Complex Systems as a model for implementing Physical Internet standards: "Using Drones for last mile logistics"

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Evaluation of models for implementing Physical Internet standards via simulations of complex system

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Paper abstract

Unmanned aerial vehicles (drones) can shorten routes and improve delivery times by obviating traffic saturation in cities. In turn, this will help to reduce congestion and the emission of pollutants into the atmosphere.

Additionally, it could be beneficial to many small and medium enterprises (SMEs) as it would allow them to finally use e-commerce without facing issues such as losing control of the distribution of their products. In this article, we put forward a model to analyse the impact of a hypothetical scenario in which a business in the Cadiz area cooperates in the implementation of common standards that enable the incorporation of a PI system.

The model is described using the ODD standard (general design information) which is commonly used for model description in fields such as ecology, sociology and economics. We have adopted this approach when developing a simulator that allows us to design a network of flight paths in the improvement of last mile deliveries.

We discuss several important issues such as gathering of initial information, factors to be included multi-agent models, and how authorities can be convinced to change to legislation to allow drones to fly over urban centres.

COMPLEX SYSTEMS AS A MODEL FOR IMPLEMENTING PHYSICAL INTERNET STANDARDS: "USING DRONES FOR LAST MILE LOGISTICS"

1. Introduction

In recent years and with an eye on the future, the fight to reach the end client has resulted in logistics companies having to be more efficient in what is known as the last mile. The development of business models for this part of the distribution chain is a headache not only for logistics operators but also for manufacturers, distributors and even cities and public administrations, given the diversity of the settings in which they compete.

The Physical Internet (PI), as a vision of how logistics should function in the future, i.e. through an integral and global logistics network (Saenz, 2017), can help to attain innovative solutions that will lay the foundations for making the PI a reality. The European Union is supporting theoretical and practical development so that the PI can be implemented on the horizon of 2050.

Obviously, the operations required in large, modern metropolises are not comparable with those needed in the historic centres of European cities or with the incessant chaos of Asian cities. Back in Europe, for more than a decade now the trend has been for city centres and historic quarters to be the realm of pedestrians. This provides greater accessibility for those on foot, enabling them to see the charms of the city and facilitating the better development of local commerce, but it also means the reduction of access by motor vehicles.

In addition to reducing the amount of combustion engine traffic, another reason behind this pedestrianization is pollution. Reducing pollution is, in many cities, an almost utopian ideal. Administrations are attempting to reduce CO_2 emissions by developing legislation within their areas of competence. The evolution of the automotive industry may help to reduce it, if it manages to increase the sales of its electric and hybrid vehicles. Regrettably, Spain's fleet of vehicles is very old and, furthermore, the number of registrations of hybrid and electric vehicles is lower than the average in the European Union. One of the reasons for this could be the almost complete lack of recharge points on public streets.

Faced with this panorama, we must search for solutions on how to evolve the logistics of city centres and historic quarters. Therefore and as we have indicated previously, we could draw help from the Physical Internet (PI) as a global logistics system founded on the interconnectivity of logistics networks through a set of standardised collaboration protocols and intelligent containers and interfaces, thus increasing efficiency and sustainability (Ballot et al., 2014).

This global logistics system advocates developments that enable, in the long term, the implementation of new infrastructures, as already occurs with internet data packets. New infrastructures, such as those we suggest in this paper, are expected to be ready for use in tests next year. We must bear in mind that the PI includes the way in which physical objects are manipulated, moved, stored, made, supplied and used. It is aimed at global logistical efficiency and sustainability, organising the transport of merchandise in a similar way as data packets flow on the digital internet. It will transform the fragmented logistics industry used in the transport of merchandise into an industry based on hyperconnected logistics (Crainic et al., 2016).

The last mile represents a serious problem for the logistics industry, due to the strong impact it has on cities, not only in terms of contaminants but also noise pollution, traffic, etc. (Gevaers et al., 2011). Therefore, last mile deliveries are susceptible to a great amount of innovative processes that could eventually[1] result in the use of unmanned aerial vehicles.

