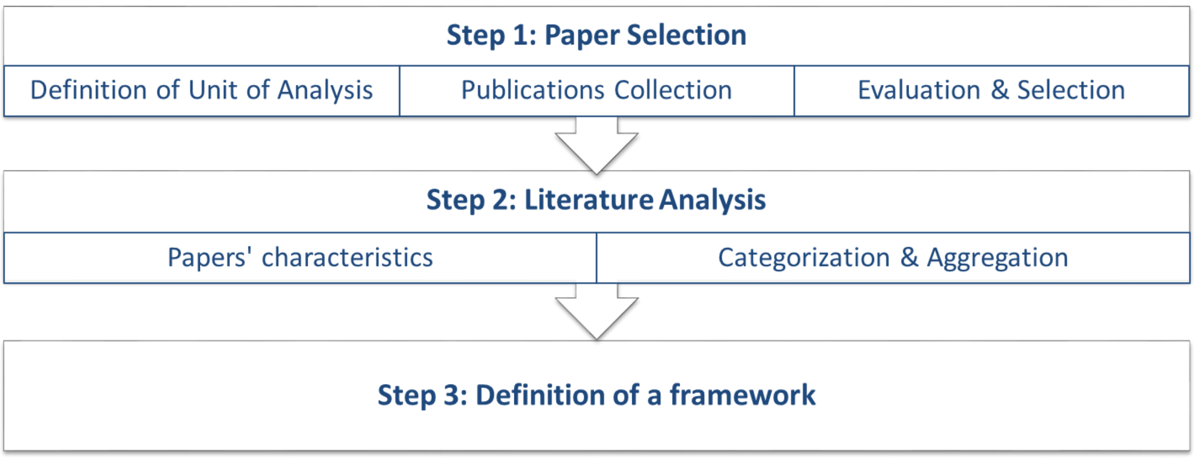


Figure 2: Methodology of the literature review

2.1 Paper selection

- **Definition of Unit of Analysis**: the unit of analysis was defined as a single scientific paper, published in an international peer-reviewed journal or presented at an international scientific conference.

- **Publication Collection:** the research was conducted on the international bibliographic database Scopus (Scopus, 2019). However, considering the novelty of the theme, it was occasionally necessary to integrate the academic material found with data and information coming from sectorial websites (*i.e.* DroneDeploy). The research was based on six main queries, which covered the most representative combinations of the following keywords: “Drone”, “UAV”, “logistic”, “supply”, “chain”, “transport”, “deliver”. Overall, by summing up all the results obtained in different search runs, 370 publications, excluding repetitions, were found. Successively, the research was carried on analyzing the references of the selected papers.

- **Evaluation and Selection:** During this step, I read all the abstracts of the acquired papers in order to attest their appropriateness and value with respect to the purpose of this study. Therefore, I choose a sub-set of 76 papers for an in-depth investigation. Figure 5 reports the result of this phase.

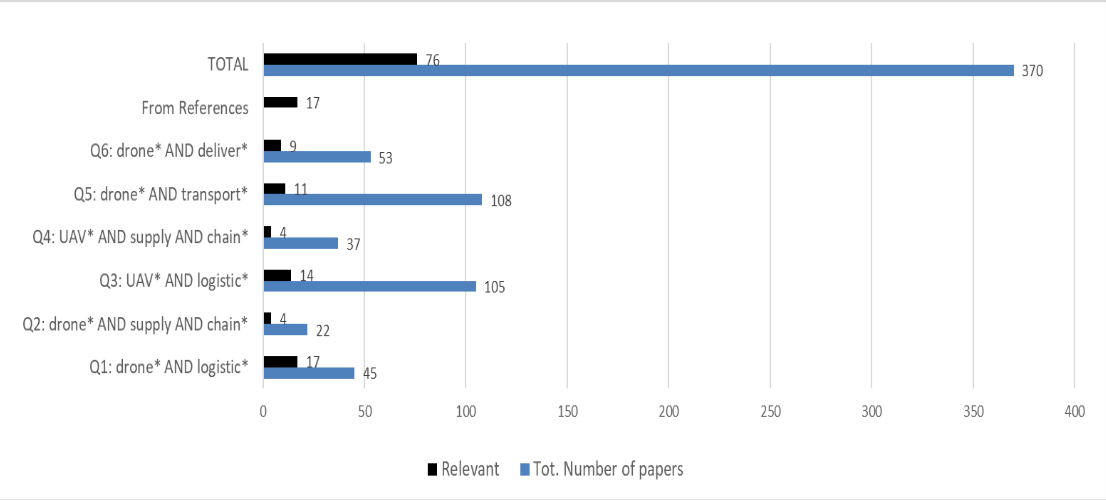


Figure 3: Queries and relative papers, both collected and selected

2.2 Literature analysis

- **Papers’ characteristics**: The 76 papers studied were published in 26 different scientific journals, with a mean value of 2.9 contributions per journal. However, it is evident from Figure 6 that the great majority of the selected papers are published on IEEE and Elsevier, which together cover around 50% of the chosen contributions. Looking at the year of publication, the majority of the papers are relatively recent and, from Figure 7, it is also noticeable that the academic interest around this topic is continuously increasing. The outlier data is the year 2019, which counts only 11 selected papers, but this data is explained by the fact that this review step was conducted in the first half of the year 2019.

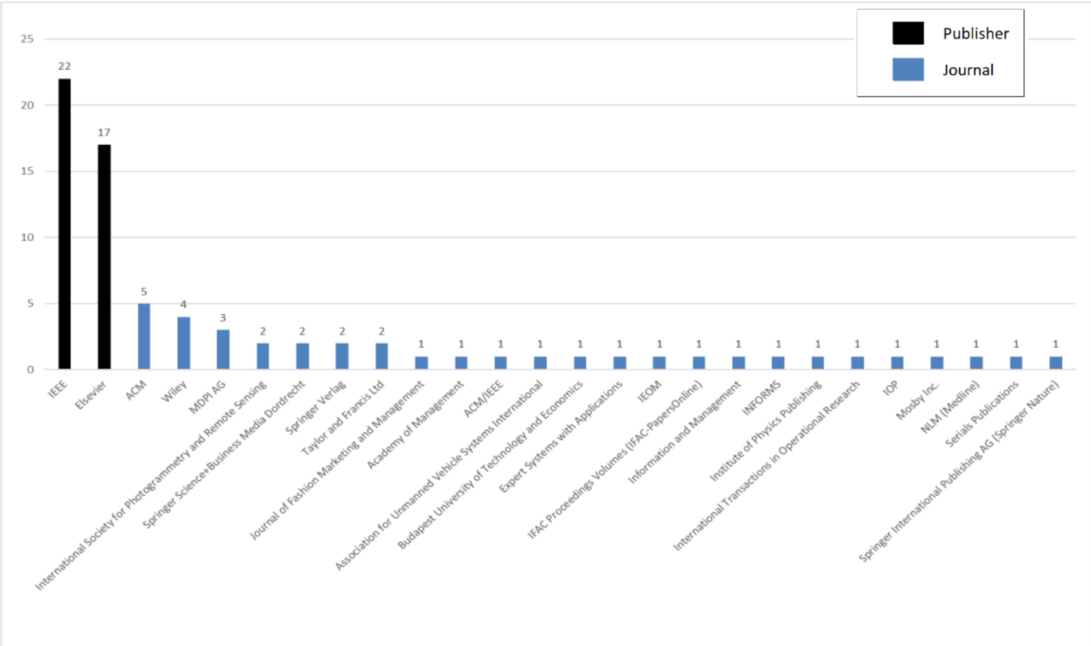


Figure 4: Selected papers from publishers and journals

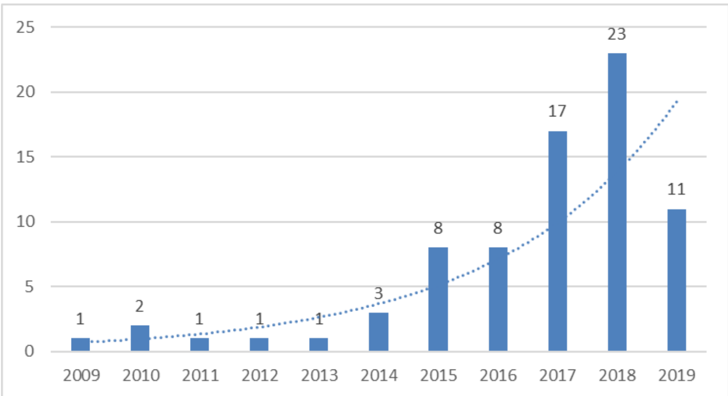


Figure 5: Distribution of selected papers in the analyzed years

- **Categorization and Aggregation:** The papers were firstly divided into the two main groups of internal and external logistics. This first passage allowed us to highlight the different requirements and opportunities, specific to the different groups of applications. Then, for each group, the papers were classified according to the specific issues tackled. I adopted this approach because I identified it as the best one to specifically address the issues related to several applications. Instead, other possible categorizations, for instance based on the sector or industry, would have been less powerful in emphasizing all the peculiar opportunities and challenges.

2.3 Definition of a framework

After the analysis of the 76 papers, the subsequent section summarizes the main assets and drawbacks of UAVs respect to alternative transportation modes (*i.e.* classical vehicles, electric vehicles, bikes, scooters ground drones, physical internet, cargo tubes, additive manufacturing). To conclude is provided a recapitulatory framework, which illustrates all the applications handled during the review and, for each of them, specifies the most representative challenges and opportunities. Thanks to this framework, the reader can have a fast and easy legible overview of the current and potential drone applications in logistics. Instead, for an exhaustive analysis of the specific applications, the author recommends the lecture of the relative review chapters.

3 OVERVIEW OF THE PAPERS INCLUDED IN THE LITERATURE REVIEW

3.1 Papers on the side of internal logistics

This part of logistics management refers to the internal activities related to information and product flows. The papers in the literature review highlight that drones are currently used in several of these activities, mainly in storage and monitoring, but there are other opportunities, for instance manipulating and transporting tasks. Moreover, UAVs' characteristics appear to be essential for the industry 4.0 revolution, with a strong contribution in collecting dynamically as much data as possible from multiple locations, and, working on the multi-robot cooperation, firms will further increase the exploitation of this technology.

3.1.1 Inventory controls

As regards internal logistics, one of the main potential fields of application for drones is inventory management, in particular, inventory taking and auditing. Among the others, this topic is investigated by Mészáros and colleagues (Mészáros et al., 2018), who affirm that UAVs could bring great benefits in these operations, due to the match between the requirements of these activities and drones' characteristics, which are high maneuverability, agility and low-cost movement in general.

Taking into consideration that inventory management should be carried out continuously, to ensure efficiency in logistics and meet with regulatory requirements, the ideal inventory should be performed automatically, efficiently, safely and in real-time, ensuring a good level of flexibility. Therefore, the use of autonomous vehicles can help in achieving these goals solving current methods' drawbacks, like frequent human errors, incidents due to working in dangerous conditions (*i.e*. large heights) and large personnel costs. Although most firms use automated methods such as bar code and radio-frequency identification (RFID), these methods are time-consuming and labor-intensive, especially, when stocks are bulky, big-sized and stored in multi-tier or outdoor environments.

The main challenge for this drone application is the requirement of accurate localization solutions, which should also be easy to install at low costs in large warehouses. Since GPS technology is not reliable in an indoor environment, this approach is not feasible indoors. Additionally, more precise positioning accuracy is required to fly between narrow racks, thereby achieving autonomous navigation of micro UAVs. Moreover, the UAV should operate close to obstacles or even in restricted indoor spaces and autonomous maneuvering, inside such a building, is highly challenging because the majority of the pace is encumbered with high shelves, which are filled with stocked goods. For these reasons, only tight aisles are left for drones' navigation, which is also frequently obstructed by other objects like forklifts. Finally, the shelf rows lack distinctive geometric features and are highly self-similar which makes precise self-localization difficult. This requires real-time localization with long-distance sensors in large maps with many structures.

