POLITECNICO DI TORINO

Master of Science in Engineering and Management

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IDENTIFICATION OF AN EMERGING DOMINANT DESIGN: THE FLYING CARS

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ABSTRACT

The scope of this thesis work is to depict a new model suitable for identifying possible emerging paradigms which can be able to deliver more value with respect to current systems and at the same time satisfying the most value-creating application areas. The initial analysis has been conducted on prototypes and projects under developments by those that have been identified as key industry players for the flying car technologies; as a second step, the experimental model is stated and implemented. It takes inspiration from the quality function deployment methods and is adapted to the scope of this work; qualitative analyses have been conducted to identify key classification parameters to show which might be the most important alternatives and their optimal vectors of characteristics which should constitute the backbone structures for different flying car typologies. Afterwards it is shown for different market segments which is the most suitable flying car for penetrating each kind of market. By subsequently analyzing the markets dimensions, it is possible to state results of the work and comments about the likelihood for a new dominant design to emerge.

INTRODUCTION

Many movies and cartoons about flying vehicles have been part of the way we have grown. Futurama is a clear example of this, with its way of presenting the far future pervaded by flying vehicles like taxis, cars, motorbikes and every kind of flying transportation system.

Primordial ideas related to this new kind of imagining the way people could commute and solve their transportation issues date back to the last years of the last century; since then, many articles, papers, patents and every kind of related informational and factual knowledge have been spreading all around the world letting us think that in the coming decades, flying for short haul distances might become an effective way that may modify our habits (BBC-Future INC-transportation 2020)[1]. Flying cars technology was considered in a report from the European commission Directorate-General for Research and Innovation as one of the "next 100 radical innovation breakthroughs for the future" capable of being one of the most important disruptive innovations of the next years, able to push mobility towards a new heavy way of thinking at it, with great potential for creating great value all around the world seen its potential ability to solve and satisfy the most common issues and needs related to the big cities mainly because of a new way of looking at the way we transport people every single day (European Commission Foresight 100 Radical Innovation Breakthroughs for the future)[2].

Technological progresses towards virtual simulations, battery power, capacity and consumption and the related materials issues have triggered the development of a variety of flying vehicles of every dimension and shape; many look like today's city cars with their monocoque structure, apart from a loss of components (e.g., wheels), some others have more "alien" shapes, others mix the shape of standard cars with aircraft wings or with helicopter propellers. Many advantages can be found in the potential reduction of massive traffic, the reduction in maintenance costs for highways and normal bridges and streets for cars (big issues from different perspectives in many parts of the world), reduction in carbon emissions, seen the different approach to the hours spent in the vehicle; at the same time the revolution we are writing about needs planning from different points of view like from safety perspective (in relation to land

and air driving) and as such needs a complete new legislative sections not fully present up to now, or powerful tracking systems and mechanical and electronic systems with low probabilities of breakages and any further cunning that might be required.

The present thesis work sets the goal of understanding and seizing the impacts of this new technology and suggesting potential ways of acting for investors in search for attractive and remunerative investments.

After extracting information about technological characteristics and related risks and as such finding the main ways for dividing flying car typologies, we may translate them into performance indicators through which it should be feasible to analyze the impacts for different markets. This is possible thanks to the approach typical of the Quality Function Deployment for which the voice of customers (those who will be using flying cars, final users) is put in relation with the technical features that should or should not be the key for a positive outcome. Probabilities of impacts and impacts in relation to given parameters like cost, security and safety, environment, and social acceptance for given industries and market segments may then be compared with the actual standards and can be weighted for importance in relation to positive outcomes.

To determine for which segments which given technology can be of major interest, trends have been analyzed leading to quantitative indications. These indications, supported by other industry-specific analyses try to take us to some conclusions with regards to the opportunity for a given technology, or more than one, for becoming something of value in the next periods for specific kinds of end users.

The possible emergence of a dominant design, or more than one, could then be considered evaluating the typical factors that are usually thought of as the triggering ones.

CHAPTER I

Flying cars

1.1 Current state of the technology

Air transportations for cities are nowadays serving a niche market that is the one of wealthy people, who are used to this kind of vehicle to be moved between destinations within the same city; but their disruptive connotation and the limited capacity is considered a limit to their full employment; also many incidents involving helicopters have been filling numerous pages of journal papers every year like the one of the AgustaWestland AW169 helicopter, become sadly worth of note after carrying the chairman of the former English Premier League champions Leicester City F.C. Vichai Srivaddhanaprabha, whose aerial vehicle fell down and caught fire right outside the King Power Stadium,0 in the United Kingdom; or the crash of the helicopter carrying the retired famous basketball player Kobe Bryant, in California, killing all the people on board.

Despite sad news, many incumbent firms and completely new ones are pushing towards improvements of flying vehicles technologies, through increasing investments and people involved, like the miniaturization of sensors and power storage capacity increase; through these advancements it can be affirmed that flying cars are on the right way for becoming really close to everyday use by common people and non. It is then worth of note the fact that many big urban conglomerates are preparing for giving way to deployments of aerial vehicles, hoping to solve urban related issues like traffic and smog; different are the ways with which companies are striving to bring flying cars to reality, like by adapting existing technologies (like in the case of drone producers) or by taking over other companies and startups through acquisitions, mergers, capital ventures that may create more value and accelerate time to market, or simply by increasing R&D investments inside the company thus enlarging market shares and creating new possibilities for surviving in a fast moving turbulent environment. (The

Verge; European Commission Foresight 100 Radical Innovation Breakthroughs for the future)[2,3].

In the latest progress directions, we can find large autonomous drones that are again increasing the market but also demanding bigger bulks and as a result oversized versions are coming out. In China, in these days, the drone producer Ehang company is attempting to find a way to be different from what the market is going towards, through a completely new version of aerial vehicle that is able to put together drone known technologies and autonomous driving features resulting in a single-seater and autonomously driven quadcopter (helicopter with four rotors) whose name is Ehang 184; it resemble a large drone with a large cabin in the center and is considered one of the most powerful new outcomes for these special vehicles (Vox)[4]. The only vehicles recognized as able to maximize the carriability of people are the utility vehicles for extinguishing the fire and to do transportation for emergency, specifically designed to carry out a predetermined kind of job; in 2016 Uber declared its willingness for building a set of vehicles, in particular they are supposed to be addressed to flying taxis services. Uber's opinion about it was made clear some months ago when the ambitious autonomous vehicles project was brought to an American start up founded in 2009 with headquarters in Santa Cruz, California, named Joby Aviation whose core business consists in electric aircrafts and in particular electric vertical take-off and landing vehicles (eVTOL). The intention was declared in a press conference where Uber said that its project Uber Elevate would require huge investments and when the flying taxi would reach the market, the partnership between the two companies would be an essential step; Uber imagined, doing the math, that a long trip from San Francisco to San Jose (about two hours long distance) would become a 10 minute enjoyable trip like also it would be the case for congested cities, where flying a car would become just cool as going to an amusement park (The New York Times, The Verge)[26,5]. Furthermore, some months ago, the shared delivery services company made possible to show helicopter trips taking off at New York's international airport John F. Kennedy and made it possible also to give tips for what it would be like to book a flying car trip instead of a normal 4-wheels, but anyway the technology used for the air driving, which is mainly addressed to electric, is still under development and has still to be pushed in the market of commercial services[5]. As said before, in seek for getting rid of money-losing parts and increasing margins, some things would have been costly to realize inbound, as such the massive set of "ground-level sky ports" and all regulatory flows of approval that are of concern for many institutional levels have been outsourced[5].