2. Proposal for a new last mile scenario in the PI via Agent-Based Modelling

Montreuil (2011) advocates the union of logistics with the development of the internet of things (in which software is being developed to allow communication between the various devices and machines of a business or between elements of our homes). He points out that the biggest challenge for sustainable and modern logistics is the design of a system which can move, store, supply and manage physical objects throughout the world in a way that is economic, environmentally and socially efficient, and sustainable. Therefore, the PI is aimed at optimising logistical processes by creating effective and efficient networks.

It has been proven that last mile delivery is essential to the development of urban logistics. It is therefore unsurprising that there have been studies and projects centred on restricted home distribution in urban areas - Taniguchi et al. (2005), BESTUFS (2007), Benjelloun et al. (2008), Marcharis et al. (2011), Montreuil and Ballot (2016), Savelsbergh et al. (2016), Crainic et al. (2016) and Goyat et al. (2016). These also include new models and case studies which implement solutions to the problems.

This effort towards development and improvement in last mile deliveries is also featured in the Urban Logistics Roadmap from Alice (2016). The European Technology Platform ALICE has established a global strategy for research and innovation in the management of the supply chain, basing it on the concept of the Physical Internet, and it should be fully implemented by 2050.

Additionally, last mile delivery is one of the most costly and least efficient processes of the entire logistics chain, as well as being the most polluting. It is therefore one of the processes with the greatest opportunities for reducing costs and negative environmental impacts, these being two of the fundamental objectives of the PI (Gevaers et al., 2011).

Furthermore, advances in using Agent-Based Modelling (ABM) to evaluate the viability of Physical Internet solutions have been addressed in current literature, with a focus on the supply network layer of the PI system, especially when analysing the impact of the PI on home delivery (last mile logistics) in a specific real city. This is because said process makes up the majority of the logistical activity of a city and is affected by behavioural changes in customers, such as their use of e-commerce (Visser et al., 2014). It requires the analysis of the city's characteristics, its demand patterns, its geography and its infrastructure (Goyat et al., 2016).

3. Hyperconnected logistics for the last mile and complex systems

The field of logistics is multi-disciplinary and framed within a globalised market in which information is moved at high speed and transactions take place instantaneously, worldwide over the internet. The physical distribution of goods, food and equipment, among other items, is a necessity for society due to the growing volume of business exchanges and their repercussions on other sectors. This distribution is realised through a network of ships, trains,

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[1] If there is a favourable change in legislation.

trucks, planes and warehouses but this network does not behave sustainably and/or efficiently, nor is it economically, socially or environmentally friendly (Perrels, 2007).

Choi et al. (2001) define Complex Adaptive Systems as systems which fulfil two conditions: they have adaptability, meaning that they adapt systematically over time; and they involve a complex environment with many relations and interactions. Various researchers agree that a logistics network must be treated as a complex adaptive system (Surana, et al., 2005; Braha, et al., 2007; Pathak, et al., 2007).

Global logistics is identified as a system formed of a large number of elements with a high level of interaction between them, thus making it, by definition, a complex system. In addition to the specific characteristics of the logistics industry and given that its elements are not random in nature but rather subject to a well-defined classification (roads, railways, rivers, shipping lanes, ports, vehicles, merchandise, hubs, planes, etc.), we can speak of a complex multi-modal network which covers various types of operations depending on the nature of the nodes and connections in question. This therefore establishes a fixed behaviour or interaction that is based on the elements and connections concerned. This, in turn, makes Agent-Based Modelling (ABM) a very useful tool for testing new scenarios in the logistics industry. For this reason, logistics networks and their components can be considered as complex adaptive systems (Hakimi, et al., 2010, 2011 and 2012).

Pathak et al. (2007) argue that the application of the CAS perspective in research into the management of the supply chain requires models based on agents, computing architecture and processes which are dynamic and generative, and on case studies of bigger groups of companies. Multi-agent modelling is flexible and suitable for representing the dynamics, complexity and dispersed nature of supply chains, given the great similarity between industrial systems and multi-agent systems. In both systems, the entities are autonomous and have an ability to make decisions, while the actors can collaborate and adapt to their environment (Moyaux, 2004; Labarthe, et al., 2007; Shen, et al., 2006; Lee, et al., 2008).

