Identification of cargo bikes and drones related challenges, potential strengths and benefits to achieve sustainable futures

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Abstract: *Nowadays, there is an ever-increasing acceptance regarding the opinion that the use of more sustainable urban freight transport has the potential to offer great energy and efficiency benefits which can be handled through the appropriate combination of various measures such as: The creation of small urban supply chain centres, the use of clean vehicles and technologies with a low environmental footprint, the establishment of "first or last mile" value-added services and the smooth integration of urban freight transport within the framework of urban mobility´s management. This study examines, via an extensive literature review, the potential strengths, benefits, and challenges of the implementation of drones and cargo bikes for the last-mile deliveries in the urban logistics sector and specifically in large urban environments. The aforementioned literature review revealed the importance of different weather conditions on the flying capabilities of the unmanned aerial vehicles and the quality of urban environment´s components upon the safe delivery of goods through the utilisation of cargo bikes. Ultimate goal of this study is to contribute in tackling identified challenges, so the drone and cargo bikes implementation may become possible to a larger degree and deliver even more value to the logistic companies and the society.*

Keywords: *Cargo bikes; Unmanned aerial vehicles; drones; green logistics*

Conference Topic(s): *Choose the most relevant topic(s) from this list and remove the rest: distributed intelligence last mile & city logistics; logistics and supply networks;*

Physical Internet Roadmap *(Link): Select the most relevant area for your paper: ☐ PI Nodes, ☐ PI Networks, ☒ System of Logistics Networks, ☐ Access and Adoption, ☐ Governance.*

1 Introduction

The sector of supply chain plays an important role in promoting economic development and economic globalization (Yang et al., 2019). However, the adverse effects of the logistics sector and freight transport on the environment are becoming more pronounced. The continuous growth of urban population and the extension of cities´ areas lead to an increase in the need for urban transport (City Logistics). The latter are associated with various issues such as the ever-increasing problem of traffic congestion, air pollution, noise, road accidents, energy consumption, and the large amount of greenhouse gases produced by fuel consumption (Chatziioannou et al., 2020). According to an analysis by the European Union (Eurostat, 2021), in 2019, road freight transport accounted for 76.3% of total land freight transport, followed by rail transport that accounted for 17.6%.

In recent years, due to the strong negative footprint on the environment, governments, companies, and citizens around the world tend to shift to a more environmentally conscious attitude. The same has happened in the transport sector, where concerns for a more ecological approach have multiplied, leading to the appearance of the term of "Green Logistics". However, it was not until 1990 (Srivastava, 2007) that the importance of green logistics was recognized as a significant economic and social issue. Current trends indicate a need for integrating environmental management into day-to-day operations (Srivastava, 2007). Therefore, the replacement of a part of conventional vehicle deliveries by environmentally friendly modes of transport could lead to a significant reduction of negative impacts worldwide, including the improvement of road safety, the enhancement of comfort concerning the interaction between heavy vehicles and vulnerable road users, the improvement of air quality and the reduction of congestion. On the other hand, this new necessity may increase the complexity of supply chain, and also create conflicts of interest between ecological and economic demands (Ebinger et al., 2006).

Several studies focusing on the introduction of cargo bikes in the supply chain, indicate their suitability for a significant share of freight movements (Narayanan and Antoniou, 2022), while an important increase in road safety is also observed, due to the reduction of accidents (Koning and Conway, 2016). In addition to cargo bikes, drones are now also used in an ever-increasing number of commercial applications. Cargo bikes and drones have also the ability to assist towards the establishment of Physical Internet´s (PI) concept so that to introduce alternative and sustainable means of transport within logistics operations (especially considering last mile delivery), actively contributing to the sustainable character of freight transport.

The objective of the paper is to transfer knowledge to researchers, the private sector of logistics and policy makers, and contribute in tackling identified challenges, so the drone and cargo bikes implementation may become possible to a larger degree and deliver even more value and benefits to the logistic companies and the whole communities that are directly or indirectly impacted by current shortcomings of the conventional methods of last-mile delivery.

2 Alternative Means of Freight Transport

Nowadays, the transportation landscape has been enriched with various innovative modes of transport as an alternative to conventional vehicles, such as electric trucks, cargo bikes, drones, etc. (McCunney and Cauwenberghe, 2019). Hence, in the following lines a presentation of drones and cargo bikes approaches for freight transportation can be appreciated so that to understand the dynamics of each mode as well as the combination of them in the effort towards sustainable development.