Management algorithms are another point seen as necessary for the air traffic monitoring and in order to get ahead with plans, Uber has been seeking for an important partner for the business, to be sure that their autonomous flying vehicles would come to life as soon as possible. The partner in question is the worldwide known Nasa, that was put under contract to construct and do the possible to make come to life all the necessary software stuff for the scope (The Guardian)[6].

Flight times are surely one of the most important points and since battery recharging times take too long, it might be necessary a trade-off with solutions for stretching flight times. As such many are working on the different fuels' characteristics. For instance, Workhorse, an Ohio-based firm, thought about some possible resolution ways and came up with the SureFly idea which represents a passenger-carrying aerial taxi vehicle able to mix different technological expertise like autonomous driving technologies (seen the drone manufacturing core business) and electric and hybrid systems knowledge which derives from their parallel business with trucks. SureFly has carbon-fiber rotors and internal combustion engines (supported by a small battery for security issues in case of engine failure) and as such it can fly continuously for more than one hundred kilometers and can be refilled just in a matter of minutes (Spectrum.ieee)[7].

Some companies are just trying to adapt old technologies and knowledge to the new purposes. One prominent candidate to bring out this kind of evolutionary innovation is Elon Musk who is trying to find ways for the redeployment of SpaceX project. His idea has to do with high-end customers willing to reach any place on earth in less than one hour; Elon Musk, CEO of SpaceX, declared his ambitious projects to fly to the Moon and also to some other planets (for now just Mars seems reachable) in a press conference with people from the space industry market to whom he made some announcing with regards to the possibility for the redeployment of rocket systems for the purpose of flying around the globe in much less than one hour at a price that can be affordable by any economy passenger of ow cost carriages; he even demonstrated the possibility to fly from Great Britain's capital London to Dubai in half an hour while laughing at the fact that he had always just imagined to put those ideas into practice while nowadays he is actually developing those claims, as tweeted recently (The Verge)[8]. And actually, the fifteen September 2021 he was able to launch civilians without professional astronauts on board to travel around the globe for 3 days at 575 km of altitude. But safety concerns with rockets represent a high barrier to entry. Moreover, as stated in the European commission report about the 100 radical innovation breakthroughs for the future, if the safety and security issues are resolved, many firms will surely be ready to start developing reusable rockets for what it is just considered a niche market.

Many companies are looking at applications for short and medium-haul distances making the cities the most predictable environment in which to see the innovation catching on carrying many pros for congested capital cities. It may also be reasonable to think at a redesign of cities that may take years. In principle, these new vehicles concepts may give birth to new neighborhoods in areas where nowadays roads are not really accessible and sometimes are even lacking (mountainous regions, waterscapes and others); with regards to existing areas dedicated to roads and land cars it is foreseeable that much more spaces could be rethought and rebuilt taking in mind that pedestrians and related social events or simply taking bikes to reach a urban destination should be the center of actual and future development seen all environmental issues. (European Commission Foresight 100 Radical Innovation Breakthroughs for the future)[2].

1.2 Legislative issues

Many issues have arisen concerning flying cars as said above. The most important can be categorized as follows:

a. Tracking systems: the need for live position identification of cars in order to find criminals (otherwise impossible to stop them in the air) but also for safety concerns: flying cars should be able to know the exact position of other cars in a certain range in order to take appropriate driving behaviors. Ramani et al (2013) in a study of them concerning tracking systems of vehicles and locking system using GSM and GPS wrote about a low-cost system thanks to which the place of a vehicle can be tracked using Global System Mobile Communications (GSM) and Global Positioning System (GPS)[9]. Law enforcement officers and car manufacturers should be in continuous cooperation to be aligned on new technological advancements and new law procedures.

b. Mechanical faults: potential mechanical faults might lead to big disasters given that the greater the weight of a vehicle, the greater would be the impact of the disaster, not considering the high speed needed to fly. It is natural to think there will be the need for parachute technologies for the avoidance of the crash landing but also of the crashing of parts of the flying cars falling from high altitude at high speed. As a result, a reliable autonomous collision avoidance system is needed to make people tranquil without being afraid of dangerous material falling from the sky, even when just sleeping under a roof. Terrorism issues may arise seen the greater impact of an air crash that may lead to instantaneous air crash recognition a necessary requisite for today's cars.

c. Law enforcement systems against technology misuse: border security would be of major concern since borders might be more difficult to be checked and, in any case, would also require police officers to be well equipped with flying cars of the same power level; furthermore, fly areas and flight paths should always be updated regularly. Basner and others also noted that all bad noises which are intrinsic into nowadays aircrafts are commonly recognized to be as important issues to take care of when it comes to people's sleeping quality in case they live close to flying areas (and with the new flying cars this problem might become a great concern for much more people) but also it is of concern with regards to children's school performances and more in general to community annoyance (cardiac diseases and other safety problems may arise as a consequence of sound pollution). The International Civil Aviation Organization (ICAO) also showed that increasing airports spaces is not seen positively by people that could have to inevitably hear all kinds of related noises[10,11].

Kyriakidis et al. (2015) presented some findings of public opinions on automated driving and noted that respondents were mostly concerned about software hacking/misuse [12,10].