All of this justifies the multiple agent approach being the most appropriate for the development of logistics web simulations that capture the complexity and dynamics of these networks. This is the reason why we have adopted this approach when developing a simulator that allows us to design a network of flight paths in the improvement of last mile deliveries.

4. An alternative solution for a specific last mile study: the city of Cadiz.

In this article, we put forward a model to analyse the impact of a hypothetical scenario in which a group of businesses in the Cadiz area is cooperating in the implementation of common standards that enable them to incorporate a PI system for their last mile deliveries

Faugere and Montreuil (2016) cite the need for new business models for last mile logistics. In many cases, deliveries to individuals are made at the end of the working day as this is when they are in their homes. This is detrimental to delivery times as there is more traffic at these peak hours, thus increasing the delivery costs. They analyse “Smart Locker Terminals,” explaining what they consist of and their relationship to the B2C and C2C models. Some of the advantages and technological solutions of Smart Lockers are: protocols for the generation of automatic keys for clients and suppliers, security, scanners, payment and printing terminals, and modularity, all of which stem from PI solutions.

Taniguchi (2002) defines city logistics as "*the process for the complete optimisation of the logistics and transport activities of private businesses in urban areas, bearing in mind the increase and congestion of traffic and fuel consumption within a market economy structure.*"

In other words, the objective of last mile analytics is the general optimisation of the logistics systems within an urban zone, taking into consideration the costs and benefits for the public and private sectors. For private agents, the objective is to reduce their overheads whilst public agents want to alleviate traffic congestion and environmental problems (Montero and Sarmiento, 2017).

Crainic et al. (2016) introduced the notion of Hyperconnected City Logistics (HCL), offering a rich framework for the design of efficient and sustainable urban logistics and transport systems.

Taniguchi (2014) introduced the concept of urban logistics for sustainable and habitable cities and discussed three essential elements for the promotion of urban logistics: (a) the application of innovative Information and Communications Technology (ICT) and Intelligent Transport Systems (ITS); (b) changes in the mentality of logistics managers; and (c) public-private associations.

Mauro Dell'Amico and Selini Hadjidimitriou (2016) discussed their last mile solutions and their impact on the reduction of CO_2 emissions and congestion.

Many proposals that are made regarding the last mile come about as customised solutions for specific cities, attempting to include the unique aspects of said cities and adapting the solution to the setting but always basing it on PI concepts. For example, Chakroun et al. (2016) opted for trams for the transport of π-containers in the city of Casablanca. This comes back to the debate on the development of specific and sustainable measures that are suited to each environment.

The proposed solution for Casablanca differs greatly from other solutions which could be established for other types of cities. The differences and possible solutions are marked by the distribution and size of the city; the demand and type of merchandise; the terrain, geography and infrastructure; the location of the factories and resource consumers; and the purchaser profile of its population. To simplify matters, in our case we are going to focus the proposal on a very distinctive city: Cadiz and more specifically on its historic centre.

To do this and having agreed that the study would be based on the hypothesis that merchandise could be sent through the air using drones (unmanned aerial vehicles), we simulate and design flight paths for the delivery of said merchandise using that method. This will bring us closer to achieving the Europe 2030 challenges. The model is described using ODD protocol (general design information) which is commonly used for the description of similar models in fields such as sociology and economics.