2.1 Drones and Cargo Bikes Utilization in Urban and Peri-urban Networks

One of the technologies that can satisfy consumers' needs for immediate delivery is the Unmanned Aerial Vehicles (UAV), commonly known as drones. The latter have varying degrees of autonomy and automation and are usually controlled remotely by an operator who is a few meters to several kilometres away or autonomously via on-board computers (Aiello et al., 2021) and can be characterized as a driving force behind the vision of Advanced Aerial Mobility (AAM) for the establishment of an 'on-demand' delivery of goods and emergency services (Boucher, 2015). The potential use of drones for 'last mile' deliveries is seen as an innovative technology that has been proposed in recent years, thanks to the advantages they offer over conventional modes of transport, such as the ability to overtake traffic, the capacity to cover longer distances, their ability to fly without a pilot but also their capacity to immediately take off in small areas (Goyal et al., 2021).

On the other hand, cargo bikes are bikes that are specially designed to carry small or large loads. Cargo bikes come in many forms, ranging from the traditional two-wheeled bicycle, three-wheeled models (cargo-trikes), and purpose-built four-wheeled models with electric pedal-assist motors for specific commercial needs". Types of cargo bikes can be found with or without electronic assistance (Joerss, 2016). The use of cargo bikes is a solution for environmental, economic, and social issues of many European cities, offering at the same time a new concept in mobility and quality of life that is the reason why they have been utilized adequately for the promotion of sustainable freight mobility and the replacement of conventional vehicles (Nocerino et al., 2016).

The combination of drones and cargo bikes is ideal for freight transport, as neither of these modes can, with some exceptions, cover the full route from origin to destination. Despite the capabilities of drones and cargo bikes, no freight transport applications were found (until now) that successfully mix these two transportation modes. On the contrary, the analysis of the existing literature showed that there is a common practice to combine either drones or bicycles with conventional vehicles or trains (Crisan and Nechita, 2019). The combination of drones and cargo bikes can be one of the most efficient ways of delivering small parcels, generating a positive impact on the environment, the reduction of freight costs as well as the faster delivery of packages. Nevertheless, both cargo bikes and drones have some limitations that need to be considered. Researchers Dybdalen and Ryeng examined the conditions for efficient movement of cargo bikes in winter months. They noticed that the uneven surfaces with accumulations of snow or ice tend to lead to bounce and possible skidding of the bicycle. Moreover, auxiliary batteries lose power faster and have a delay in charging under low temperatures. Some cargo bike users have reported that ice and cold temperatures intensify the wear and tear on the bike, raising the need for more frequent maintenance (Dybdalen and Ryeng, 2021). In steep hills is difficult to use cargo bikes, especially if the load is heavy, as it greatly increases the total delivery time (Dybdalen and Ryeng, 2021).

Regarding drones, there are two important conditions to be considered for the beginning of provision services in freight transport. The first one is related to technical feasibility-safety and the second is associated to existing legislative frameworks (Nentwich and Horváth, 2018). On a technical level, the most important limitation is the drone´s battery. At present, the flight duration of drones is limited due to the lack of batteries capabilities (Conceicao, 2019). Adverse weather conditions are another factor by which the drones are affected. High wind speeds, rain and snow make drones´ flying impossible. The legislative ones are also particularly important restrictions, such as the prohibition of drone flights over hospitals, camps, government buildings, airports, etc. These restrictions arise due to safety standards but also because of drones' ability to collect images, which can be recorded, stored, and even uploaded to the internet, thereby infringing private life. In addition, drones can be equipped with other devices, the use of which may assist the collection and processing of personal data, thus violating the applicable law upon the rights of citizens regarding the protection of privacy and data (Fridewald et al., 2017).

2.2 Vehicles Categorization

This section will deal with the categorization of vehicles and the recording of their main technical characteristics per category so that to have a clear idea about the differences, the similarities, and the selection of right equipment for the job. Several types of cargo bikes and drones will be presented through the following table for economy of words and space.

Table 1: Key features and types of vehicles concerning cargo bikes and drones (Joerss et al., 2016; Watts, 2012).