Mofolasayo (2018) in his presentation at the Canadian transportation research forum proposed some solutions for addressing the issue about software hacking/misuse in autonomous driving. Some of these includes improving on security system that can quickly identify data breach and prevent hacking. When a data breach has been identified, the system to be implemented and maintained should be such that can promptly advise users and stop working in autonomous modalities[10,13].

d. Finance sustainability: many kinds of fundings are needed like those for incentivizing the purchase and subsequent maintenance of all technological components in order to make the system safe for everyone and at the same time a system for appropriate billing for the distance may balance the cash outflows.

e. VTOL power systems: It will not be a desirable thing to see cars falling from the air because they have run out of energy. It will be a good idea for every jurisdiction to evaluate the energy systems in their jurisdiction to determine what will be the most reasonable energy system that can efficiently support the transportation systems in their community [10].

f. Environmental impact: the habitat loss is considered as an important danger for species and colonies of birds that might alter their paths altering the ecosystems and becoming classified as extinct or endangered. Acoustic pollution would become an important issue and while urbanization has already taken the lead in the actual century, a completely new air development has not the freedom to spread all over the world without passing through environmental strict checks.

1.3 Other information

The last years have seen the development and rapid growth of urban areas worldwide especially in the African continent and Asia.

Increasing demographic levels has led to the amplification of business districts and commercial areas; as a consequence, also all transportation systems have seen an increasing pressure for expansion, safety and affordability.

To be efficient, actual systems of transportation include ground-level, waterborne, high-altitude spaces and underground spaces; the most used ground transportation systems are road and train transports that are facing several sustainability issues from an economic, social (poor flexibility) and environmental point of view; waterborne transport is mainly used for long-haul distances for tourism purpose and especially for freight transport because of low costs behind the service. In any case the maritime ways are not considered efficient economically speaking and are not also affordable for many urban conglomerates seen that not all cities have passable waters.

Transportation through air vehicles is also actually suitable just for long distances and very long distances (one of the many issues that Italian state owned company Alitalia has faced during the recent months has been the lack of sufficient long range flights which constitute the major source of revenues for big non-low cost companies); in any case just high altitude space (HAS) is actually considered as a revenue source while it should be reasonable to consider short and medium distances, as such the near ground space (NGS) could be the alternative for urban scenarios.

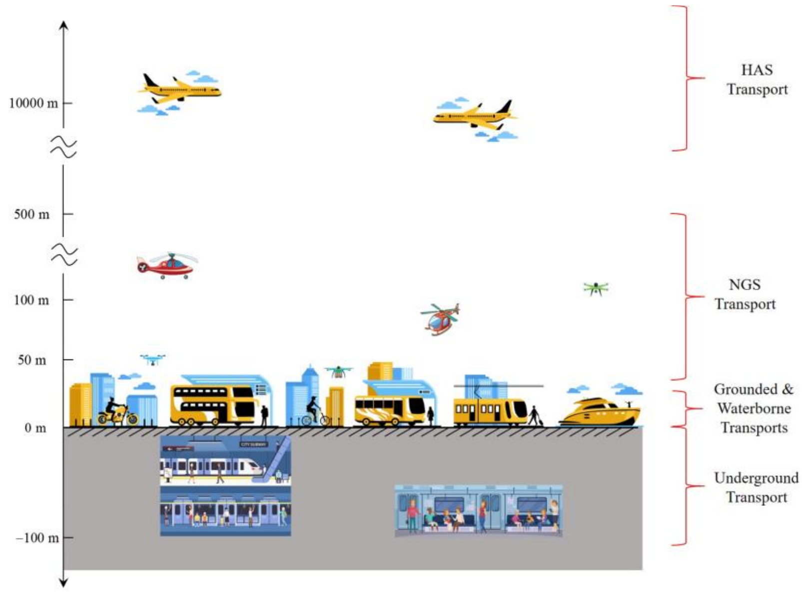

Fig. 1. Main transportation systems

To relieve actual traffic pressures and transportation issues, many firms have been trying to find valid alternatives and normal outcomes were found when thinking at separating the main problems that seem inevitably related one to another (streets and cars) into air space and cars, leading to imagine that congestion problems might be solved when cars do not go anymore on normal infrastructures but on completely new ones[25].

When talking about flying cars, many types of aspects can be considered like the taking-off and landing modes, the operation modes, pilot modes and power systems. With regards to flying modes we could take into consideration more than one typology like the vertical take-off horizontal landing (VTHL) which reminds the typical way for aircrafts to land on earth, the horizontal take off vertical landing (HTVL) mode where landing only is not subject to the need for long runways like in airports, the horizontal take off landing which is normally used and vertical take-off and landing mode (VTOL), which is considered the main typology seen that almost all firms producing flying cars are concentrating in this field seen the easier and more practical way for making people fly around a city.

With regards to power modes, the main typologies consist in electric power (lower emissions and noise pollution make of batteries the preferred way for energy source but at the same time issues regarding energy density, recharging time, the number of charge and discharge cycles before breakage and average price of batteries), hydrocarbon fuel (for which environmental issues still persist but for which manufacturing complexity and lower hardware costs significantly help towards this direction) and hybrid power (which presents many advantages seen environmental benefits and weight reductions as well as reduced charging times and increased durability with respect to completely electric vehicles but at the same time present disadvantages like increased hardware complexity and costs that may result in poor commercial performances).

Operation modes can be classified into airplane (not really explored for future flying cars, unsuitable for being deployed for the purposes of flying cars seen that this typology does not even present wheels for going on normal streets), helicopter (which makes flying cars with this operational mode suitable for city landscapes seen that no long runways are needed for the purpose of taking off and landing), and hybrid modes (like helicopter-car mode or airplane-car mode, different one from the other from the point of view of being able to well perform in the air like airplanes or not and from spaces needed to land because of wings and runways, making this last operational mode not really fitting urban needs)[25].

Pilot modes have been considered the most important categories to find subdivisions for flying cars. In the following chapters and when explaining the model, it has been considered of vital importance for the analysis whether to consider piloted or unpiloted flying cars, seen that they can be considered the two main ways for talking about future developments of the industry; hybrid modes should also be taken into consideration but seen the much higher production costs with respects to the before mentioned systems it is reasonable to affirm that it is not as much important for classifying future innovations trajectories. This categorization, seen the important differences between the two technologies backing the whole systems, should be profoundly analyzed in order to achieve the scope of this thesis work.

1.4 Market outlook

Flying cars can be considered to have a wide variety of applications, indeed they can be used for professional services like medical services and police services; day to day commute inside the same city or among different ones; and commercial transport in substitution for normal taxi services and every kind of related way to make money at passenger transport services.

The new outlooks concerning urban mobility and the ever-increasing investments made by incumbents and new entrants in the industry can be considered as the main factors that could lead to the fast evolution of the market and its fast time to market, thus driving the growth of these systems. However, legal issues and related stringent regulations and aviation licenses needed for flying on cities and huge costs matter more than one could imagine for the final positive outcome of the technologies analyzed. High potential and increasing agreements on these themes anyway could facilitate the overcoming of the major problems offering lucrative opportunities especially where the number of patents is increasing exponentially like in Asia Pacific and North America scenarios[14].