To remedy these issues there are different options in the literature. Firstly, Macoir and colleagues (Macoir et al., 2019) designed an Ultra-Wideband (UWB) solution that uses infrastructure anchor nodes, which do not require any wired backbone and can be battery powered; such systems can replace the GPS by anchor-based localization systems. The high accuracy (cm-level ranging error) and low cost of UWB radios for indoor positioning make it the perfect technology for tracking drones in warehouses for autonomous inventory-taking. Secondly, Beul and colleagues (Beul et al., 2018) presented a self-localization and mapping approach based on a 3D lidar, with a low-level obstacle avoidance mechanism. The robot carries a sensor setup to identify the stocked material by means of fiducial markers and radio-frequency identification (RFID) tags. Finally, regarding outdoors stocks, Han and colleagues (Han et al., 2018) designed an integrated inventory management system based on small UAV and beacon.

To sum up and clarify this topic, Fernández-Caramés and colleagues (Fernández-Caramés et al., 2019) built an interesting table of comparison of the most relevant UAV-based inventory systems. Moreover, they proposed their own system based on DLTs (Distributed Ledger Technology). This solution seems to be the most promising in order to guarantee operational efficiency, data transparency, authenticity, and security. The proposed alternative requires four essential elements to keep product traceability and obtain the inventory of a warehouse: a labeling technology, an identification technology, a UAV and supply management techniques.

3.1.2 Handling

In many manufacturing plants, at the stage of product assembly and/or customization, there are problems related to the high number of products, machines, and routings. The use of quadcopters could lead to a higher level of efficiency, effectiveness, and productivity, since drones allow transporting materials in a 3D space, thus overcoming the limitations of AGVs, belt conveyors, hand trucks and others, which can only work in very rigid routes and on a plane or the floor.

To study this situation, Olivares and colleagues (Olivares et al., 2015) analyzed a manufacturer of injection molding plastic products as a reference model and they proposed a solution in which a drone fleet transports materials and semi-finished products. One year later, Olivares and Cordova (Olivares & Cordova, 2016) took the previously mentioned case study as a starting point and developed further the reasoning. Indeed, considering the drones' limited battery and that it is not efficient to wait for their energy restriction, the authors proposed to use the "pull" concept jointly with the Kanban signal, to generate the transport order. Lead Time and in-process inventory would have a significant reduction since there will be a control of in-process inventory, in both semi-finished products and accessories. The control is performed on overproduction, queues, and reduction of waiting times produced by battery replacement in drones.

Another use case from literature is the one proposed by Ham and Kim (A. Ham & Kim, 2018), who investigated the potential use of a drone to transfer jobs between locations in a semiconductor factory. Each job could be picked, transferred and dropped off by a drone and might be characterized by origin, destination, priority, and precedence-relationship. Mészáros and colleagues further studied (Mészáros et al., 2018) this concept, declaring that drones could substitute human labor for a lot of picking activities. This idea could be seen as a mix between two emerging trends/technologies: Amazon’s warehouse robots and adoption of drones for last-mile small parcel delivery. Regarding this field, the main issues are related to fleet coordination and job orchestration. Moreover, the limited payload decreases the available savings potential and the authors argued that “if a process can only be replaced partially, then the added coordination efforts will subtract as well”.

Always referring to the handling and transporting activities, it is possible to cite two prototype projects specific for the port logistics operations. The first is sponsored by Kotug (Kotug, 2019)and regards the support during the trailer operations of big ships. Specifically, the drone will transport the “messenger line” (that is the thinnest rope with which the strongest cable, used for the actual towing, is anchored) and will facilitate one of the most dangerous and complex activities in this context, indeed the tug will not navigate in front of the ship but only next to it, maintaining a greater safety distance. Instead, the second project is sponsored by Airbus and Wilhelmsen (Wilhelmsen, 2019), where drones will be used to transport spare parts or light material between the quay and the various ships present in the port, optimizing the internal distribution. These operations will be conducted quicker, safer and in an environmentally friendly way.

Moreover, with reference to the internal transportation and handling activities using drones, Fedorko and colleagues (Fedorko et al., 2018) investigated the issues related to the movement of cargo along the designated flight routes, since these flight corridors usually overlap with the routes designed for employees' use. On one hand, from the legislative point of view, the current law regulations should be amended so nothing would obstruct the usage of drones in branches of industry. On the other hand, as regards the technical element, there are several open points, such as the question of whether the flight corridors should be designed in a way that they would lead above employee's areas or their paths should be created above the isolated parts where employees are not allowed.

Finally, it is important to mention the new paradigm of Multi-Robot Cooperation. In fact, this could represent a valuable opportunity to overcome the drone's peculiar drawbacks, like restricted cover range, limited payload capacity, and energy efficiency. This theme is increasingly attracting the attention of researchers, essentially for the numerous advantages that the deployment of a multi-robot system brings to perform a specific task. In fact, the problem is brought to a simpler level when the activity is too complex to be accomplished by a single-robot. However, multi-robot cooperation could introduce other issues, like the challenges related to perception, decision, and action. In this respect, Harik and colleagues (Harik et al., 2015) studied the specific type of multi-robot cooperation named Air-Ground-Cooperation (AGC), where Unmanned Aerial Vehicles (UAVs) and Unmanned Ground Vehicles (UGVs) work in a cooperative way to perform a given task. The main advantage that can be drawn from AGC is the complementary skills provided by each type to overcome the specific limitations of the other. For the team of UGVs, they used a leader-follower approach, in which the leader sends relative angular and linear velocities to the followers in order to maintain the desired formation. A UAV is used to guide among a team of UGVs (mobile robots) to perform objects transportation tasks (tools, gas masks, etc.) in unsafe industrial areas. The camera installed on the UAV continuously transmits the video flow to the ground station; then these images and coordinates are used in real-time to provide localization information to the UGV's leader, to navigate in the industrial area through the on-the-go waypoints selected by a human operator. The other UGVs are called followers and are used to carry heavy loads.

3.1.3 Monitoring

Monitoring is one of the most promising fields of application for drones and many companies are already using them for civil operations. Traditionally, inspection tasks require considerable expenses and might need to be performed in difficult-to-access or dangerous areas. In many situations, UAVs can take over the visual inspection part of the tasks, reducing the need for human intervention, and therefore save a significant amount of resources.

On one hand, UAVs can be used indoors in the sphere of inspection activities towards active and passive elements from the field of logistics as Fedorko and colleagues (Fedorko et al., 2018) pointed out. In this regard, the crucial condition that has to be fulfilled to enable active usage of drones in watching complexes, production halls, and warehouses, is the availability of suitable and sufficient monitoring technology, without which performing of such activities would not be possible. This monitoring technology has already been found, for instance, we shall list technology Eysee (Hardis Group, 2019).

On the other hand, UAVs are commonly used outdoors for the inspection of logistic or industrial facilities like bridges, power lines, pipelines or building facades. In this context, Mathe and colleagues (Mathe et al., 2016) suggested using drones for railways inspection, where various components of the railway infrastructure must be monitored, including tracks, catenaries, poles, semaphores, etc. Here, a further advantage of using UAVs is that traffic does not have to be stopped, unlike in the case of inspection by humans. However, the authors highlighted the obstacle avoidance as the most challenging issue for safer navigation. Similarly, Rengarajan and colleagues (Rengarajan et al., 2017) remarked that the Indian government has granted permission to use drones for aerial surveillance of its gas pipelines sections passing through forests, rivers, environmentally sensitive and other inaccessible areas. The Indian government has also employed drones for similar monitoring purposes in its Railways and Highways infrastructures. Following this direction, Olsen and colleagues (Olsen et al., 2017) suggested Small Unmanned Aircraft Systems (UAS) as a valuable new tool in the inspection and maintenance of electrical power transmission and distribution lines.

Another sphere of UAVs monitoring application is environmental control. To this end, three works were analyzed: the first two consider drones serving as a data mule, exporting data from isolated wireless multimedia sensor networks located in remote nature reservations, while the third recommend drones as direct controller of vessels' compliance with pollution emission regulations. Firstly, Caballero and colleagues (Caballero et al., 2017) focused on the wildlife inventories of the Amazon rainforest and designed the hardware and software of a low-cost long-lasting time flight drone with the purpose of serving as a data mule. They proposed to install a router on a UAV, which will fly over the study area to extract periodically the information accumulated on the hub node. Secondly, Katoh and colleagues (Katoh et al., 2017) looked instead at the several problems pertaining to the forest in Japan: current forest resources are measured manually, there are many types of dangers and the accuracy of the information obtained is low relative to the excessive cost of surveying. To resolve the issues mentioned above, the authors have developed integrated information technology for obtaining useful forest information, including ALS, drone LS, personal LS (PLS) carried by backpack, and TLS, which saves manual labor for forest monitoring and enables sustainable timber productivity. Finally, Xia and colleagues (Xia et al., 2019) advised the drones' usage to inspect shipping operations and related emissions, which account for nearly 10–15% of total anthropogenic SO x emissions around the world. Martek Marine is developing durable drones (over 50 km for a flight trip) to sample vessels' gases using self-equipped sensors. The goal is timely monitoring of the vessels' emissions since on-shore supervisors can check promptly the emissions compliance with regulations.

Staying in the maritime sector, Maersk (DroneBlog News - Maersk, 2016) is sponsoring the adoption of drones for the active monitoring of the logistic activities performed in ports. In fact, drones will not just monitor the work areas but they will be equipped with a loudspeaker for prompt communication to workers. The main goal of the project is to ensure a higher control and safety level on the handling operations, which will be performed following the strict regulations. The company states that, for the moment, the project will not be conducted in Italy due to labor oppositions, indeed trade unions argue that the drone, instead of helping the worker and increase safety, will cause an increase in his stress level due to the control itself.

3.1.4 Multi Moment Analysis

Traditional Multi Moment Analysis is a measurement where objects serving in the production supply processes, such as people, forklifts, etc. are monitored with the purpose of defining their utilization. The observation is done by inspectors that walk around, at random intervals, and compile forms annotating what activity the person or machine was executing at the moment (Multi Moment Analysis, 2019). This statistical technique is useful and popular, even though it is fairly expensive (according to Krisztián Bóna's expert opinion, an average measurement requires 10 people plus a project lead, lasting 5 days). The traditional method is not only costly, but the worst drawback is that people have different judgments, thus there is a high observation uncertainty and low data integrity. Instead, UAVs could be utilized for these operations, replacing the human workforce and offering significant benefits. In fact, these activities can be made cheaper, faster and more reliable at the same time. In addition, Mészáros and colleagues (Mészáros et al., 2018) stated that Multi Moment Analysis is a perfect use case where, similarly to inventory taking, the natural advantages of drones can be leveraged, as they are not required to carry a payload. The authors advise also that setup costs of the measurement would slightly increase, as first, an indoor localization system had to be installed, but afterward, it would be needed just one person, who supervises the monitoring process, as UAVs would be able to autonomously detect the target objects and film them. These videos could be live-streamed into (or recorded and then played in) a control room, where a single person could record the activity of the object (already digitally), therefore homogenizing and speeding up the measurement.

3.2 Papers on the side of external logistics

Drones will be fundamental for the future of external logistics operations. Indeed, this technology will ease the alignment with many of our society megatrends like digitalization, autonomous mobility, smart cities, higher demand for delivery, shorter delivery lead-time, complex traffic congestions, and environmental problems. Moreover, this technology is consistent with Industry 4.0 principles and processes, regarding not only internal activities and operations but also the external once. In fact, drones could integrate with 4.0 technologies, ease the data acquisition and information exchange, allowing the cooperation between suppliers and manufacturers.