ID	Category	Types of Vehicles	Key Features
1	Drones	Micro Air Vehicles or Nano Air Vehicles (MAV or NAV).	Vehicles of small size, capacity to reach low altitude flights (<330 m) short flight duration (5–30 minutes).
2	Drones	Vertical Take-Off and Landing (VTOL)	No special take-off or landing space is required, Vehicles of small size, capacity to reach low altitude.
3	Drones	Low Altitude, Short Endurance (LASE)	Short duration flights (from 45 minutes to 2 hours) at relatively low altitude (up to 450 m). Their weight is relatively small (2–5 Kg) and their wingspan is usually less than 3 meters.
4	Drones	Low Altitude, Long Endurance (LALE)	Flight duration of more than 20 hours. Ability to cover several kilometres away from ground control stations, carrying a considerable payload of several kilograms.
5	Drones	Medium Altitude, Long Endurance (MALE)	High operational requirements (used for military operations). MALE drones have advanced aerodynamic design and control systems and can operate at altitudes above 9000 m. Ability to fly (20–40 hours) and hundreds of kilometres away from the ground stations.
6	Drones	High Altitude, Long Endurance (HALE)	They are the bigger and most complex category of UAVs that can operate even as "very low orbit satellites" remaining at an altitude of over 14 km for days, weeks or even months.
7	Cargo Bikes	Messenger Cargo Bike	Cargo bike has 2 wheels, and their basket is located on the front and/or rear of the handlebar with dimensions of 0.03 – 0.05 sq.m. It has a load capacity of up to 20-40 kg and used for small parcels.
8	Cargo Bikes	Rear-load cargo bike	Cargo bike has 2 wheels and can load up to 100 kg. The cargo basket is located on the back of the bike and its dimensions are 0.4 – 0.8 sq.m. Electric assistance is also available.
9	Cargo Bikes	Front-load cargo bike	This type can carry a load of up to 125 kg. The cargo basket is located between the steering wheel and the front wheel with dimensions of 0.1 – 0.7 sq.m. Electric assistance is available.
10	Cargo Bikes	Rear-load cargo trike	Load capacity of up to 300 kg. The basket is on the back of the bike with dimensions of 0.5 – 1.5 sq.m. Electric assistance is necessary for its usage.
11	Cargo Bikes	Front-load cargo trike	Maximum load capacity equal to 200 kg. Cargo basket is located at the front of the bike with dimensions of 0.2 – 0.6 sq.m. Electric assistance is necessary for its usage.

2.3 Physical Internet and Alternative Means of Freight Transportation

The primary objective of City Logistics is to mitigate the adverse effects of freight vehicle movements on urban living conditions, specifically congestion and environmental impacts, without negatively affecting social and economic activities (Crainic and Montreuil, 2016). PI constitutes a modern approach of freight transport and logistics that aim to enhance and fortify the economic, environmental, and societal efficiency and sustainability of moving, storing, delivering, and using physical goods worldwide (Montreuil, 2011). The concept of PI involves the integration of various modes of transportation and logistics services into a single, interconnected network that allows for seamless movement of goods across the supply chain (via several hubs) and is based upon the idea of modularization, standardization, and collaboration, where goods are broken down into smaller units that can be easily transported and stored, and different logistics providers work together to move these units from one point to another (Montreuil, 2011).

In this point comes to the conversation the introduction of alternative and sustainable means of transport such as cargo bikes and drones so that to collaborate with the PI concept in a beneficial symbiosis for sustainable development. The latter can be justified through the positive impact that the adoption of drones and cargo bikes, for last-mile delivery purposes, will have upon the society via the reduction of greenhouse gases, the reduction of congestion phenomena, the mitigation of air pollution and noise, the enhancement of transportation system´s level of service and the improvement of livability of the people within a certain geographic region (Boysen et al., 2021). On the other hand, the demand for hubs in a PI network using cargo bikes and drones will depend on various factors such as the volume and frequency of shipments, the distance between the origin and destination, the capacity of cargo bikes and drones, and the availability of suitable landing and pickup locations. In general, the PI network using cargo bikes and drones will require decentralized hubs that serve as intermediate points for transferring and consolidating cargo since both are not able to cover long distances. These hubs will need to be strategically located especially in places where there are access restrictions (e.g., pedestrian zones) and where parking space is rare to ensure optimal routing and reduce delivery times.

The main priority of this paper is to review studies upon the factors that affect the flight performance of drones and to identify the environmental parameters that impact the quality of cargo bikes usage. More specifically, through desk research, the most important parameters in the movement environment of drones and cyclists were identified and recorded. Initially, a literature search was carried out, concerning studies related to a) the effects of weather conditions on the flying ability of drones, based on long-term - historical data about factors such as the speed of wind, temperature, rainfall data and b) all types of cycling travels, with the aim of identifying those factors that influence the choice of routes by cyclists. We then analyzed publications investigating whether cyclist accidents are statistically correlated to route´s environmental characteristics, followed by publications that statistically correlate the cyclist's perceived safety with the route´s environmental characteristics, and publications that statistically correlate the actual route choices that cyclists make in accordance with the features of the routes. The full text of these initially screened articles was then read against the research aim. This led to a review pool consisting of 38 articles, that were re-read, revised, and analyzed. The inclusion criteria of the selected investigations were defined as peer reviewed academic journals and conference papers written in English that are in line to our research objective. We decided to focus on peer reviewed journals and conference papers so that to ensure the quality of selected corpus. The search was conducted using Google Scholar.