As per papers and research gone through for this thesis work, it has been possible to think at a possible high-level classification of the market as follows:

a. Base technology: piloted cars or autonomous driving cars;

b. Type of use: commercial use, professional use, personal commute;

c. Region of use: across the continents the demand for the technology can differ based on different political, environmental, social, technological, economic, and legal factors.

Key players nowadays recognized are the following:

- AeroMobil (Slovakia): Aeromobil is a flying car that had its commercial design revealed in the spring of 2017, it is then piloted and flown but not with a vertical take-off and landing scheme. AeroMobil has started taking pre-orders, with deliveries anticipated to commence in 2020.

It is proposing many kinds of models, powered by different kinds of engine like electric, hybrid fuel/electric, gasoline, fuel cell, jet fuel; the proposed ranges are then floating from 45 to 800 km, also considering the different lift architectures (propeller, multi rotor, and ducted fan) and different airframe types (from flying car/hover bike to tiltwing or lift+cruise or fixed wing or multicopter or tiltrotor).

They are also proposing solutions to many questions already raised in the previous paragraphs (regulatory environment, ground infrastructure, air traffic management and power technology).

The company is actually looking for partners in the supply chain of key system components and is looking for a business model that includes subcontracting final assemblers in order to reduce costs on non-core operations for the company.

Meeting certification requirements and optimization of performances is the critical issue in their actual production of flying cars[15].

In the following table some data related to technical characteristics and performances have been shown for curiosity purposes and in some cases for making a final analysis concerning actual overall performances of flying cars under production.

	ACTUAL PROTOTYPE TO BE CONSIDERED FOR ANALYSIS
	AEROMOBIL 3.0 (flying car)
General characteristics	**Crew:** two **Capacity:** two passengers **Length:** 6 m **Wingspan:** 8.50 m **Weight**: 610 kg
Performance	**Max flight speed:** 220 km/h **Range:** 650 km **Fuel consumption when on land:** 0,1 l/km **Fuel consumption:** 16 l/hour

Tab 1. Aeromobil 3.0 general characteristics and performance

- Airbus S.A.S. (France): they came out with the idea of a compact flying taxi to commute around the city, the CityAirbus, which has the aspect of a small drone and is conceived for a sharing market scheme, for which the customers, normal people, can book a seat on it like they would for an Uber ride. CityAirbus sub-scale prototype has already passed dozens of flying tests which have demonstrated the correct aero dynamicity and the consequent possibility for it to be produced on a large scale[16]. Its autonomy is of 15 minutes, a four-passenger capacity, 120km/h speed with propellers and electric motors, with a battery capacity of 110KWh.

Fig. 2. CityAirbus

- Hyundai Motor Company (South Korea): Briton Michael Cole, the head of the board of directors of the European market reached by the company has been supposing that, because of the needs and problems that will be realistically overcome, the aerial vehicles will surely represent the immediate next versions of what they produce nowadays. The next step for this is building a set of complementary assets like airports appositely built (or rented from existing areas) for vertical take-off and landing aircrafts.

  Hyundai gave a move to its plans regarding flying cars at the beginning of 2020 when an electric mode aircraft was presented in partnership with Uber at the Consumer Electronics Show of Las Vegas; its flying capacity was estimated around more than 100 km in aerial spaces of less than 600 meters, with a cruising speed of just less than 210mph.

For their agreements, Hyundai should provide manufacturing knowledge and capabilities while Uber should be the airspace support services provider[17].

- Klein Vision s.r.o. (Slovakia): their AirCar model is composed of different functional units able to integrate and give solutions to the large space requirement of hypothetical passengers and at the same time weight and lift issues for flying standards. Retractable wings are one of the most important characteristics for this model as well as folding tail surfaces for improved longitudinal stability and parachute systems[18].

- Lilium (Germany): it took many years for the company to develop a proprietary technology for sustaining take-off and landing standards in the completely electric vehicles scenario.

  Many prototypes have been analyzed and constructed, like the curious case of a 5-seaters capacity flying car demonstrator; an even larger flying car is under development, a 7-seaters model, which can also reach high cruise speeds, and whose commercial launch is programmed for 2024[19]. It is based on 36 ducted fans

- PAL-V N.V. (Netherlands): this company presents its flying car as the world first flying car production model with a solid Dutch engineering and elegant Italian design. Its technical characteristics comprehend a dual engine, for 2 persons with 170 km/h max speed. The PAL-V Liberty project is a mix of a car and a gyrocopter (a type of rotary wing aircraft that uses an unpowered rotor in free autorotation).

  Both a pilot license and an autogiro license are required to run the vehicle.

  As it normally happens for many grounds car models, PAL-V has thought about two diverse models for their flying car, the sport version, and the Liberty Pioneer. The sport one is the base level while the latter is the limited-edition version; as normally happens, the Pioneer edition will be out earlier and will be including any possible kind of new generation technologies.

Prices are in the order of several hundreds of thousands of Euros. Manufacturing plants are established in India where low costs for working puts PAL-V in a competitive position in this initial turbulent period; it has been signed anyway an agreement for exporting plants in Europe and US by this year.

In the following table, some characteristics have been reported for the seek of curiosity and in some cases to compute better analyses with regards to performance issues.

	ACTUAL PROTOTYPES TO BE CONSIDERED FOR ANALYSIS
	PAL-V LIBERTY (flying car)
General characteristics	**Capacity**: pilot and one passenger **Weight**: 650 kg **Fuel type**: Euro 95, Euro 98, E10 **Fuel capacity:** 100 l
Performance	**Drive mode** Max speed: 170 km/h acceleration (0-100 km/h): less than 10 seconds Engine power: 100 hp Dimensions, L×W×H: 4 × 2 × 1,7m Range: 1350 km **Flight mode** cruise speed: 140 km/h Max speed: 200 km/h Engine power: 200 hp Dimensions, L×W×H: 6,1 × 2 × 3,2 m Rotor diameter: 10,75 m Maximum altitude: 3500 m Range: 460 km

Tab. 2. PAL-V Liberty general characteristics and performance

Fig. 3. PAL-V Liberty

- Samson Motors, Inc. (UK): The Switchblade has flown in the area between The Oregon and California (US), it is made of a gasoline type of fuel, hybrid drive and fly system. Safety issues have been taken in serious consideration seen the regenerative braking system and the reverse thrust which both are part of the parachute system required for this kind of vehicles and specifically for bad weather conditions; also brake assists when landing is part of these revised safety related solutions[20].