5. The designation of Cadiz to simulate flight paths for last mile deliveries

There are two main reasons why we are using Cadiz (which was originally formed of the two islands Erytheia and Kotinoussa) as our example in defining a strategy for improving last mile distribution. The first is that it is a peninsula that is located at the southern end of another peninsula, the Iberian Peninsula[2]. The second is because Cadiz, as the provincial capital, has the highest population density in Andalusia and is in the top twenty in the country, with 10,399 inhabitants per square kilometre. Although Spain theoretically only has 93 inhabitants per square kilometre, it has a very high density per population centre. According to Alasdair Rae, a Professor of Urban Studies and Planning at Sheffield University[3]: "*Spain contains within it more than 505,000 1km squares. But only 13% of them are lived in. This means that the 'lived density*[4]*' for Spain is in fact 737 people per km², rather than 93. So even though the settlement pattern appears sparse, people are actually quite tightly packed together.*

In fact, Spain could claim to be the most densely populated major European country by this measure, despite its appearance on the table. This also helps explain why Spain has the most densely populated km² in Europe." Following this logic and using lived density as the measurement, Spain would be 4th in Europe: one place above Holland in 5th and after Monaco, Andorra and Malta which are in 1st, 2nd and 3rd place, respectively, as shown in Figure 2.

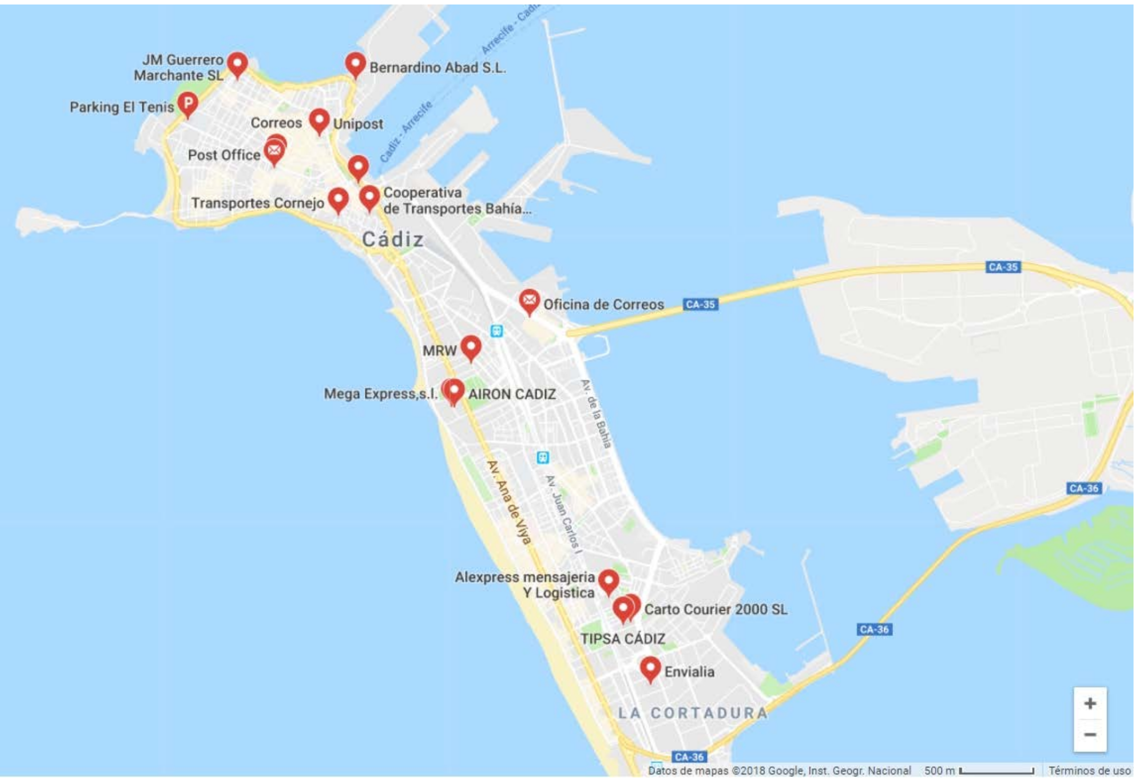

Figure 1: Data taken from Google Maps on 25/04/2018:

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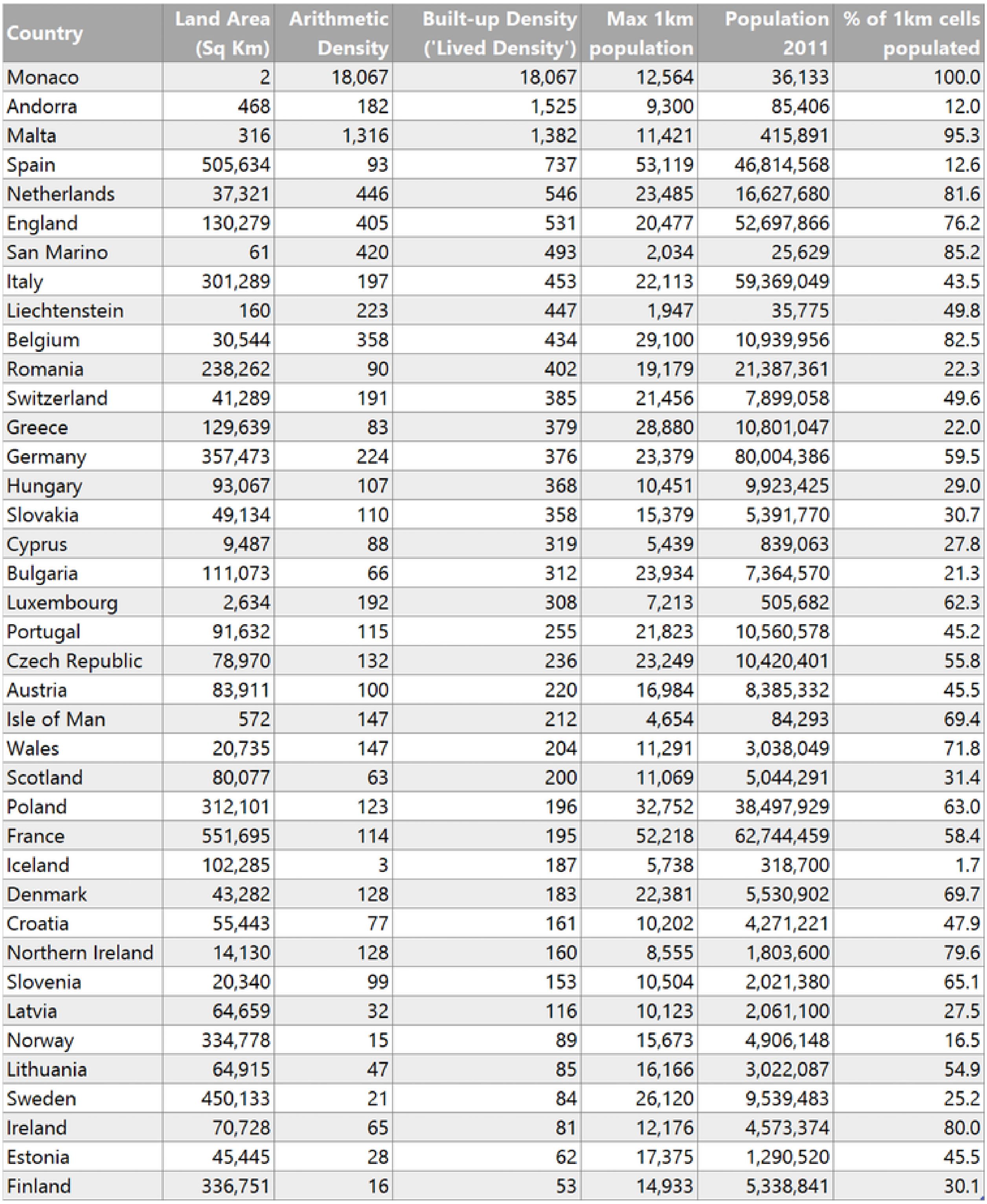
[2] See a local map of the Cadiz peninsula in Figure 1.

[3] https://theconversation.com/think-your-country-is-crowded-these-maps-reveal-the-truth-about-population-density-across-europe-90345

[4] The population of Spain lives in 13% of its territory and therefore the actual population density, which includes all the land used for other purposes, is misrepresentative.