3 Literature Review about the Environmental Factors affecting the Flight Ability of Drones

Weather conditions are an important factor that can significantly affect the efforts towards drone applications expansion. International studies show that global flying ability is at higher rates over hot and dry continental regions and at lower rates over oceans and at high latitudes. With the growing demand for drones, there is a need to better understand the effects that different weather conditions have on these systems (which include operators, observers, and aircraft) to plan and execute a delivery successfully. The classification of weather hazards to drone operations ranges from moderate to adverse and finally to severe (Ranquist et al., 2017).

Table 2: Classification of Hazards according to Weather Conditions.

Severity	Hazards	Weather Types	Operations	Sources
Moderate	Reduced visibility.	Fog	BVLOS	(Ranquist et al., 2017).
		Haze	BVLOS	
		Glare	VLOS	
		Cloud Cover	BVLOS	
Adverse	Loss of communication Loss of command Loss of control Reduced operator effectiveness Diminished aerodynamic performance.	Wind and turbulence Rain Solar Storms Snow and Ice Temperature and Humidity	VLOS BVLOS VLOS BVLOS VLOS	(Ranquist et al., 2017; Joslin, 2015; Warner, 2015; Hansman and Craig, 1987; Cao et al., 2014).
Severe	Unacceptable risk for operator and personnel Severe damage to or loss of aircraft.	Lightning Hail Tornadoes Hurricanes	BVLOS BVLOS BVLOS BVLOS	(Ranquist et al., 2017).

4 Environmental Parameters Affecting the Mobility of Cargo Bikes

In the literature there is a significant amount of research that examines the factors that affect the quality of a route for cyclists. The criteria by which the quality of the route is evaluated differ from survey to survey and consider the following themes: a) Objective safety (factors that increase the likelihood of a cyclist accident); b) Subjective safety (factors affecting cyclists' sense of safety); c) The statement of preference and route preference (surveys relating routes, declared to be preferred by cyclists, to the characteristics of those routes). Through literature analysis, the following factors/parameters were identified as the ones mainly affecting the choice of routes for cyclists.

Table 3: Identification of Environmental parameters affecting cargo bikes mobility.

ID	Factors	Sources	Description
1	Bicycle Infrastructure	(Reynolds et al., 2009)	Existing bicycle infrastructure (either as bicycle lanes or separated cycling routes) is one of the main factors that increase safety (both objective and subjective) for cyclists.

2	Street Lighting Elements (horizontal signings, public lights)	(Boettge et al., 2017)	Lack of lighting increases the likelihood of an accident and is often a cause of road crashes. Street lighting elements (horizontal reflective markings, light poles, etc.) are beneficial because they make visible points that would otherwise be dangerous and could cause cyclists to fall.
3	Number of Car Lanes	(Chataway et al., 2014)	The increase in cyclists risk appears to be proportional to the number of road´s traffic lanes, as more accidents occur in roads having more than two traffic lanes per direction. Such a result is logical because on such roads cars accelerate more and therefore cyclists become more vulnerable.
4	Width of Road lanes and bike-lanes	(Hamann and Peek-Asa, 2013)	The width of the road significantly affects safety, with wide roads increasing the likelihood of an accident to occur. In particular, the research of Hamann and Peek-Asa (2013) showed a 37% increase in the probability of an accident for every 3 meters of increase in the total width of the road.
5	Slopes	(Zimmermann et al., 2017)	This parameter is directly related to lower safety levels and consequently constitutes an inhibiting factor for bicycle utilization as considerably increases the probability of accidents for cyclists to occur.
6	Bicycle Infrastructure in Pedestrianized Areas	(De Rome et al., 2014)	The most numerous and serious accidents occur in mixed bicycle-pedestrian infrastructures. Proximity of cyclists to pedestrians often creates a sense of insecurity.
7	Velocity and Speed Limits	(Hamann and Peek-Asa, 2013)	Speed limits on roads (and by extension the actual speeds that the vehicles are allowed to develop) significantly affect the concept of objective safety for cyclists.
8	Intersections and Joints	(Strauss et al., 2015)	Intersections (signalized or not) are considered as high-risk points for cyclists. Consequently, the number of accidents increases in accordance with the number of signalized intersections that a cyclist encounters on his/her route.
9	Traffic Load	(Ghekiere et al., 2018)	Traffic load is considerably associated with the reduction of cyclists´ safety, in contrast to light traffic roads which were judged to be the most suitable environments.
10	Sharp Turns	(Broach et al., 2012; Zimmermann et al., 2017)	Lack of visibility due to sharp turns is a frequent cause of accidents. According to Zimmermann et al. (2017) and Broach et al. (2012) cyclists do not choose left turns on high-traffic roads, preferring to perform detours to avoid them.
11	Routes Length	(Hood et al., 2011)	Cyclists, prefer shorter routes, something that is totally expected, since every extra pedalling increases their fatigue. In parallel, cyclists are more sensitive to the characteristics of the environment through which they travel and consequently are willing to increase the length of their route in search of a safer environment.
12	Quality of Road Surface	(Ghekiere et al., 2018)	The quality of road surface constitutes another environmental parameter that affects the utilization of cargo bikes. Its importance is highlighted by Ghekiere et al. (2018) and is associated with high rate of accidentability.