  Many shapes have been dragged from Ferrari automotive designs in order to give sporty impressions and letting people remember the famous Italian automobile company in order to catch a certain kind of market; the company is also delivering systems for producing the model through technologies of industry 4.0 like factory builder assistance.

  New models are not far from their initial production like it happens for normal ground cars, differently equipped based on the segment to be reached. To be flown, this aerial vehicle needs a driver's license for operating on the ground and a private pilot license for flying. The projects related to this kind of car anyway are estimated to be among the longest ever experienced.

- Terrafugia (US): Volvo's parent company Geely was the big company acquiring Terrafugia in 2017, which is considered a flying car start up.

  Terrafugia's first flying car is named Transition, a two-seat aircraft a few months ago in testing phase, that has now reached an important milestone (FAA certificate), but it is considered still an initial version.

  Terrafugia is also working on a vertical take-off and landing flying car which is expected to debut in 2023.

  The following table's been considered for the purpose of curiosity and for further analyses.

	ACTUAL PROTOTYPES TO BE CONSIDERED FOR ANALYSIS
	TERRAFUGIA TRANSITION (flying car)
General characteristics	**Crew:** 1 pilot **Capacity:** 1 passenger **Length:** 7 m **Wingspan**: 8.08 m **Height:** 2 m **Weight:** 500 kg **Cockpit:** 1.5 m **Length on road**: less than 6 m **Width on road**: 3 m with wings down **Height on road**: 2.00 m **Propellers:** 2 m as diameter
Performance	**Maximum speed:** 210 km/h **Cruise speed**: 180 km/h **Range**: 800 km when flying **Maximum speed on road**: more than 100 km/h **Fuel economy in cruise flight**: 0,11 l/km **Certifications:** Both FAA and FMVSS certifications have been planned

Tab. 3 – Terrafugia Transition general characteristics and performance

Fig. 4. Terrafugia Transition

- The Boeing company (US): Boeing NeXt is an organization that is leading the next generation air vehicles for urban, regional and global mobility. Some flying cars are being designed in these days. An autonomous aerial driving vehicle, a passenger aerial vehicle (PAV) was built with a multirotor scheme for Boeing NeXtfe for the purpose of on-demand mobility. It passed the controlled takeoff tests like also hover and landing tests; additional tests are in any case still required[21].

Fig. 5. Boeing PAV

- EHang Holdings (SK): one of the largest listed companies in South Korea is testing aerial cars with a 2-seaters capacity.

  The EHang 184 is an autonomous passenger drone which reaches normal city ground cars speeds. It made many journeys under different weather conditions like also storm-force winds and in low visibility like at late night.

  The following table has the purpose of curiosity and further analyses.

	ACTUAL PROTOTYPES TO BE CONSIDERED FOR ANALYSIS
	EHANG 184 (passenger drone)
General characteristics	**Cabin:** self-piloted, 1 passenger **Length:** 4 m **Wingspan: 6** m **Height:** 1.5 m
Performance	**Cruise speed:** 140 km/h **Range:** less than 20 km **Aerial space limit:** 600 m

Tab. 4. EHang 184 general characteristics and performance

Fig. 6. EHang 184

- Volocopter GmbH (Germany): a complete set of fully electric aircrafts is being developed and tested. Within the coming years commercial flights are planned to take off with the purpose of urban air mobility (UAM)[22].

  Volocopter is building an ecosystem of digital and physical infrastructures like VoloIQ which is the digital booking platform and Voloport that will represent small airports owned by the company, even more than one in big cities is actually planned.

  Volocopter 2x project is a two-seat flying car which can be piloted in some cases and is classifiable as a multirotor electric helicopter. Seen that it is classifiable as a flying car, it is to be considered a personal air vehicle.

Fig. 7. Volocopter 2X.

CHAPTER II

Limits of models to explain the technology

2.1 Paradigm, dominant design and standard

In order to better define a technology, we may use these terms relating them to different aspects of an analysis: a technological paradigm should be used to describe a broad aspect, a huge amount of actors building up the way the technology is brought to the customer: the supply side comprehends producers and the related suppliers, complementors and research institutes; the demand side concerns the needs, beliefs, meanings that the market gives to the product making it desirable.

Abernathy and Utterback introduced the concept of dynamicity when looking at innovations talking about three main phases, the fluid phase, the transitional phase and the specific phase, in case of a discrete product, that characterize the evolution of it. In the first phase the uncertainty about the way the technology operates and as such the uncertainty with regards to the market prevail, leading to many changes; innovations happen in the product and not in the process seen that every player tries to make its own product the most acceptable through different business strategies or product models. In the transition phase the producers and in some cases the ecosystem around, try to converge towards one way of presenting the product, innovators adhere to some defined features and increase their market acceptance leading to increased market share. This is then the phase of the emergence of the dominant design.

The product differentiation and the organization get more rigid, so threats are coming from imitators and inventors of product breakthroughs while the processes start to change in large steps. In the last phase, cost reduction and product performance take the lead, equipment and labor get highly skilled; the competition becomes severe leading to a few winners.

The standard arises when there will be a large network of market operators that go towards the same direction leading to economies of scale and learning economies; it is more linked to creating a large market share which will lead the producers to be the only winners leaving behind weaker standards that will necessarily fail.

2.1.1 Abernathy and Utterback's theory

Abernathy and Utterback's model in the case of discrete products allows to give information about the phase in which it lays thanks to a set of possible indicators like the number of firms, sales, performance achieved, rate of innovations and many others, that might be compared on a time scale.

In fig. 1 it is possible to look at a significant increase in market size in North America, which is actually the main area for flying cars interest (almost 50% of initiatives can be found there), soon followed by the Chinese market. The overall market is actually estimated to be 55 million USD (Fortune)[23].