Delivery applications are very wide and include package deliveries to remote rural regions and first- and last-mile deliveries in urban and suburban areas as well as express deliveries of, for example, defibrillators to treat out-of-hospital cardiac arrests or customized parts to assembly lines. Delivery of medical supplies, especially of vaccines and blood, may significantly improve the quality of medical service in developing countries, where road infrastructure is poor and some parts of the route may become impassable during certain seasons. Unsurprisingly, the first production-level use of a delivery drone to move beyond a pilot test or demonstration project was blood delivery in Rwanda by Zipline's fixed-wing drone (Ackerman & Koziol, 2019). It is also important to take into account that, according to expert estimates, the cost savings of the drone vaccine delivery, compared to the vaccine transportation using common trucks, surpass the required fixed cost for establishing drone infrastructure.

The reasons for this technology employment during deliveries could be found in the increasing pressure for efficiency, as explained by Perboli and Rosano (Perboli & Rosano, 2019), who added:

"The analysis of the BMCs shows how combining traditional and green subcontractors might determine benefits in terms of efficient last-mile supply chain management but, at the same time, may hide the threat of a price war, reducing the service quality".

Overall, although the total distance traveled in a drone-only delivery system will likely be longer than in a truck-only delivery system due to the drone's limited payload, drones may be faster than trucks, have a lower cost per mile to operate and emit less CO_2. Thus, they represent a greener alternative to conventional delivery mode. However, regulations will potentially restrict the development of the delivery segment more than other fields of application, due to safety and privacy issues.

3.2.1 Urgent delivery

In situations of emergency, drones could perform deliveries to ensure higher effectiveness. In fact, deliveries would be faster, since drones would not be constrained by traffic slowdowns, and it would be possible to reach areas that are traditionally difficult to serve, such as mountain regions or villages with bad roads connections. Moreover, the exploitation of an autonomous aircraft could make it possible to reduce road-based deliveries, thus allowing a decrease in the working force as well as minor pollution.

One of the main fields of application is medication delivery. Indeed, these products are not only urgently needed, but also small and lightweight, thus the healthcare sector could strongly benefit from UAV technology. In this regard, a shift to drone-based shipments could be even more relevant when urgent medications are needed after disasters, in contexts of broken ground or bad road connections. However, some risks need to be carefully assessed. For instance, there are aviation concerns deriving from the crowding effect of proliferating UAVs. In addition, some specific medical items, like blood products, must be packaged in a manner that ensures minimal risks of exposure and tampering during transit, thus protections must be implemented to prevent unauthorized interception of controlled substances. Other issues regard the patient's privacy, health insurance portability, and accountability act regulations.

Although many factors can complicate a disaster response, it is clear that distribution, not supply, remains a critical problem. Hence, the ability to expeditiously shift blood products between centers to resolve shortages, without involving humans in the transport process, would improve patient care and reduce expenses. To study more in-depth the above-mentioned issues, Gatteschi and colleagues (Gatteschi et al., 2015) designed a prototype system for order placement and autonomous delivery using an unmanned aircraft. Even if their system's target is drug delivery, the authors affirm that the reasoning is easily extendable to other medical areas. They identified that safety is the major issue, mainly due to the problem of moving obstacles. Moreover, correct delivery would be a challenge because risks deriving from an incorrect delivery is not only related to a good consigned in the neighbors' courtyard but could have worst consequences when the package is erroneously delivered in traffic areas such as highways. Finally, the authors pointed out the theme of drone preservation and, more specifically, its ability to correctly return to base. To overcome these problems, it would be necessary a continuous evaluation of the expected power required to finish the mission and a periodic check on drone components' state. Lastly, it would be wise to avoid deliveries during bad weather conditions.

Another promising application for drone emergency delivery is organ transportation. The current logistics system involves a complex network of couriers and commercial aircraft and the most challenging issue is time. In fact, vital organs must be transported within a certain time limit in order to make them available to the patient as soon as possible. This is even more complicated in metropolitan cities, due to high traffic congestion, and longer CITs (Cold Ischemia Time) are associated with poorer organ function. To support the service and ensure traceability, Scalea and colleagues (Scalea et al., 2018) proposed the HOMAL (Human Organ Monitoring and Quality Assurance Apparatus for Long-Distance Travel) technology which improves geographic access to organs and could be of potential benefit to waitlisted organ transplant candidates. HOMAL is a novel device designed to measure temperature, barometric pressure, altitude, vibration and location via GPS during transportation. This theme was also studied by Balakrishnan and colleagues (Balakrishnan et al., 2016), who presented the idea of using manually controlled UAVs to transport organs. They adjusted the motor and the battery capacity, such that it can be able to lift the organ box for a longer distance (50 to 60 km in radius) and they added a 360° camera to enable remote controlling.

Staying in the healthcare sector, Thiels and colleagues (Thiels, et al., 2015) wrote about the use of UAVs to transport medical supplies, like blood products and pharmaceuticals, which often have limited availability during emergencies and when conventional channels of supply are disrupted. Their article outlined the demand, feasibility, and risks regarding the use of small UAVs to transport blood and pharmaceutical products to critical access hospitals, mass casualty scenes and offshore vessels in times of critical demand. In fact, although many critical access hospitals have blood products available, inventory is limited and supplies of platelets and plasma are typically even more restricted than red cell products. The ability to maintain an inventory of these products is complicated by numerous factors, including shelf life and cost. For instance, a product like platelets and thawed plasma have a five days shelf life, so they may be wasted when the demand is low. Another example is anti-venom, which is not only rarely used, but also expensive and with a limited shelf life, thus, it is not practical to stock it in many hospitals. As a result, in all these cases either the patient must be transferred to the product or the product must be shipped to the patient, which could cause significant delays in medical treatment. Additionally, current standards of care recommend transporting patients who require transfusions to larger hospitals when resources, including blood products, are unavailable or limited. UAVs might fulfill the shipper role without risk to transport crews and without requiring the patient to be transferred. The authors suggest that UAVs may also transport other medical devices, such as automatic defibrillators, combat gauze, external fixator devices, and tourniquets.

Another interesting use case is carried by Fleck (Fleck, 2016), who proposed to use UAVs for express deliveries of defibrillators. Indeed, Sudden Cardiac Arrest (SCA) is a leading cause of death in adults and less than 8% of people suffering SCA outside of a hospital survive the episode since the survival rates for defibrillation are directly tied to how quickly the AED is administered. Hence, the rapidity of a small, light delivery aircraft could be a critical advantage (every minute lapsed after cardiac arrest before receiving a shock, results in a 7-10% decrease in survival rate). In many rural or congested regions, ambulances can take more than 10 minutes to arrive with the life-saving defibrillator, while a UAV could fly more rapidly to similar distances.

However, defibrillators are often heavy, since they embed a large battery in order to remain functional through many months of disuse. Manufacturers should explore how to integrate medical devices with new emergency response systems, such as UAVs, by optimizing usability and weight (for example, replace a standard 3-year battery with a much smaller, but more frequently maintained 3-week battery).

Finally, Ackerman and Koziol (Ackerman & Koziol, 2019) talked about the first real commercial application of drones in the healthcare sector that passed the test phase and proved to represent a sustainable business model. The article reports the reality of Zepline, which is delivering by drone blood to 25 hospitals and clinics across Rwanda every day. Zipline is betting that transporting lifesaving medical supplies, which are often lightweight and urgently needed, will be the killer app for delivery drones. For hospitals in need of critical medical supplies, Rwanda's roads pose a real problem. Hospital administrators worry most about blood and blood products, which have a short shelf life and strict storage requirements. It is also difficult to predict how many packs of each blood type will be needed at a given facility, and when. In an emergency, it can take up to 5 hours for a Rwandan hospital to receive a blood delivery via road, which could easily mean death for a patient in need. The company does admit that routine blood deliveries by drones are currently more expensive than routine deliveries by ground vehicles, which move more blood per load. However, the economics change in emergencies. Over the long term, Zipline argues that minimizing waste in the medical system will help the drones pay for themselves. In Rwanda, the cost to collect, test, and store a unit of blood is about $80. Before Zipline came along, about 7 percent of blood packs expired without being used, costing the Rwandan government more than $1 million annually. In 2018, the hospitals that Zipline serves wasted no blood packs at all. Anywhere else on Earth, it would be futuristic while in rural Rwanda it is just routine.

Here below a list of projects regarding urgent drone delivery:

Healthcare logistics using drones: The FAA authorized UPS to transport drugs and blood in the USA, from WakeMed Campus to a laboratory in Raleigh. UPS and

Matternet sponsored the program and designed the drone, which is also daily used by the Suisse mail delivery (UPS, 2019).

Drone for blood transportation: The drone realized by Johns Hopkins University reached an important flight record of 161 miles (260 km). It traveled in the Arizona desert with blood samples on board. The blood was stocked in specific boxes with temperature control and, at the end of the voyage, the blood was in perfect condition. Drones will be more efficient, safe and fast in moving biologic samples from different laboratories (Johns Hopkins University, 2017).

Drugs drone-delivery: DHL and Wingcopter successfully completed a drug delivery to an island in the Victoria Lake, using the drone DHL Parcelcopter 4.0. It traveled for 40 minutes and 60 km. There are important advantages in using this technology in Africa and especially in the healthcare sector, due to the poor infrastructure (Wingcopter, 2019).

Disposable drones for drug transport: The project is called ICARUS (Inbound Controlled Air-ReasonableUnrecoverable Systems) and is targeted to several situations like wars and natural disasters. These drones are designed to do just the outbound flight, they have not a driving motor but they act as gliders, they just have a GPS receiver and aerodynamic actuators to keep the right navigation trim and allow the remote control of the drone. They can load up to 2 kg and they are 100% biodegradable, after their usage they can be abandoned (DroneBlog News - ICARUS, 2017).

Drones for defibrillator delivery: The use of drone technology for defibrillator transport would decrease the rescue time by 10 minutes compared with traditional relief operations. Tests show that the response time decreases up to 6.43 minutes in urban areas and up to 10.34 minutes in rural areas. Further results and analysis regarding tests are present on the Circulation website (DroneBlog News - Defibrillators, 2017).

Drones for drugs transport and people rescue, Italy: “Asl Toscana Sud-Est” made the first tests with drones in Punta Ala (Grosseto). These experiments are embedded into a wider project that is at the national level, which is declined in two parts: healthcare transport and search of missing people. Drones will be piloted by trained rescue staff and will be used for operations in areas difficult to reach with traditional means of transport. Moreover, the University of Bologna joined the project and designed a special delivery box with thermal control, for drug delivery (DroneZine, 2018).

Rescue drone AVY ONE: Avy and the European Space Agency (ESA) designed the rescue drone Avy One. This drone will be used to give relief to the people that everyday escape from their land and set sail to navigate the Mediterranean Sea, with dangerous boats. Avy One will cover long distances (up to 400 k km) and it will localize refugees' boats to give them food, drugs and rescue stuff in general (drone capacity 10 kg). Avy is also designing a drone, Avy Life, equipped with a special refrigerator, that will be used for organ transport between hospitals (Avy, 2019).

Human emergency rescue drone: Windhorse has a 3 meters wingspan and a load capacity of 50 kg. It is targeted to human emergency rescue and, thanks to its important capacity, can feed 100 people for a whole day. Moreover, sever parts of the drone are edible, to maximize the drone food load. The first flight will be in Syria, as support to the population suffering an endless conflict (Windhorse, 2018).