5 Discussion and Conclusions

In modern societies, the mass accumulation of people in urban centres has led to elevated emissions of carbon dioxide. The goal of every urban centre, mainly because of climate crisis, is the reduction of these pollutants. Thus, integrating cargo bikes and drones into freight transport can benefit in achieving this goal. The resulting benefits from the use of cargo bikes and drones in freight urban and peri-urban transport are important as they contribute to the society via the reduction of greenhouse gases, the reduction of congestion phenomena, the mitigation of air pollution and noise. Within this context, the purpose of this article is to identify the environmental characteristics and elements that are important for cyclists during their journey, as well as the environmental factors that affect the flying ability of drones.

The most essential factors resulted to be traffic load along with speed limits and the circulation of heavy vehicles. The research showed that increased traffic, as well as higher speed limits, pose a greater risk to cyclists. The latter also feel particularly uncomfortable when riding next to heavy vehicles, as there is an increase in the number and the severity of accidents when the share of heavy vehicles in the traffic composition is high. Cycling infrastructures as well as the existence of slopes also constitute important elements for cycling adoption as they are the backbone for comfortable and safe cycling travels. Two more factors that can seriously affect the sense of cyclists´ safety are road intersections-joints and the width and number of road traffic lanes as the interaction between cargo bikes and motorized vehicles raise the possibility of road accidents occurrence. All the previous mentioned factors can be related and considered by several public policies that are not isolated countermeasures but form part of Sustainable Urban Mobility Plans to assure continuity and generate sustainable futures. The policies that have been identified as closely related to the cargo bikes and drones' environmental factors can be seen in the following lines:

- Reorganization of road network hierarchy and speed limits reduction.
- Creation of peripheral roads around the settlements to avoid through flows.
- Upgrade of intersections in the road environment to enhance road safety.
- Creation of exclusive and mixed-use cycling infrastructure and bicycle parking spaces.
- Implementation of traffic calming measures.
- Creating a smart freight supply system with innovative tools.
- Promotion of Urban Air Mobility schemes.
- Traffic management of heavy vehicles.
- Replacement of asphalt paving materials on the streets.

Regarding drones, the literature review highlighted the effect of mainly atmospheric factors, which can cause moderate to very severe hazards. Moderate hazards are those resulting from phenomena that reduce visibility but do not damage the aircraft, such as fog, glare, and cloud cover. Adverse hazards are related to weather conditions that may cause loss of control and communication, and may adversely affect the operator, such as wind and turbulence, rain, solar storms and extreme temperatures. Finally, severe hazards are those that would result in serious damage or loss of drone and would place the operator or personnel in a dangerous situation. These hazards include thunderstorms, lightning, hail, tornadoes, and similar phenomena.

Safety issues in the operation of unmanned aircrafts are critical, due to the exponential increase in the number of these aerial vehicles and the involvement they now have in many sectors, such as industry, medicine and especially in the commercial sector. Nowadays, through innovative perspectives in terms of legislation development, several steps have been implemented for drones´ usage to be safer. In general, there are several challenges accompanying the use of

drones within urban centres that should be considered to achieve their broad utilization, these include the following: a) Legislation framework; b) Civil liability insurance; c) Protection against illegalities related to specific applications; d) Weather conditions and air traffic control. The present research can be enriched through participatory methods so that to organize the aforementioned identified factors in order of importance and help researcher, practitioners and policy-makers enhance their freight transport paradigm towards greener and cleaner solutions.

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