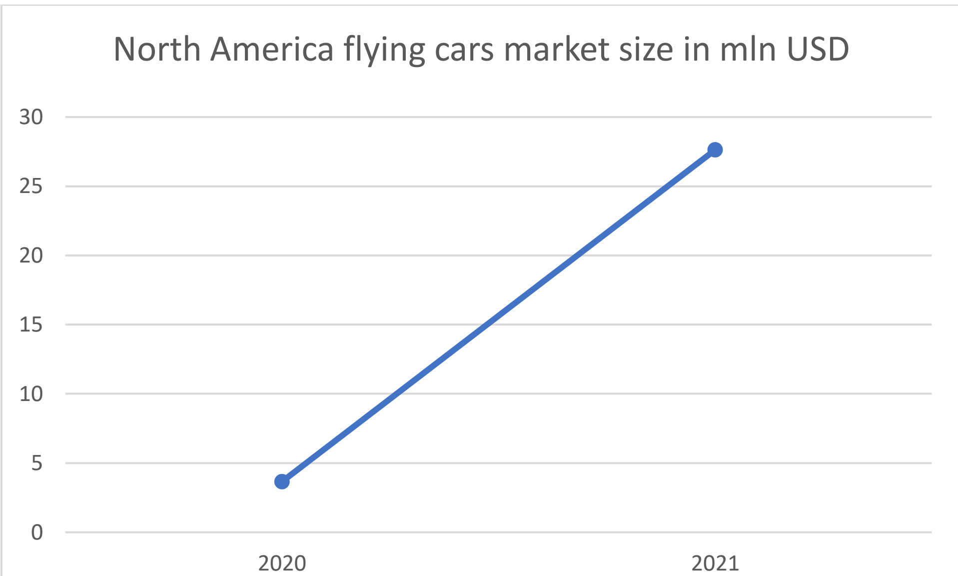

Fig. 8. North America flying cars market size in million USD.

Patents related to flying cars technology date back to the first years of the new century and see an ever-increasing amount filings and consequent developments of prototypes of any kind.

Through research on Espacenet, the European patent office, it has been possible to find the number of patents through the years all around the world. This is the graph that came out of the analysis:

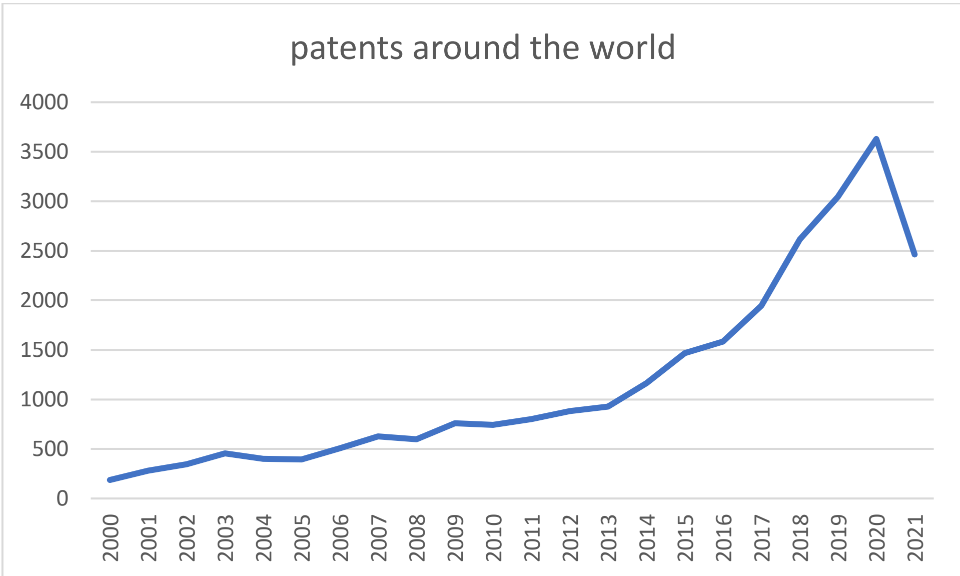

Fig. 9. Patents around the world in the new century.

This shows an ever-increasing number of registered patents with a weird decrease in the last year, mainly due to the Covid-19 pandemic lockdowns. Applicants come mainly from US, remotely followed by Asian countries (Japan, South Korea, China) and European countries (Germany and UK mainly).

Another possible analysis can be made considering the number of firms approaching the flying car's theme.

The analysis in this case has been conducted looking at the dates in which projects started or prototypes came to life. Furthermore, only concepts of the new century have been taken into consideration seen that only in the recent years technological knowledge advancements have brought to valid and worth of note concepts. Moreover only the main and most worth of note initiatives have been considered.

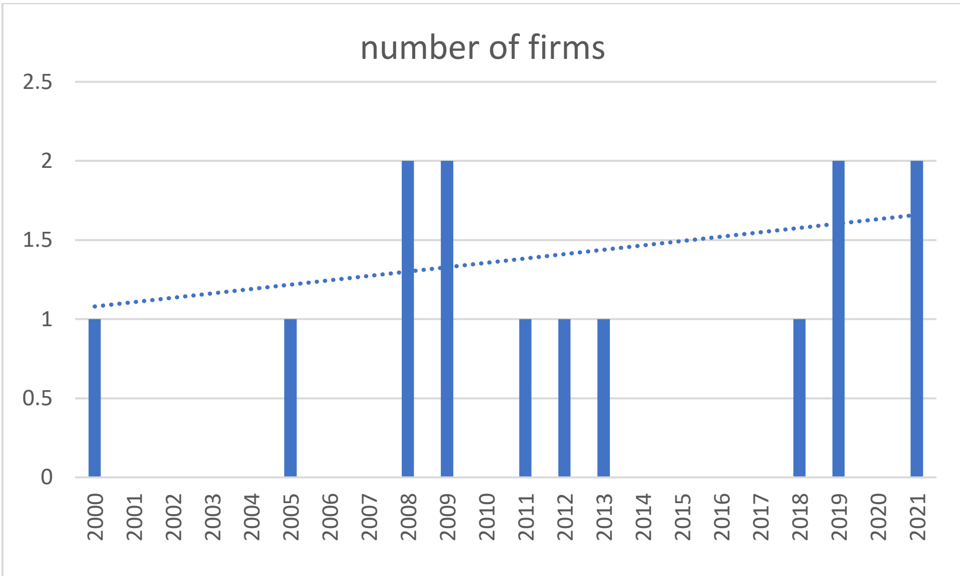

Fig. 10. Number of firms approaching new flying cars initiatives in the new century.

As per the graph, the trend line shows an almost flat slope which anyways gives room for stating that in the last years the number of firms approaching aerial vehicles initiatives is greater than the first years of the new century (the trend line is not horizontal).

It can be affirmed that the flying car technology is in the initial phase where commercialization starts to be of interest, diversified technical solutions are still present and the rate of product innovation is high.

Abernathy and Utterback's model does not really provide any precise tool for interpreting our technology as something related also to the service that might be built around: product systems may see their evolution thanks to additional functionalities that have not to do with the core of the product; the case of Volocopter in Germany can be seen as an example for which the system of complementarities may add much more value to a flying car than it would have by standing alone and relying on old infrastructures which should be rethought deeply for the way of providing flying services.

Some other related models have tried to explain and forecast which could be the possible future directions of new technologies but given the complexity and interdependency of many parameters it is quite difficult to find a well-defined solution.