Drone delivery, emergency situations: The drone DevilAir, designed by Cambridge Consultants, will make automatic express delivery in emergency contexts. It will make the drop directly into the receiver hands, thanks to an extremely precise localization system, formed by two technologies: GPS for the macro area individualization and 3D imaging (optical sensor) to recognize the signals emitted by the receiver' device ("DroneBlog News - DevilAir," 2017).

Drone lifeguard, Italy: In Gallipoli (Lecce), the port authority is implementing a drone service to assist the rescue operations. The drone will quickly deliver the life preserver to the swimmer in trouble and it will ease the rescue operations, especially during bad weather conditions, reducing the risks for emergency personnel (DroneBlog News - Drone Bagnino, 2018).

Food emergency delivery: For instance, Lawson and Rakuten are applying drones for food delivery in Fukushima, an area with strong infrastructural problems after the earthquake and tsunami in 2011. Also thanks to this technology, the city is gaining back its lost vitality (Quarz, 2018).

3.2.2 Last-mile delivery

While there is increasing attention on the design and navigation techniques of individual drones, it is important to addresses the feasibility and profitability of the whole business. In this regard, Balaban and colleagues (Balaban et al., 2017) presented the drone delivery business model's characteristics and highlighted the differences with traditional operations. The process starts when an order is placed by a customer, then it is prepared and loaded onto an available drone. Afterward, it ascends to a prescribed altitude and flies to the customer along a route. Once it has arrived at the target location, the drone descends and sends a notification. When the customer is ready to receive the product at the landing location, the drone lands and releases the product. Subsequently, the drone ascends to the designated altitude and flies back to the business's location, where it descends again. Then, depending on the fleet management policy and drone type, the batteries are recharged or swapped. The authors also highlighted the requirement of advanced technology for human-drone interaction, to confirm the ready status before the customer receives the product (section 3.2.2.1, *i.e.* Human-Drone Interaction, is focused on this thematic). They conclude considering that, given several drawbacks like current drone fly-time, max cargo weight capacity and additional technical requirements during the transaction step, it would be challenging in the near future to perform multiple deliveries per single trip.

Other authors investigated the various challenges of the drone-delivery business process, to evaluate its technical and economic feasibility. Among them, there are Otto and colleagues (Otto et al., 2018), who identified the most critical stage with the package release, due to the possible damages to the transported goods. To reduce these risks, numerous technical solutions have been developed to fit various applications, including drone landing at specified locations (*i.e.* platforms or "delivery rugs") and the use of a parachute or tether to lower the item. Another technical issue is represented by batteries and, in this regard, Park and colleagues (S. Park et al., 2016) investigated the drone disadvantages coming from the high price of batteries, low energy density and limited lifetime. Drone batteries suffer from even a harsher environment compared with electric vehicles, since delivery drones are inherently more weight sensitive and this forces them to attach the minimum amount of batteries and exploit the full capacity. They designed a system for the battery management specifically for a drone delivery service in which batteries are automatically detachable from the drones for re-charging. Therefore, drones can make the next flight immediately and this increases the drone utilization of drones drastically. The authors identified the source of major recurring costs in the electricity one and in the battery purchasing, highlighting how the incidence of these costs is affected by design parameters and runtime techniques.

Taking into account the aforementioned UAVs drawbacks, drone logistics providers have to consider an alternative delivery model for some shipments (*i.e.* outsourcing). In fact, Sawadsitang and colleagues (Sawadsitang et al., 2019) affirmed that the flying distance limit and the location of a supplier's depot are the most relevant parameters affecting the serving area of the drone-delivery service. The cost of outsourcing the package delivery to a carrier is usually higher than that of the drone delivery and this trade-off needs to be optimized. Moreover, multiple suppliers can cooperate and create a pool of suppliers, which share not only drones but also depots and customers to serve. As such, the pool of drones can extend the drone serving area of one supplier to significantly reduce the final delivery costs and improve the resources' utilization. The authors proposed the supplier CoDD (Cooperation in Drone Delivery) framework, which has three decision-making components: supplier cooperation, cost management, and package assignment.

Results, coming from the previous model (CoDD by Sawadsitang et al.), show that if the number of customers in the serving area is small (*i.e.* low densely populated area), then outsourcing packages to a carrier is cheaper than drone delivery. While, if the number of customers in the serving area is large, the initial cost of drones and the locations of depots have an impact on the stable coalition structure. An opposite thesis is the one coming from Lim and Jung (Lim & Jung, 2018), who affirm

"It is more likely that drones will be used outside the city (plane area, mountains, islands) rather than putting the drones into the crowded city. Demand in either small islands or mountainous regions might be hard to fulfill using the conventional carriers".

The motivations are that current delivery drones are usually limited to carrying one package of goods to a single destination, but also that the available moving distance is only about 10/15 km and the weight of the loadable item is limited to approximatively 5 kg. Therefore, it is difficult to think about route delivery with multiple items, within current levels of technology. In addition, in many countries, drones are not allowed to fly in the city because the risks and the impact of accidents would be higher respect for the countryside.

To analyze the theme of last-mile drone logistics, it is important to elevate the reasoning, taking into consideration the consistency with our society trends. In fact, two-thirds of the world's population will live in urban cities by 2050 (UN, 2018) and e-commerce industry is growing, so the major problem of future last-mile delivery is not only limited to shortening delivery time and fulfilling customer demand but also minimizing the use of on-road transportation for flexible transportation networks. Furthermore, since fully autonomous vehicles could replace 90% of overall vehicles in the future, autonomous mobility will lead to a massive transformation in future transportation. In this regard, Yoo and Chankoov (Yoo & Chankov, 2019) proposed an innovative delivery concept called Drone-Delivery using Autonomous Mobility (DDAM), which links drone technology and autonomous mobility. Results reveal a high potential for utilizing autonomous mobility in last-mile delivery and indicate that the DDAM concept is more feasible as an alternative delivery method in high-demand seasons. Drones will use autonomous mobility vehicles as an intermediate transportation method to deliver packages to Delivery Destinations. In the paper, the authors illustrate the details of the DDAM concept, which comprises seven physics steps, and identified the current legislations and regulations of drone operations as the main barriers for its implementation. This concept addresses different future cities' issues, like high demand for delivery, short delivery lead-time, and complex traffic congestions.

In favor of the aforementioned reasoning, Meincke and Geike (Meincke & Geike, 2018) studied the concept of Automated Low Altitude Delivery (ALAADy), which was invented by the DLR (German Aerospace Center) and elaborated an innovative approach for cargo delivery, using very low-level flight UAVs. The main goals are the increase in productivity and the reduction of wasted times ("air freight goods spend around 80% of their time between sender and recipient on the ground"). In the paper, there are also comparisons between current supply chains and innovative ones, which use ALAAdy at different levels of the chain and involve the integration of Autonomous Robotic-Container-System. Finally, the authors describe eight options to overcome the limitations of traditional vehicles, which derive from the absence of landing infrastructure at destination:

"If infrastructure for cargo handling does not exist at the destination, then the use of a UCA opens up a new last-mile - or rather, a penultimate mile - in logistics, for which no means of transport existed so far. For such niches or exceptional situations, UCAs are a suitable solution".

Another useful paper is Moura and colleagues (Moura et al., 2018), which reports a specific use case of last-mile drone delivery, in the context of port operations. It presents the case of Maersk Tankers, who is conducting a wide program to test whether UAVs can be used and implemented in its supply. In 2017, the company completed its first drone delivery to a ship, in which a package was dropped from a height of 5m above deck level. Through this experiment, the company explored the possible application of small drones to supply vessels with spare parts, mail or medicines. Markus Kuhn, Supply Chain Manager at Maersk, want to leverage this technology to increase efficiency, cutting costs ("Shippingwatch.com," 2016):

"Costs for a barge are on average USD 1,000 and can easily go up to USD 3,000 or more. With the current payload of drones, on average a vessel has 3 cases per year

in which the barge transport could be substituted by a drone – meaning a potential avoidance of barge costs of USD 3,000-9,000 per vessel per year. And if you consider that Maersk Tankers has around 100 vessels, the savings potential could be substantial."

One of the main drawbacks identified by the manager is the dependence of the performance from weather conditions. However, the company wants to implement this technology in several activities, identifying its best application in the maintenance process, thanks to the huge potential savings in terms of time and costs. In fact, ships would be enabled to diagnose their own defects at sea.

Let us focus on another application that could strongly benefit from the introduction of UAVs: food delivery. In this context, Hwang and colleagues (Hwang, 2019) collected in their paper several examples of commercial implementations. For instance, Yogiyo, one of the largest food delivery service companies in Korea, successfully completed a food delivery test using drones. In addition, in Reykjavik, Flytrex started to provide a food-delivery using drones, it is not a door-to-door service but it allows to directly transport goods from two opposite parts of the city, with strong savings in delivery times, energy and human resources used. At Kite Beach (Dubai), Costa Coffee began delivering ice coffee to customers on the beach using drones. UberEats also announced that it would launch in 2021 a service to deliver food to customers using drones. Drone food delivery services are automatic and the computer designates the path the drones follow before delivering food, so the risk associated with air traffic or accidents is very low. Although drone food delivery services are currently limited in certain areas, they will be available in the future in many more locations.

Moreover, many studies demonstrated that, in the case of multiple-destination delivery in the same area, drones are less efficient than traditional vehicles. Therefore, Park and colleagues (J. Park et al., 2018) selected food-delivery for his study because

"Using drones for food delivery is more appropriate than parcel delivery because the weight and volume of the products are constant, the shipping distance is relatively short, and the recipients are much less likely to be absent".

In addition, the time advantage of this delivery mode can generate great benefits in terms of service level, preventing the food from turning cool or rotten.

Another useful witness is the one from Milhouse (Milhouse, 2015), who designed and fabricated an electronic delivery mechanism, which allowed the drone to carry and release the package automatically. Additionally, he took into consideration issues related to aerodynamics and package wobbling, which can be a huge impediment to flight. The author reported the following problems during tests: electromagnetic interference, range and capacity, weather conditions and construction.

Finally, Burton and colleagues (Burton et al., 2017) talked about a drone-delivery project, which could bring great social value to the future smart cities. It is about an app, AirShare, which has the goal of reducing food waste and encouraging communities to come together. Using the app it will be possible to offer a free meal to the community, select offered meals for delivery or meet and share a meal with your favorite local AirShare cook. Delivery by drone fits best to the concept because drone deliveries are faster than traditional delivery methods and, to keep shared meals fresh and warm, quick delivery is of high importance. Additionally, drone-delivery can be much cheaper. In fact, the authors calculate the costs, for power and battery for delivering a payload of 2kg, to be only 1 cent per km.

3.2.2.1 Innovativeness

Hwang and colleagues (Hwang et al., 2019) suggested that drone adoption could embed emotional benefits that would enhance the functional ones, which were examined in the previous chapters. The authors refer to the concept of innovativeness and, specifically, to the strong link between perceived innovativeness and firm success. To better clarify, Watchravesringkan and colleagues (Kittichai et al., 2010) define the perceived innovativeness as "the degree to which consumers believe that the product possesses important attributes of innovation such as newness and uniqueness". Furthermore, Ahlstrom (Ahlstrom, 2010) considered the role of perceived innovativeness in the construction of competitive advantage, because it helps in differentiating companies from other companies.

Hwang focused on the specific case of drone food delivery services and results show that when customers perceive the services' innovativeness, they are stimulated to have a favorable attitude toward using the services when ordering food and recommending the services to others. Moreover, it is important to consider that the customer personal characteristics have an influence on the adaptation to new technology (Lin, Featherman, & Sarker, 2017). Hence, companies should investigate the gender and age moderating role to effectively choose the target customer segments, for each specific drone service. The author's analysis is in line with the aforementioned reasoning and demonstrates that, regarding the specific case of drone food delivery services, companies should choose females as primary targets.