Country	Land Area (Sq Km)	Arithmetic Density	Built-up Density ('Lived Density')	Max 1km population	Population 2011	% of 1km cells populated
Monaco	2	18,067	18,067	12,564	36,133	100.0
Andorra	468	182	1,525	9,300	85,406	12.0
Malta	316	1,316	1,382	11,421	415,891	95.3
Spain	505,634	93	737	53,119	46,814,568	12.6
Netherlands	37,321	446	546	23,485	16,627,680	81.6
England	130,279	405	531	20,477	52,697,866	76.2
San Marino	61	420	493	2,034	25,629	85.2
Italy	301,289	197	453	22,113	59,369,049	43.5
Liechtenstein	160	223	447	1,947	35,775	49.8
Belgium	30,544	358	434	29,100	10,939,956	82.5
Romania	238,262	90	402	19,179	21,387,361	22.3
Switzerland	41,289	191	385	21,456	7,899,058	49.6
Greece	129,639	83	379	28,880	10,801,047	22.0
Germany	357,473	224	376	23,379	80,004,386	59.5
Hungary	93,067	107	368	10,451	9,923,425	29.0
Slovakia	49,134	110	358	15,379	5,391,770	30.7
Cyprus	9,487	88	319	5,439	839,063	27.8
Bulgaria	111,073	66	312	23,934	7,364,570	21.3
Luxembourg	2,634	192	308	7,213	505,682	62.3
Portugal	91,632	115	255	21,823	10,560,578	45.2
Czech Republic	78,970	132	236	23,249	10,420,401	55.8
Austria	83,911	100	220	16,984	8,385,332	45.5
Isle of Man	572	147	212	4,654	84,293	69.4
Wales	20,735	147	204	11,291	3,038,049	71.8
Scotland	80,077	63	200	11,069	5,044,291	31.4
Poland	312,101	123	196	32,752	38,497,929	63.0
France	551,695	114	195	52,218	62,744,459	58.4
Iceland	102,285	3	187	5,738	318,700	1.7
Denmark	43,282	128	183	22,381	5,530,902	69.7
Croatia	55,443	77	161	10,202	4,271,221	47.9
Northern Ireland	14,130	128	160	8,555	1,803,600	79.6
Slovenia	20,340	99	153	10,504	2,021,380	65.1
Latvia	64,659	32	116	10,123	2,061,100	27.5
Norway	334,778	15	89	15,673	4,906,148	16.5
Lithuania	64,915	47	85	16,166	3,022,087	54.9
Sweden	450,133	21	84	26,120	9,539,483	25.2
Ireland	70,728	65	81	12,176	4,573,374	80.0
Estonia	45,445	28	62	17,375	1,290,520	45.5
Finland	336,751	16	53	14,933	5,338,841	30.1

Figure 2: Population density metrics. Data: Eurostat. Calculations by Rae (2018).

As indicated by Rae (2018): "*The final column shows how many 1km cells have people in them, but within that the level of density also varies, so this is not a percent urbanised measure.*"

We must add that in recent years there has been an increase in e-commerce, with this requiring a large deployment to reach the end clients. Businesses have been fighting to be the best and fastest in their deployment for last mile deliveries.

The use of drones in the future is another emerging factor and, seen from the point of view of the life cycle of an industry, it is at the creation and diffusion of knowledge phase. Grant (2004) writes the following about this phase: "*New knowledge in the form of product innovation is responsible for the rise of a sector and the dual processes of creation and diffusion of knowledge have a big influence on its development pattern. In the introductory phase, product technology develops rapidly. There is no dominant product technology and rival technologies compete for attention. The competition is basically centred on design alternatives and configurations."* This idea is also found in the information about the 4th International Physical Internet Conference (2017): one of the topics, which unfortunately was not addressed by anybody, was "Technology vs. Physical Internet: Impact of new technologies and concepts such as drones." Romstorfer et al. (2017) were the only ones to include a reference to drones when they mentioned them from a long term perspective. But the development of the technology may make this long term vision become a reality in a much shorter period of time.

Consultancy firms such as McKinsey & Company also include drones in the battle for the last mile (Parcel Delivery: The future of Last Mile, Travel, Transport and Logistics, McKinsey & Company, 2016), although their idea is to make occasional deliveries in rural areas.