CHAPTER III

Methodology and evaluations

3.1 Methodology

The scope of this thesis work is mainly to answer questions that may arise following a new technology. Will it be impacting society in the future? Is it promising? Does it have the potential and the odds to become a dominant design for some specific market segments? Is it worth investing in it now? As such, this thesis work candidates to find a methodology to allow the early identification of a dominant design. As per definition, it will be the case only if it will deliver more value than other technologies, in markets where the best opportunities are present and where there is room for cost, profit and technology improvements.

Many difficulties have been found in the search for data related to flying cars technologies seen the relatively recent evolutions and the biases due to information mainly coming from companies reports and outsiders' insights found on internet.

Our main concerns relate to the two possible future technology clusters that are gaining room for being possible future used ways of living our cities: manned and unmanned flying cars; the pilot modes indeed can be considered the most important way for classifying different flying cars since the backing technologies are completely different and represent a crossroad for the deployment of innovative mobility.

The unmanned kind is commonly known as drone and does not need any human pilot as such it is also defined as self-piloted vehicle; all self-piloted aerial vehicles which have the purpose of carrying people and let them commute can be defined passenger drones and the basic requirement for this is the full automation of every kind of cars systems (Dronelife)[24].

A more complex unmanned aircraft system that includes a ground-based controller and a system of communications should be considered; it may operate through human controllers or with different levels of autonomy up to a completely autonomous.

On the other hand, manned flying cars can cover large areas and can be on air much more time with respect to a drone. Usually, the airframe of a flying car should not be lightweight seen that it should be able to contrast safely the possible impacts coming from a road crash with another roadable vehicle and anyway it should be able to pass safety standards of robustness, but at the same time it should be light enough to be able to take off when necessary.

As said before, hybrid modes will not be considered since systematically higher costs because of the integration between autonomous and non-autonomous systems can be considered an important factor that will not give room for this technology to be fully used, while it can be considered as a transitional phase for some kinds of vehicles.
Furthermore, only VTOL flying vehicles have been considered for the analysis since they represent the vast majority of aerial vehicles initiatives because of their better attitude towards space and urban issues (runways and supports not needed and no fixed wings present); another important assumption for the scope of this thesis work concerns the power types considered: because of the recent worldwide directions towards green and sustainable energy sources, only electric powered aerial vehicles have been considered since most benefits overcome those coming from hydrocarbon fuel, think about lower emissions, lower noise, lower hardware complexity, lower weight, essential for flying purposes, and better energy efficiency; surely there are not only good news because for what concerns endurance and refueling speed (which can be compared with the changing speed for electric vehicles) hydrocarbon fuel powered cars seem better equipped, though it should be worth of note that many firms and research are putting all efforts for overcoming these problems.

3.1.1 Method

The method that this thesis work proposes is based, as already stated, on the principles of the quality function deployment method that puts into schematic tables numbers able to weight customer related features, tertiary needs expressed by customers, and relate them to more technical requirements that compose the product. Seen the difficulty of finding correct data, the analysis has been conducted more on a qualitative approach than quantitative. Comments and sentences about specific areas of the technologies have been triggered through research analysis, posts, scientific papers, which let them be the base point of reference for reaching a solution to the already stated questions.

The methodology follows the following points:

1. Collection of data and papers regarding the two main typologies of flying cars.
2. Construction of a rectangular matrix which presents the main ways for classifying flying cars; those are by capacity of carrying more than one passenger (2-seaters, 3-seaters, 4-seaters), by air space that means the altitude to which the vehicle is able or allowed to fly (high altitude space, near ground space), by geography where the flying car is better supposed to grow because of social, historical, legislative and economic factors able to improve the development of the technology and boost its adoption, or geographies where those factors have the opposite effect, binding the growing impetuses; these geographies are classifiable into North America, Europe, Asia Pacific and rest of the world; and by covered distance (short range transportation and medium range transportation). These classification opportunities will be qualitatively evaluated for both the main technological sets considered for this analysis (human-piloted and self-piloted flying cars) in order to find for both of them the optimal vector of best choices for every classification mode. Evaluations for each single classification mode for each single technology are expressed after a pro and cons/risks analysis that highlights the main points.
3. Construction of a rectangular matrix where manned and unmanned flying cars are analyzed by single market segment; 4 macro areas have been identified: military, private (it is regarding civilians willing to take a VTOL vehicle for personal purposes like they would with a normal ground car), commercial (which can be better subdivided into B2C, like can be the case of flying taxi

cars and food/beverage delivery, and B2C for sharing), professional (subdivided into firefighting services, police services and medical aid services). Then some scores are assigned for both manned and unmanned vehicles for each market segment, considering the same technical aspects for all the segments which are related to low-end aspects, comprehensible by the usual customer, that might have different importance for different segments (e.g., social acceptance might be considered as a most impacting and to be systematically considered aspect when considering a private sector for flying cars while in the military framework it can be surely less heavy as a leading factor for driving the acceptance and diffusion of the technology). Weighting and evaluating those aspects for each market segment and for both piloted and unpiloted aerial vehicles will lead to give a certain score that will allow us to make some judgements about the possibility for a certain cluster of elements to become a dominant design or at least something to look at when considering future evolutions of the transportation systems all around the world.

4. Analysis of the different market dimensions and some additional insights regarding R&D investments related to transportation, in order to trigger conclusions about the possible emergence of a dominant design.

Implementation of the method

Collection of data related to actual flying cars initiatives like just concepts announcements or prototypes deployment, even if in different stages, has led to several vehicles that should be taken into consideration for the purpose of subsequent analyses. In table 5 we can find some of the most important flying car's initiatives for which some characteristics have been selected and reported; those classifications were important to state, as per scope of the table, that almost all initiatives focus on the VTOL (vertical take-off and landing) flying mode, that consists in the easiest way for urban needs: indeed the possibility for vertically take off and vertically land suggests no need for runways alike for usual commercial and military airplanes so no need for huge airports which should have been increasing exponentially for the development of flying car's technology which would render them difficult to become of communities interest. One further remark should be done with regards to geographical areas where most initiatives have been growing; Europe and North America as well as Asia-Pacific are the areas of greater effervescence, in particular the States are the most active into these ways of interpreting the future mobility pictures.