3.2.2.1 Human-Drone interaction

Human interaction with drones is a key topic to explore because it is fundamental for the effective use of the service as well as for a great user and customer satisfaction. To begin, it is important to investigate the possible control methods and, in this regard, Alwateer and colleagues (Alwateer et al., 2019) provide a useful list of the four methods, explaining the correspondent benefits and drawbacks. The first interaction method is through apps installed on virtual or physical remotes, like smartphones or tablets, which ensure Wi-Fi connection, provide virtual joysticks and a live video streaming, coming from the drone camera. In this context, Bristeau and colleagues (Bristeau et al., 2011) analyzed how drones interpret the basic signals and commands, to generate high-level flight controls and allow easier device-drone communication. The second control method is through Brain-Computer Interfaces (BCIs), which consists of sensors, placed over the sensorimotor cortex, able to capture brain wave patterns. The third method is gesture recognition, which could represent a natural and easy mean for human-robot interaction (HRI). In this regard, wearable devices, like smartwatches, would enable several actions; for instance, Sony developed a system for their SmartWatch 2 that translates accelerometer's signals into controls for a Parrot AR. Drone 2.0. Numerous authors studied the HRI theme (Monajjemi, Bruce, Sadat, Wawerla, & Vaughan, 2015) and they identify as the main drawback of the fact that, in order to interact with the user, the UAV must keep a line of sight with him. Instead, Cauchard and colleagues (Cauchard, Zhai, Spadafora, & Landay, 2016) explored how drones, using their body language, can gesture to humans to communicate. For instance, it can express that the battery is almost flat, using lights or sounds. Finally, the last method for human-drone interaction is voice recognition. Voice commands could be captured by smartwatches, sent to a paired smartphone, forwarded into the cloud for processing and then commands would be transferred to drones.

Control	Pros	Cons
Virtual remote	No additional equipment required; Feedback through screen/video feed	Basic controls
Physical remote	Allows precise manoeuvring	Requires piloting skills Large hardware controller
BCI	Hands free Fun concept	Poor manoeuvring precision Very basic commands
Gestures	Natural interaction	Gestures can vary by individual and can fail to be recognised
Voice	Pet metaphor relationship	Miscommunication can occur

Figure 6: Pros and cons of each type of drone control technique

Additionally, Tan and colleagues (Tan et al., 2018) investigated on the most important factors which make the UAV a more social-friendly robot. In this regard, distances, moving patterns and other drone's characteristics (like speed, sounds, and appearance) could play an important role in changing people's perception of the specific drone service. The authors' studies revealed that users have, on average, negative impressions about drones describing them as unpredictable or unstable, but also noisy, windy, breakable and fast. Additionally, the majority of tests participants thought that the drone was for military purposes or that it looked like a servant. Other people told that the UAV flight too fast and too close to them, which made them felt the drone as rude and intrusive. An interesting citation from Tan is:

"Regarding the interaction process, participants preferred themselves approach the drone once the drone stopped at a certain distance. This interaction pattern could make them more comfortable and secure, as well as make the drone less intrusive".

Therefore, to mitigate the above-mentioned issues, he suggested three actions: the drone must show its intention to be 'gentle' (make the interaction comfortable), demonstrate a respect for personal space (generate a sense of control to users) and finally have a friendly look (modern or business design).

Finally, Ramadan and colleagues (Ramadan et al., 2017) wrote a useful paper regarding the consumers' acceptance of drone technology, in the specific context of retail. The authors noticed that retailers are strongly leveraging technological advancements, specifically self-service technologies (SSTs), resulting in a general reduction of employee participation and an increase in customer participation, both in the creation and delivery of the service. In this regard, Ramadan explained:

"The adoption of such technologies is responsible for the shift of the consumer–brand relationship from a customer co-created value (e.g. ATMs) to a customer–technology relationship (e.g. drones). The shopper is expected eventually to start considering drones not only as part of the brand, but also as part of the retail experience as a whole. The drone, whether a delivery tool at Amazon.com or a brand activation touch point mean, will become a core element of the interaction with the brand. As a result, the relational experiences between the consumer and the brand will have to be reassessed in instances where the drone is acting as the main interface in this relationship".

An example of drone employment in retail activities is Crocs, a shoe manufacturer that staffed its shop in Tokyo with UAVs, to promote a new pair of sneakers. Drones were able to withdraw the boxes from the shelves and directly deliver them to customers within the store. The entire shop experience was automated and, other than innovativeness, the message behind this initiative was the incredible product lightness.

To conclude, the authors provided a series of statements and thesis:

- The higher is the drone's service performance, the more favorable is the consumer's attitude toward its usage
- The integration of drone technology into retailers' delivery process implies a consumer–drone–retailer relationship, whereby the drone acts not only as a delivery agent but also as a tangible representation of the retailer's service.
- The higher the personification of the drone, the more favorable the consumer's attitude toward its usage
- The attitude toward drone usage will influence a consumer's intentions to use that drone

3.2.2.3 Fleet management

DHL with PaketKopter, Amazon with Amazon PrimeAir, Google with Project Wing and recently GeoPoste with Geodrone have tested drones as a transportation means to deliver parcels. These programs propose an attractive delivery solution following a rapid urbanization context. However, the future challenge underlying this application is not only the design of drones for parcel delivery but also how to manage and organize the Logistics Support for UAVs fleet in order to deliver packages and satisfy the customers.

The establishment of the Logistics Support represents a critical phase to provide the park of all the necessary support tools for an efficient fleet. The logistics Support system is fundamental to handle and manage a massive fleet of UAVs because it extends to warehousing systems, warranty management, and maintenance. Indeed it provides the system or the product the necessary resources, humans or materials, to ensure its operational services. Moreover, the nature of the drone delivery operator activity demands operators to adapt the Logistics Support system in the function of the exploitation rate and the activity constraint (missions, maintenance, etc.). Since the exploitation rate of the fleet could influence the Logistics Support System, its requirements should be evaluated continuously.

To clarify, it would be useful to explore different definitions of the Logistics Support. Firstly, Chiesa and Fioriti (Chiesa & Fioriti, 2015) introduced the Logistics Support system as a concept that helps systems to operate properly in a satisfactory way. With a more specific reference to the drone application in logistics, the works of Omidshafiei and colleagues (Omidshafiei et al., 2017) focus on the maintenance facilitates, in terms of UAV health status, in a context of delivery missions. In this works, the authors develop a decision-making tool for each UAV: the vehicle decides in which base will return after the delivery mission and when to execute a repair operation, depending on its health status (low, medium, high). Starting from the previous works, Asma and colleagues (Asma et al., 2017) concluded that the application of the UAV status influence the UAV operations and missions and that maintenance could be applied following three parameters: maintenance levels, maintenance stakeholder and maintenance infrastructure.

Analyzing more in-depth the paper mentioned above written by Chiesa (Chiesa & Fioriti, 2015), it identifies four elements as the fundamental aspects to ensure that any complex system could operate for an extended time: providing the system with energy and/or consumables; supply equipment, spare parts, staff training, and technical handbooks; transport the system in case the area in which it works have to be changed; to house, in suitable facilities, the activities, people and hardware involved, as well as, if necessary, the primary system. The authors specified that, in this view, the design process is undoubtedly more complex, but the resulting "integrated logistic support-ILS" is extremely more efficient in terms of R.A.M.S. (Reliability, Availability, Maintainability, Safety), and this completely justifies the increased engagement in the design phase.

Moreover, Troudi and colleagues (Troudi et al., 2018) helped to solve the challenges linked to the management of a large fleet of drones, which is ready to deliver parcels to costumers, modeling the drone parcel delivery fleet with VRP. Additionally, the author identified the impact that the choice of the objective has on the sustainability indicators, like energy consumption or the number of used batteries (this theme will be discussed further in section 3.2.4). This model is based on a defined battery strategy, 100% of battery capacity for each mission performed by a drone, and it considers three different objectives joined: the minimization of the distance, the number of drones and the number of batteries used. Once the parcels are received, the operator organizes the different missions through a CVRP-TW (Capacitated Vehicle Routing Problem with Time Windows). Then, the UAVs are assigned from the available fleet and they perform the loading. When a UAV starts its mission, it is considered as an active vehicle and, once it has finished, it will be in a standby status for controls and inspections.

Staying in the sphere of outdoor fleet management, Ni and colleagues (Ni et al., 2018) presented a smart regional logistics transportation system based on UAVs. They mainly designed an application to support and coordinate the fleet, which sends from the mobile phone the coordinate information and delivery route to the UAV. They divide the system into two main modules. The first one is the UAV and this module takes the automatic navigation and precise positioning of UAV as the main control purpose. To realize the coordinate work, the GPS and infrared camera are involved via the PX4 open-source flight control and STM32 board respectively. The second one is the handheld terminal module, which should embed the saving algorithm to calculate the shortest path and dock with the UAV. Firstly, the coordinate of the target point is set by using the mobile phone app. Then, the UAV invokes GPS by PX4 and flies automatically to the target area and, once there, the precise position is found through the infrared camera and infrared beacon. They choose infrared technology because it is stable and it can be detected reliably in any light conditions. This peculiarity allows night deliveries and, consequently, an increase in utilization rate.

Another management issue that should be addressed for the application of UAVs in commercial delivery service is establishing a traffic system to prevent collisions. Youn and colleagues (Youn, 2018) pointed out that in the USA, the Federal Aviation Administration (FAA) and NASA have been conducting Unmanned Aerial Systems Traffic Management (UTM) project since 2015. This system gives pilots the necessary information to keep a safe distance from other aircraft and it allows securing space for programmed routes. This management system takes spatial limitations and bad weather conditions into account to guarantee the safe operation of private drones in low-altitude airspace. The authors collected and elaborated detailed 3D spatial information using aerial LIDAR surveying (to include buildings, trees, and the bare ground) and MMS (to manually add transmission towers, utility poles and power lines). Further, they propose a lightweight 3D grid system, which depicts all types of obstacles for UAVs, thus it is suitable for UAV air road application.

Considering instead indoor fleet management, Pereira and colleagues (Pereira et al., 2019) designed a platform for controlling and getting data from network-connected drones in internal environments. Mechanisms for controlling drones are classified in ‘specifying flight plants/destination points’ or ‘direct teleoperation’. The first approach usually requires less attention and work by the user. Moreover, a user could move simultaneously more than one drone using flight plans but it is difficult to teleoperated more than one drone at the same time. In this paper, connected drones are controlled using indoor flight plans, which are defined by users in a web application. Their proposal is composed by three parts: a web application specially designed to manage the drones (its functions is to define flight plans and enable continuous communication with the drones to send and accomplish these flight plans), a local Wi-Fi network which covers whole the indoor place (the server and the drones must be connected to this network) and the drones which are connected to the server and exchange data with it. The application divides the flight plan into a small group of movements, every time these movements are executed, the drone location is updated and the required corrections in the flight plan are sent. Commands are not the only communication system but the drone also can start a communication process and send events to the server. When some states of the drone change, like the battery level, hovering and measurement of sensors, their notification is sent automatically. The system is also valid for monitoring tasks, it shows data from drone sensors, and it is designed for including an extra external sensor.

3.2.2.4 Routing and planning combined operations with other vehicles

To overcome the current UAVs limitations, in terms of flight-duration and load capacity, several authors focused their efforts on finding the best performing optimization algorithms, for the different drone-delivery situations. In doing this, a lot of them included in the reasoning also other vehicles, mainly traditional trucks but also other non-aerial unmanned vehicles, to leverage the peculiarities of the different transportation modes and achieve valuable synergies.