In fact, Amazon is pioneering and making a firm commitment to the development of this new delivery technology. In its progress proposals, the company already has patents such as a beehive-like warehouse designed for drones and one for a drone (USPTO Patent: https://goo.gl/fehKNG, 12/04/2018) equipped with sensors, cameras and enough technological appliances to recognise hand gestures and voice commands, in order to recognise customers and connect to their mobile devices.

Also, the automobile manufacturer, Daimler (Mercedes Benz), is participating in a drone project called "Vans & Drones" (https://goo.gl/9YfdEH, 14/02/2018).

Another example is the Swiss Postal Service, whose website affirms that technological development is changing the logistics sector and that drones will play a growing role therein, especially in terms of the last mile. The following website contains videos of the Swiss Post making deliveries with drones: (https://goo.gl/P1bN9H, 16/04/2018).

In this scenario and in the city of Cadiz, this new type of vehicle could be used for the task. Unmanned aerial vehicles (drones) can already shorten routes and improve delivery times by obviating traffic saturation in cities, and in turn this will help to reduce congestion and the emission of pollutants into the atmosphere. Additionally, it could be beneficial to many small and medium enterprises (SMEs) as it would allow them to finally use e-commerce, something which up until now they may not have risked doing, due to issues such as simply losing control of the distribution of their products.

The starting information gathered for the study is:

Maximum weight of merchandise up to 3kg
Maximum load size of 150x150cm
Maximum flight time of up to 2 hours with a hybrid vehicle
Cruising speed of 53km/h at full load
Fuelled using an electric battery plus a mixed auxiliary tank (petrol/oil)

Drone maintenance every 50 hours of flight
Point-to-point flight plans (up to 100 waypoints)
Transmission of video and control from up to 50km using 3g/4g (120ms latency)
Autonomous takeoff and landing
Drone diameter of 200cm

6. Procedure of the Study

Having carried out the analysis of the technical requirements for the creation of the flight paths, it was concluded that the following factors would need to be determined prior to the in-depth work with the multi-agent model:

Approximate size of the fleet operating simultaneously
Expected number of deliveries per hour
Minimum recommended safety distance between drones in flight
Approximate size of the launch pads and/or their distribution
Cruising speed factoring in wind speed
Range of heights at which the drones would fly (maximum and minimum)
Parameter for quantifying route deviations due to gusts of wind
Areas of the map that should be avoided (public squares, marketplaces, etc.)

7. Conclusions

Despite current legislation prohibiting drones flying over urban centres, we have started a simulation to establish the technical and economic viability, in order to confirm whether the activity would be possible (after the necessary legal modifications).

The starting hypothesis is that there is a pressing need to resolve the problems presented by a process that is one of the most costly and least efficient, as well as being the most polluting, of the entire logistics chain: the final delivery of products to the consumer, the so-called last mile. The first issue is the need to reduce contaminating emissions, thus reducing the negative impacts of the logistics process on the environment. The second issue is to increase the efficiency of the process by improving delivery times and shortening delivery routes, thus reducing costs for the companies and causing a reduction of city traffic.

To do this, the solution is to carry out a technical and economic viability study of the design and potential implementation of a aerial roadmap or a flight path system in Cadiz city, therefore enabling the transport of merchandise by drones in the future. In the last mile, this would enable us to:

1. Reduce the emission of pollutants by avoiding deliveries by van and motorbike.

2. Reduce delivery times by using routes that reduce distances.

3. Reduce the overheads of logistics companies by optimising their resources.

4. Improve the quality of the process for the final delivery of the product.

5. Contribute to the development of regulations and laws for the use of drones in business activities.

6. Develop a pilot experiment with an established company.

7. Determine ways to measure the impact and performance of the practical application of the Physical Internet.

The development of the Physical Internet should help to reduce the use of resources, reduce waste production and limit energy consumption. It should also play a part in reorienting the production of numerous countries. Indeed, in addition to the environmental benefits, this emerging activity will be a creator of wealth and employment throughout the country and its development should allow us to obtain a competitive edge in the context of globalisation.

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