For instance, Jiang and colleagues (Jiang et al., 2017) used the Vehicle Routing Problem with Time Windows (VRPTW) to define a model that allows assigning tasks to UAVs in logistics operations. The model takes into consideration many constraints (loads, time windows, UAVs characteristics, etc.) and the authors use Particle Swarm Optimization (PSO) algorithm to solve it, considering its complexity. Instead, Klochkov and Karpov (Klochkov & Karpov, 2018) proposed a mathematical model that allows minimizing freight transportation costs. It works on the allocation of loads to drones and optimizes the connectivity of road networks.

Other authors took into consideration multiple automated service stations, used for recharge and product-reload, to serve persistently customers. In this regard, Kim and Morrison (Kim & Morrison, 2014) developed a mixed-integer linear program (MILP) that minimizes total costs, both travel and resource ones, and used a branch and bound method (B&B) to reduce the time to compute the optimal solution. Similarly, Song and colleagues (Song et al., 2018) proposed a MILP, but he added the concept of the control center, other than stations, which elaborates all the system information and ensure a better resource utilization.

Moreover, Otto and colleagues (Otto et al., 2018) extended the reasoning drone routing to other fields of application and regrouped the optimization problems in three sections: area coverage, search operations and routing for a set of delivery. The third section fits with our research focus and highlights several useful points: drones might change batteries frequently according to the tour characteristics (since the energy consumption is strongly affected by the drone weight), they fly in a 3D space that is independent of road network and they have a minimum turning radius (with the assumption of constant speed, Dublin's path). Additionally, the authors suggest that all the routing problems regarding drone delivery operations can be generalized to one of the basic routing problems (TSP, multiple TSP or VRP) and they for sure take into consideration at least one goal among the minimization of operational costs, fixed costs, and makespan.

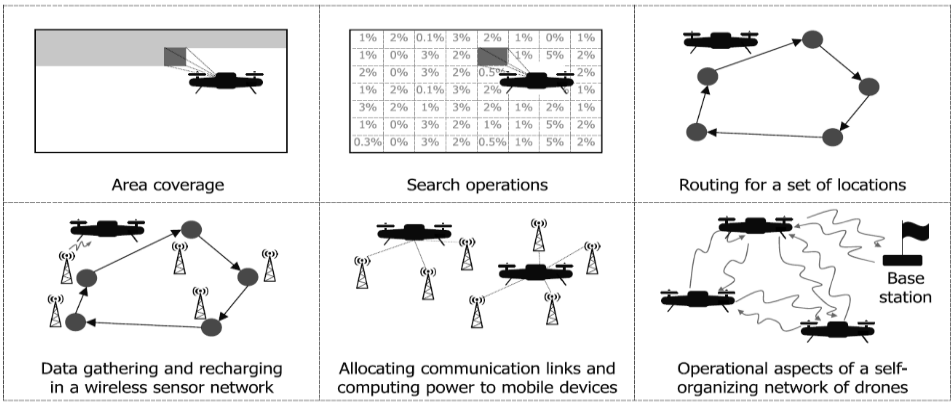


Figure 7: Classification of drone operations, Otto et al 2018

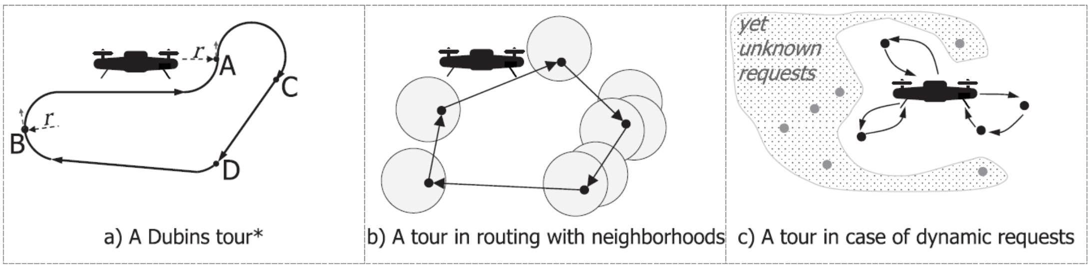


Figure 8: Illustration of some possible drone tours, Otto et al 2018

After the choice of an appropriate routing system, a way to further increase the drone-delivery efficiency and effectiveness is to combine UAV's operations with other robots or traditional means of transportation. In several of these applications, a certain degree of synchronization is necessary (e.g. when a UAV needs to wait for a lower-speed carrier for recharge) but, in others, drones are independent. The expected performances are better in terms of time, costs and environmental impacts (as explained in section 3.2.4 – Environmental impact).

The first researcher that structured this idea was Murray and Chu (Murray & Chu, 2015), who provided two mathematical programming models in which a drone collaborates with a traditional delivery truck for parcel distribution. Later, many authors took this model as reference and further developed it. Among them, there are Carlsson and Song (Carlsson & Song, 2018) who linked the real word results, coming from simulations and tests on specific road networks, with a theoretical analysis on the Euclidean plane and demonstrated that "the improvement in efficiency is proportional to the square root of the ratio of the speeds of the truck and the UAV". Instead, Schermer and colleagues (Schermer et al., 2018) specifically extended the traditional VRP to the Vehicle Routing Problem with Drones (VRPD) and they solve it using heuristic algorithms numerical experiments. Moreover, Mbiadou Saleu and colleagues (Mbiadou Saleu et al., 2018) solved the Murray and Chu models, proposing an iterative two-step heuristic algorithm, which embed a coding step that generate a customer sequence and a decoding one that transform the location sequence into a tour for the vehicle and trips for the drones. Furthermore, Ham (A. M. Ham, 2018) extended the analysis considering not only the drop task but also the pickup one. They proposed a constraint programming and they tested it in a problem with m-truck, m-drone, m-depot and customers distributed across an 8-mile square region.

Staying in the theme of truck and drone delivery, Liu and colleagues (Liu et al., 2018) focused on solving the problem under sparse demand condition while Ulmer and Thomas (Ulmer & Thomas, 2018) worked on a useful policy function, based on geographical division in districts, which helps to decide if an order should be delivered by a drone or by a truck. Instead, Boysen and colleagues (Boysenm et al., 2018) studied a system that employs trucks just as mobile landing and take-off platforms, preventing them from direct delivery operations.

To summarize the aforementioned contributions, Otto and colleagues (Otto et al., 2018) provided a classification of four possible ways in which drones can cooperate with other vehicles:

- Vehicles supporting operations of drones: The vehicle is just a support and cannot execute deliveries. The drone uses it to save energy during traverse times.

- Drones supporting operations of vehicles: Drones may provide communication to ground vehicles to connect them to the ground control station and/or with each other.
- Drones and vehicles perform independent tasks, no synchronization: Both drones and trucks deliver packages, with huge differences in load capacities and speed. In this case, UAVs are not allowed to land on the truck to pick packages, so they have to come back frequently to the warehouse. Tavana and colleagues (Tavana et al., 2017), who considered parallel operations of trucks and drones in cross-docking, provide an example of this application.
- Drones and vehicles as synchronized working units: every time a drone has to land on a supporting vehicle, synchronization is required. In all these cases, difficulties could arise due to the speed differences and resulting in cross-docking waiting times.

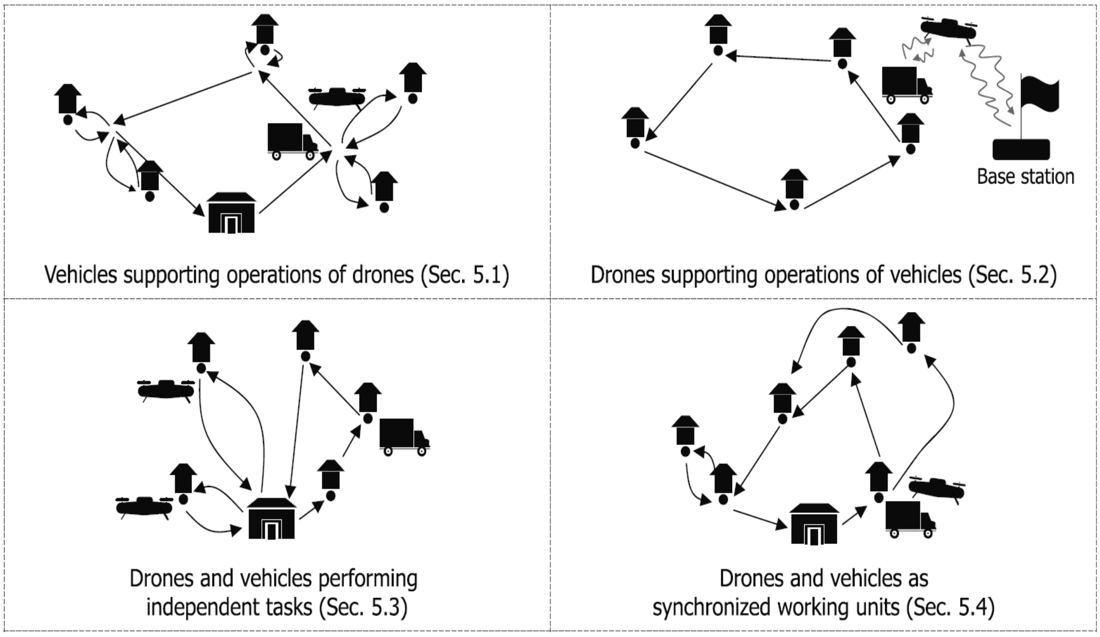


Figure 9: Illustrative examples of different types of combined operations. Straight arrows depict trajectories of the vehicle, bending arrows depict trajectories of the drones, small homes correspond to customer locations, larger facilities correspond to depots. Image and sections 5.1 -5.4 refers to the paper by Otto et al 2018.

3.2.3 Humanitarian logistics

After natural disaster events, the transportation network could be partially or totally disrupted. In these situations, conventional land-based vehicles could not be applicable during relief activities, but also other transportation means, like helicopters, could not be sufficient, due to the lack of resources, equipment or trained personnel. Instead, drones could play an important role in natural disaster response, specifically in Humanitarian Logistics, which is defined as (Tomasini & Van Wassenhove, 2009):

"the process of planning, implementing, and controlling the efficient, cost-effective flow and storage of goods and materials, as well as related information, from a point of origin to a point of consumption for the purpose of meeting the end beneficiaries requirements".

In this regard, Estrada and Ndoma (Estrada & Ndoma, 2019) identified nine factors that have an impact on UAV's efficiency in case of natural disasters and they explain:

"Drones, Smart-Platforms (SP) and LUAV's have three core missions in any natural disasters event: aerial monitoring post-natural disaster damage evaluation, natural disaster logistics, and cargo delivery and post-natural disaster aerial assessment".

As regards the second mission type, Rabta and colleagues (Rabta et al., 2018) investigated the application of UAVs in the last-mile distribution of relief packages and their results show that drones could be more effective when road networks are disrupted and even more efficient in terms of time and costs if compared to conventional vehicles. Staying in this context, to overcome the main UAV's problem of limited battery capacity, the Austrian Red Cross worked together with Land Rover in the project "Hero" (LandRover, 2018). Here, a jeep was used as a support vehicle for drones' take-off, landing, and recharging. However, jeeps are not the only possible drone partner and Oruc and Kara (Oruc & Kara, 2018) figure out possible cooperation of drones and motorcycles. The authors argued that the information collected by both units are fundamental for "three immediate logistics operations: evacuation, relief item distribution and debris removal" when, after the disaster, the transportation network is only off-road.

Furthermore, Chowdhury and colleagues (Chowdhury et al., 2017) took a wider perspective and analyzed the current and potential level of drones' employment during the four main stages of relief cycles, which are prevention, preparation, response, and recovery. While UAVs could be precious in each of the steps, they are almost only used in the response one. In fact, while they could provide a fast response after the event, they could also support other types of activities like risk assessment, mapping, and planning operations (Measure, 2015). In their paper, the authors proposed an integrated facility location-inventory allocation model, in which drones could be used to transport emergency supplies and they recommended using drones also for other purposes, as the establishment of temporary communication structures. Looking instead at the first stage of relief lifecycle, Ackerman (Ackerman, 2017) described an unusual drone application in the field of environmental control and health prevention. In this regard, UAVs could transport and spread sterile mosquitos in developing countries, to reduce drastically their population (-90%). This is one of the most effective control methods of diseases like malaria, dengue fever, West Nile virus or Zika, which annually kill millions of people. However, it is a challenging activity to do with traditional vehicles, due to the poorness of the local road network, thus WeRobotics created a prototype drone-based mosquito control system in South America. Interestingly, the company has previously employed UAVs for other social purposes in Nepal (to map roads), Peru (to deliver medicines) and in the Caribbean (to coordinate humanitarian efforts).

Moreover, Otto and colleagues (Otto et al., 2018) provided a worthwhile paper collection about the employment of heterogeneous vehicles in disaster management applications. For instance, they cite Wu et al.'s framework, which allocated monitoring tasks to drones, or Phan_Liu's idea to use UAVs in cooperation with UGVs, to predict blazes spread and manage fire extinguishing, thanks to water drop. In addition, the afore-mentioned Estrada and Ndoma (Estrada & Ndoma, 2019) considered these use cases to elaborate two models of Smart-Platforms (SP): fire-fighter SP and the natural disasters cargo express SP (which could be used to deliver water, food, medicines, lights and communication systems to survivors). SPs, or Droneports, ensure efficient and systematic logistics coordination and they offer a deposit for food, water, and medicines, which may be supplied anytime and in disparate places, also simultaneously. The authors provided a list of the Droneports five core aspects: keep storage deposits, recharging stations, stock parts/accessories, strategic geographical location (based on population density), UAVs routes to design and portfolio of prototypes according to the different natural disaster hazards. Staying in the theme of support and coordination, Filkar and colleagues (Fikar et al., 2016) presented a Decision Support System (DSS) for humanitarian logistics. This framework should not only be seen as an optimization tool but it would mainly be valuable in terms of coordination and information exchange among the numerous players involved in this complex supply chain. The DSS takes into consideration several phased of the relief process and it suggests the transfer points location, it optimizes the requests scheduling and it ensures coordination of the different relief units. Therefore, the authors conclude:

> *"Combining strengths of private and relief organizations and facilitating emerging technologies has the potential to provide fast supply of relief goods to victims".*

Finally, Mohammed and colleagues (Mohammed et al., 2014) presented a series of examples of UAVs' involvement in humanitarian activities, like for instance wildlife protection in Nepal or Japan. The authors highlighted how these drone employment in humanitarian activities had a positive impact on research and technical communities, generating a favorable impression of UAVs. Other similar examples are brought by Gatteschi and colleagues (2015), in the context of Hurricane Sandy (Haiti, 2012) and the Typhoon Haiyan (the Philippines, 2013).

3.2.4 Environmental impact

As with past penetration of technology in markets and industries, the focus has been heavily placed on the economic and social impacts that the introduction of drone technology might bring. On one hand, companies anticipate a reduction in transportation costs (D'Andrea, 2014) but, at the same time, concerns exist regarding other aspects like individual privacy rights and airspace congestion. On the other hand, these researches demonstrated that is difficult to give a definitive answer about the goodness of the potential environmental impacts. For instance, drones that require an average of 40 Wh/mi to operate will generally have a net positive impact in most delivery situations, while drones at an 80 Wh/mi average energy requirement will not. Moreover, given a particular energy requirement level, the emissions change tremendously depending on the different delivery service zones, due to the influence of other variables like the number of recipients and distance away from the depot.

From the reasoning of Goodchild and Toy (Goodchild & Toy, 2018), it appears that drones have a CO 2 emissions advantage over trucks in service zones that are either closer to the depot or have smaller numbers of recipients or both. This suggests the existence of a plausible market for drones in the delivery industry if CO 2 emissions are the weighing factor. However, as a drone’s average energy requirement (AER drone) increases, trucks become more advantageous in terms of emitting less CO2. This is due to the comparative analysis’s assumption that drones can only deliver one package at a time and so they must make a return trip after visiting each individual recipient, which dramatically increases their VMT (Vehicles-miles traveled) respect to trucks. Overall, it appears that the best performances, in terms of emissions, are reached with a blended system in which drones deliver to nearby locations and trucks serve the ones farther.

	50 Stops	100 Stops	150 Stops	200 Stops	250 Stops	300 Stops	350 Stops	400 Stops	450 Stops	500 Stops
Mile 10	113	66	48	39	33	29	25	23	21	19
Mile 9	118	69	50	41	35	30	27	24	22	21
Mile 8	122	72	53	44	37	33	29	27	24	23
Mile 7	126	76	57	47	39	35	31	28	26	24
Mile 6	135	83	62	50	45	38	34	3	29	27
Mile 5	143	90	68	55	48	43	38	35	32	30
Mile 4	169	106	82	68	58	52	47	43	39	37
Mile 3	195	126	101	83	71	64	57	52	48	45
Mile 2	225	152	122	105	90	81	73	67	61	58
Mile 1	408	296	234	207	180	159	148	134	124	119
Mile 0	544	370	301	263	230	209	191	175	163	152

Figure 10: Maximum allowable AER (Wh/mi) for drones to emit less CO2 than trucks, Goodchild and Toy 2017

Additionally, Chiang and colleagues (Chiang et al., 2019) used a mixed-integer (0–1 linear) green routing model to support the notion that using UAVs for last-mile logistics is not only cost-effective but also environmentally friendly. Unfortunately, current UAV delivery has a limited range (distance and flight time) and capacity (weight and size), so they often cannot deliver all packages by themselves in one trip. The best solution could be to pair the UAV with a traditional delivery vehicle, as previously explained in section 3.2.2.4 (routing and planning combined operations with other vehicles). In this regard, although UAVs only serves a subset of customers, this package-delivery mode still has the potential of substantially reducing the negative environmental effects. The authors find that optimally routing and delivering packages with UAVs would save energy and reduce carbon emissions.

Number of customers	Number of vehicles		Number of vehicle reduction if UAVs are Used	CO_2 emissions (Kg)				Emission reduction if UAVs are used	
	Without UAVs	With UAVs		Without UAVs	With UAVs			Quantity (Kg)	Percentage (%)
					From vehicles	From UAVs	Total emissions		
200	2	2	0	420.3101	352.569	0.2629	352.8319	67.4782	16.05
300	3	2	1	619.4375	441.7351	0.3396	442.0747	177.3628	28.63
400	4	3	1	741.5133	575.6478	0.5100	576.1578	165.3555	22.30
500	4	3	1	905.8123	719.3013	0.5855	719.8868	185.9255	20.53

Figure 11: Comparison of the results of carbon emissions without UAVs and with UAVs, Chiang et al. 2019

If smaller packages would be delivered by drones, there will be strong benefits in terms of the overall energy used and CO 2 emissions. Hence, companies should leverage this technology to offer more environmentally friendly products/services, but they have to carefully evaluate and plan the routing and coordination strategies of drones and trucks.

While the above-mentioned works have a focus on the drone sustainability impact during the delivery phase, the following three papers take a more comprehensive perspective. The first one is by Figliozzi (Figliozzi, 2017), who compared CO 2 emissions of UAVs and ground vehicles, during two distinct phases: vehicle utilization and vehicle production/disposal. The results of his empirical analysis indicate that UAVs, currently available in the market, are significantly more CO 2 efficient (around 47 times) than typical US diesel delivery vehicles in terms of energy consumption. Considering the emissions, the differences are even greater (more than 1000 times).

However, the efficiency measures are more favorable for the conventional van when the analysis is done in terms of energy consumption and emissions per unit distance and per kilogram of payload delivered. Hence, considering that electric trucks are much more efficient than the typical US van, the UAV is less efficient than electric vans in delivery scenarios with more than 10 customers per route. Conventional vehicles outperform UAVs in cases where payloads are not small or if a customer is located far beyond the relatively limited range of a UAV (range is affected by numerous variables but, for small quadcopter, the range is currently lower than 25 km). Other vehicles, like for instance tricycles, are likely to outperform UAVs in dense urban areas, in terms of both energy consumption and lifecycle CO_2e emissions. To conclude, UAVs can fill a service niche in sparsely populated areas with a low number of customers and density, while substantially lowering energy and emissions per service when the payloads are relatively small. It emerges that UAVs can also reduce significantly energy consumption and emissions in urban areas with high congestion and low commercial vehicle fuel/energy efficiency.

The other two selected papers are by Koiwanit (Koiwanit, 2018) and Xia and colleagues (Xia et al., 2019), who used a cradle-to-grave approach. Therefore, they take into account the overall environmental effects associated with coal mining, electrical generating station operations, drone raw materials, drone productions, drone use phase, and disposal. Results show that the global warming impact is 0.079 kg CO_2-Equiv. in the drone delivery system. In this regard, the drone's part production, which accounted for 99.2% of the impact, is the main contributor to all impact categories.

All the aforementioned considerations were applied to a specific use case by Park and colleagues (J. Park et al., 2018), which investigated the environmental impact of drones and motorcycles pizza delivery. They focused exclusively on the delivery stage and they considered shipping distance and fuel efficiency to evaluate the number of pollutants and the environmental impacts of the delivery method.

4 CONCLUSION

To summarize the main characteristics of drone technology and try to figure out the future adoption of UAVs in logistics, it could be useful the work of Kunze (Kunze, 2016), who examined different technological solutions with a very wide perspective. Indeed, the author starts its reasoning taking into account the main global trends (Digitalization & Technology Change; Demographic Change; Climate Change; Urbanization; Globalization; Individualization) as well as the logistics ones (Digitalization in logistics; Compliance, process & organization; Supply Chain Risks; Development of infrastructure; Shortage of trained staff; New forms of mobility; Sustainable & Green logistics), to formulate the considerations illustrated in Table 1.

	KEY ASSETS (+)	**KEY PROBLEMS (-)**
SMALL UNMANNED AIRCRAFT SYSTEMS	+Drivers are not required (but not necessarily the same for drone operators, it depends on future administrative regulations) +Inbuilt loading & unloading device +Access speed due to theoretical beeline delivery (if regulations don't require other routes)	-Noise emission -Security, risk of damaging cargo in cases of collision and technical defect or sabotage -Safety, risk of causing harm to humans or assets under the flight path of the drone or potential danger to helicopter rescue operations -Energetic efficiency -Local ecologic impacts (e.g. on birdlife) -Lack of adequate near ground air traffic regulations
CLASSICAL VEHICLES	+Their "installed base" (established technical and organizational structures and their profitable business models)	-Dependency on fossil fuels and the resulting emissions -Requirement to employ a driver -Consumption of space (either parking space consumption or street space consumption during delivery stops in the second lane (including delaying impact on through traffic)
ELECTRIC VEHICLES	+They could substitute classical vehicles in established transport organizations almost 1:1 +They would significantly reduce local and global emissions.	-Lack of recharging infrastructure -Current low of fossil fuel prices -Requirement to employ a driver and -Consumption of space

BIKE & SCOOTERS	+Better navigation on congested streets +Reduced parking space requirements (*i.e.* no need for second lane parking in streets).	-Requirement to employ a driver. Due to the small cargo volume, this problem is more severe than for vans or trucks. This type of logistics operations is only applicable for cases where high last-mile delivery costs are commercially justified or where congestion hinders van delivery
AUTONOMOUS ELECTRIC VEHICLES (Ground Drones)	+Drivers not required (leading to reduced operating costs) +Possibility for small EAVs to co-use public transport infrastructure during off-peak hours	-Necessity to load and unload the vehicles. This requires mechanisms (which cause higher investment costs) or on-board or on both ends of the last mile transport. -Need standards for physical unloading (technical compatibility problems could complicate the delivery at the destination location) -Security, theft protection -Safety, the risk of causing harm to humans walking or driving by
CROWD LOGISTICS AND PHYSICAL INTERNET	+Own transport resources are not needed +Environmentally friendly	-Problems to generate sufficient local momentum -Guaranteed service levels -Lack of infrastructure to exchange goods for part-way transports
CARGO PIPELINES AND CARGO TUBES	+Insensitivity to traffic jams +Environmental friendliness and +“Invisibility”	-Infrastructure has to be built from scratch, big investment
3D PRINTERS AND ADDITIVE MANUFACTURING	+Creation of individualized goods (in line with the global trend of individualization) +Reduction of miles in the upstream transport chain(in line with the logistics trend of “green and sustainable logistics”) +Reduction of availability times in case of need (urgent goods)	-Different 3D-printers are required to handle different uniform materials -Location structure: 3D-printers are costly and material-specific so local centers could pool different printer types and thus offer a wide range of 3D-print-on-demand products -New Business Models would be required for the vendors as they would sell reproduction licenses instead of products if they don’t print their products within their own shop-network (similar BM change has already happened in the music industry)

Table 1: UAVs and alternative vehicle main assets and problems, based on Kunze 2016

Staying in the theme of forecasts regarding the future adoption of drone technology, another remarkable observation is the one from Alwateer and colleagues (Alwateer et al., 2019):

"While it is not likely in the near future that everyone will have a drone, and not conceivable that there will be as many drones as smartphones today, a range of companies operating drones to deliver particular services (i.e. a 'phone-a-drone' or drone rental services) might be conceivable in the near future. While many people might have their own personal drones that they can use out of their pockets, regulatory, practical and technical constraints might force the usage of drones into particular service niches".

Many other authors endorsed this vision, like Balaban and colleagues (Balaban et al., 2017), who designed the Drone Hub as a Service Process. This framework consists of a hub with UAVs that are shared by several companies working in different businesses, which have to deliver products to a common customer base. In this way, it would be possible to increase drones utilization, reduce delivery costs and consequently boost local economies. For example, a small local shop would exploit the on-demand delivery services provided by a "hub" company, avoiding the possession of a drone fleet.

To conclude, Table 2 presents a recapitulatory framework that illustrates all the applications handled during the review and highlights, for each of them, the relative challenges and opportunities.

APPLICATIONS	CHALLENGES	OPPORTUNITIES
Internal logistics -inventory taking -transporting & manipulating -inspection & evaluation (MMA multi moment analysis)	-VRP (Vehicle Routing Problem) TSP (Travelling Salesman Problem) -Fleet and jobs orchestration: complexity due to the high number of products, machines, and routings -Task rotation in the fleet of drones -Trade-off payload vs energy consumption -In drone MMA, setup costs of measurement would slightly increase, as first, an indoor localization system had to be installed (But afterward only one person monitoring the measurement would be needed) -Flight corridors often overlap with the routes designed for employees' use (legislative and technical aspects)	- Painstaking and extensive labor efforts can be significantly relieved - Transportation of materials and semi-finished products - Higher level of efficiency, effectiveness, and productivity - Transporting materials in a 3D space, thus overcoming the limitations of AGVs, belt conveyors, hand trucks and others, that can only work on a plane or the floor and in very rigid routes - High maneuverability, agility and very cheap movement in general -Multi-robot cooperation (also air and ground) -Traditional MMA is expensive, people have different judgments (increasing uncertainty and time consuming (collecting and digitalizing the forms take rather long
Inventory management	-Accurate localization solutions could be expensive (solution could be UWB, 3D lidar) - Shelf rows lack distinctive geometric features and are highly self-similar which makes precise self-localization difficult -Obstruction by other objects like forklifts - Industry 4.0 technologies have to be integrated horizontally so that manufacturers and suppliers can cooperate -Need identification and labeling technologies - Trade-off between cost, modularity, payload capacity, and robustness	-No errors, no accidents, automation, safe, efficient, flexible -Allow carrying out repetitive and dangerous tasks without almost any human intervention or supervision - Perform tasks that constitute one of the foundations of Industry 4.0: to collect as much data as possible from multiple locations dynamically - Possible link with a forklift, so the drone would be constantly powered (Flibox) -No production stop or plant closing
Natural disaster response	-Could interfere with the rescue operations -design different prototypes according to the natural disaster hazard - Droneports or Smart-Platforms to generate efficient and systematic logistics coordination - Limited payload and operations range due to energy constraints	- Scan an area to identify people; evacuation - Assessment of damaged areas; debris removal -Up-to-date information on infrastructures' damages - Logistic and cargo delivery; relief item distribution - Establish temporary communication structures -A good impression about UAVs and encouraged their use
Freight transport	-Fast and flexible delivery of urgently needed goods and parts, which is largely detached from a road or rail network. The condition for this is the possibility to unload cargo after landing on a landing zone and then independently carry out a restart. The system must be minimally dependent on external supply in order to be able to operate independently of existing airfields.	- Airfreight goods spend around 80% of their time between the sender and recipient on the ground. Need to re-think the traditional processes and structures and develop innovative model solutions -If infrastructure for cargo handling does not exist at the destination, then the use of a UCA opens up a new last-mile logistics, for which no means of transport existed so far. For such niches or exceptional situations, UCAs are a suitable solution
Monitoring	-Obstacle avoidance for safer navigation -Improving object detection and make the detection work from multiple view angles of the target -Limited computing resources and storage, so is difficult to process the huge amount of data in real time - Generally, UAVs are deployed in different terrains where only limited bandwidth is available	-Inspect vessels' compliance with the regulations -Railway inspection -Pipeline surveillance (India) - Inspection and maintenance of electrical power transmission and distribution lines -Forest, timber (in Japan) -Wildlife inventory (Amazon forest)

Delivery	-Synchronization -Limited battery, energy efficiency -Precise localization -Public safety - Regulations -The most critical stage is package release (the transported goods may be damaged) -Correct delivery: not only related to a good consigned in the neighbor's courtyard but could have worst consequences when the package is erroneously delivered in traffic areas. GPS fails are not acceptable - Ability to correctly return to base -Drone preservation -In traditional human delivery, customers can pay by cash or by a credit card at the time of delivery, these options may be restricted to card or online-based payments - Customer's private information and any communicated data between the drone and the customer's site such as a landing spot must be protected against eavesdropping and the physical capture of the drone.	-Door-to-door food delivery -Food delivery in emergency situations or disrupted infrastructure - Truck & Drone -Acoustic or vision-based sensing -Solar power - Drones may be faster than trucks, have a lower cost per mile to operate, and emit less CO2 - Drugs and mail delivery: they could be urgently needed, they are small and lightweight -Suppliers cooperation to create a pool of drones (to reduce the delivery cost and improve their resource utilization) -Demand in small islands or mountainous regions might be hard to fulfill using the conventional carriers. -Social: AirShare app to reduce food waste while at the same time encourage communities to come together. Possibility to offer a free meal to the community, select offered meals for delivery, meet and share a meal with your favorite local AirShare cook.
Healthcare delivery	- Routine blood deliveries by drones are currently more expensive than routine deliveries by ground vehicles, which move more blood per load. But the economics change in emergencies -Organs should be transported within a certain time limit in order to make the organ available - Short shelf life and strict storage requirements. It's also difficult to predict how many packs of each blood type will be needed at a given facility, and when. Without drones, a lot of precious products are wasted when the demand is low. -Blood products must be packaged in a manner that ensures minimal risks of exposure and tampering during transit -protections must be implemented to prevent -Unauthorized interception of controlled substances. Patient privacy and Health Insurance Portability and Accountability Act regulations must be considered -Defibrillators are often fairly heavy, packing a large battery in order to remain functional through many months of disuse. They are typically designed to be mounted on the walls of public areas for long periods of time, rather than optimizing for weight and flight -Successfully using a defibrillator is a complicated, multi-step process, and few laypersons possess training in AED use	-HOMAL (Human Organ Monitoring and Quality Assurance Apparatus for Long-Distance Travel) is a novel device designed to measure all important parameters during transportation - Transport to critical access hospitals, mass casualty scenes, and offshore vessels in times of critical demand - Standards of care recommend transporting patients who require transfusions to larger hospitals when resources, including blood products, are unavailable or limited. This is often a costly process and may delay appropriate initial care - The survival rates for defibrillation are directly tied to how quickly the AED is administered; thus, the rapidity of a drone could be a critical advantage
Environmental control (mosquito / diseases)	- The challenge here is not the drone itself, it is how you carry and release mosquitoes from that drone. "Mosquitoes are very fragile animals".	Spreading sterile mosquitoes in the developing world is a challenge. Roads are non-existent or in poor condition, so it may not be possible to release insects from a car or truck, and using a crewed aircraft is too expensive.

Maritime sector/port	-Instead of helping the dockworker, the risk is to increase his stress level because the drone constantly controls him. In this way, the effect of drone employment could be opposite to the desired one (Italy – trade union)	-Supplying vessels with spare parts, mail or medicine -Ship internal spaces remote inspection -Inspection of ship exteriors while at sea -Security (prevent ships illegally anchoring in nearby sea lanes) - Tug drones for maritime use (Kotug) - Easylier monitoring and surveillance of the port areas - Verify that the handling operations are performed following the strict procedures and safety rules. Drones will be equipped with megaphones to promptly communicate with workers and prevent collisions and incidents - Lifeguard drones, life preserver transport
Retail -delivery tool -brand activation touchpoint	-Getting legal approval for utilization -Ensuring a positive public perception related to the effect of drone usage on customers' safety and privacy - Anxiety stems from their ability to collect and save large amounts of information on consumers. Smartphone case: consumers have already willingly handed some of their privacy over to companies in return for convenience and efficiency	-Self-service technologies, reduced employee involvement and increased customer participation in both service creation and delivery -Consumer–brand relationship: shift from a customer co-created value to a customer–technology relationship (drones) -The integration of drone technology into retailers' delivery process implies a consumer–drone–retailer relationship, whereby the drone acts not only as a delivery agent but also as a tangible representation of the retailer's service
Taxi (Future / related area of research)	Safety Regulations	Airport-city center link; City transport Speed; Low cost; On-demand mobility; Less noise than helicopter; Less environmental impact
Smart city (Future / related area of research)	Political and cultural issues	-Geo-spatial and Surveying activities -Civil security control (from reactive to proactive) - Traffic and Crowd Management - Natural Disaster Control and Monitoring - Agriculture and Environmental Management - Urban Security Increasing the city's attractiveness - Big Data Processing - Coordination between heterogeneous systems -Pollution monitoring -control of natural resources

Table 2: Framework applications of drones in logistics, Di Paolo 2019

Among the aforementioned challenges, some of them are shared between different logistic applications. For instance, it is possible to cite the limited range and payload capacity, which limits the available savings potential. Consequently, many logistics activities could be performed by drones, but not all of them, thus the added coordination efforts would further reduce the expected benefits. Additionally, other common drawbacks are the dependence on weather conditions, the requirement of human-drone interaction (both front and backhand) and the establishment of a logistic support system. Finally, as suggested by Mohammed and colleagues (Mohammed et al., 2014), it is possible to divide the afore-mentioned challenges into two groups:

Managerial challenges, which include privacy, ethics (drones wrong utilization), cost (developing, training, systems integration), legislation and business adoption.

Technical challenges, like adaptable middleware (for smooth UAVs operations), development of fail-safe systems, creation of high-performance platforms (efficient, low vibration, engines and a gyro-stabilized) but also flight precision (enabled by sensors), environment awareness (sense and avoid mechanisms, evasive actions) and development of a network-centric infrastructure for effective control.

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