flying car model	TOL mode	geography	passengers	distance range
PAL-V Liberty	VTOL	Europe	multiple	1300 km
SD-XX	VTOL		multiple	25 km
Elevate	VTOL		multiple	322 km
Heaviside	VTOL	US	single	
Flyer	VTOL	US	single	
The City Airbus	VTOL	Europe	multiple	
Vahana	VTOL	US	single	52 km
The Transition	VTOL	US	multiple	787 km
Aeromobil V. 4.0	VTOL	Europe	multiple	700 km
VoloCity	VTOL	Europe	multiple	33 km
MOOG	VTOL	US	multiple	
BlackFly	VTOL	US	single	65 km
Samson Motors	VTOL	Europe	multiple	
Parajet Skycar		Europe		
DR-7	VTOL		multiple	190 km
AirCar Klein Vision	VTOL	Europe	multiple	
The TF2	VTOL	US	multiple	300 km
Ehang 184	VTOL	South Korea	single	16 km
Nexus	HTOL	US	multiple	240 km
Hyundai	VTOL	South Korea	multiple	
Cora	VTOL	US	multiple	41 km
Volante Vision	VTOL		multiple	
Joy aviation	VTOL		multiple	240 km
Audi PopUP-Next	VTOL	Europe	multiple	
Butterfly Super Sky Cycle		US		
Jaunt Aircraft	VTOL	North America	multiple	
Moller M400	VTOL	North America	multiple	
Lilium	VTOL	Europe	multiple	
WD-1	VTOL		multiple	500 km
Boeing Cargo Air Vehicle	VTOL	US	none	

Tab. 5. Flying cars initiatives

As to the maximum number of passengers allowed on the aerial vehicle, most initiatives concern multiple-seaters scenarios (also 2-seaters vehicles including one pilot and one passenger have been considered amongst these multiple-seaters cars and represent a great number of them). This gives space for flying cars to be used not only in war scenarios where even just one pilot and no soldiers are needed to perlustrate grounds from above but also for commercial purposes like normal freight transportation, aerial taxi services and private commute.

Apart from some isolated cases, normal flying cars projects try to reach a distance range that goes from 80 to 322 km (so it makes a sense to think at battery autonomies) which represent a great starting point for future technological improvements. Concerning freight transportation, we could affirm that flying car transportation systems could be of help when it comes to non-heavy loads alike normal trucks or trains do nowadays; some high-priority freights indeed could be easily and rapidly transported by aerial means with human-piloted cars that should take the lead over self-piloted in this particular case, seen the difficulties in large loads carriable by drones and seen the necessity for fast emergency transportation between two places far away one from the other (human-piloted reach greater distances).

Once collected data from various sources through surfing the net, it has been possible to fill in a table where 4 parameters are indicated:

a. Capacity
b. Distance range
c. Geography
d. Air space

For each parameter, human-piloted and self-piloted vehicles present two sections, pros and cons, that allow us to trigger some conclusions with regards to optimal vectors that should be later quantitatively analyzed; two optimal vectors as such are required as result of this initial work, one for each technology cluster considered.

The first parameter concerns the number of seats that manned and unmanned vehicles are actually building, and it can be shown that 2-seaters aerial cars are the most widespread and built ones; it is because of the easiness in production plants and previous considerations of the usage required. 2-seaters are the optimal dimension for both solutions.

As to the optimal distance range, some considerations have been dragged: human-piloted flying cars can reach larger distances, usually medium to long distances, making them attractive for freight transportation which could be thinking at using flying cars as an alternative for normal trucks and trains; for what concerns self-piloted vehicles, shorter distances are allowed (usually up to 104 km which means short to medium distances) making them possibly attractive for professional services to be delivered within the same urban conglomerate (think of urgent medical assistance) where traffic is considered the major obstacle to short times to be served. Social acceptance would then be quite high considered the improved medical services especially in metropolitan areas.

Reasoning about the second element to insert in both the optimal vectors, short-haul distances for unmanned and medium-haul distances for manned vehicles have been identified as the best possible solutions to be explored in the coming periods.

About optimal geographies, some macro areas have been considered (North America, Asia-Pacific, Europe, rest of the world); these geographies have been selected since most initiatives come from US and Canada, sometimes in collaboration, while at the same time Europe (with Germany actually taking the lead for number of patents and prototypes developed, followed by UK, France and Slovakia) and Asia Pacific (with Chine heading the number of patents and South Korea greatly interested in outcomes) are showing great interest towards new urban sustainable ways for developing their cities. The rest of the world, including as such mostly poor countries especially in the African scenario, has been considered since in some cases it could be argued that, because of lacking roads and more in general ground infrastructure, aerial space could be a great opportunity for a fast development.

As shown in the following table, anyway, drones self-piloted cannot be considered of interest since, given the initial need for green mobility to overcome crowded cities issues, the major scope would not find any application (crowded cities are part of the developed world where the concern is higher).

In general, manned aerial vehicles, because in many cases present fixed or not fixed large wings, would be better suited for areas where large grounds are found like for example many suburbs and rural areas.

In order to find this technology interesting anyway, the high development costs should be dramatically dropped because resulting high purchasing costs would generally not be fitting people living in suburbs (reach people usually live in congested financial districts which are part of the city centers).

On the other hand, then, drones seem better fitting big conglomerates where spaces for cars are going to be continuously decreased and large spaces are usually not applicable and if the possibility exists, cycling ways and pedestrian ways are nowadays taking the lead in urban projects.

For the optimal vectors, anyway, North America and Asia-Pacific can be considered the most interested areas for flying cars developments, for both manned and unmanned vehicles.

While a commonly accepted statistic regarding flights is that airplanes are the most safe way to commute and to travel, more than cars and trains, many people refuse to fly for many weird but comprehensible reasons like the fact that, while on the airplane, we lack control and find ourselves at the mercy of pilots that we do not even know or see during the flight time, or the frightening common fear of heights, or past bad experiences of flight crashes we heard of on social media and on television which do increase human unwillingness to fly, or simply the fact that we cannot see what is under us. This last factor could be slightly improved when talking about unmanned passenger drones since they are allowed to fly in the near ground space as shown before in figure 1. on the contrary of human-piloted flying cars which should be allowed in high altitude space, then persisting the fear of altitude and impossibility for the sight.

In general, anyway, it should be considered as positive the fact that manned flying cars are allowed in high altitudes since noise related pollution and disturbance for humans is reduced at minimum; also ethical issues could be easily overcome since there would not be any disturbance to ecosystems (and related problems previously signaled), no invasion of human privacy would be of concern and no environmental pollution would be an issue seen that for the scope of this analysis only fully electric vehicles have been analyzed because of their vast majority presence in flying cars initiatives.

With regards to the optimal vectors, the last element can then be inserted; for manned vehicles this element is represented by medium altitude while for unmanned vehicles the optimal element is the low altitude.
At this point of the work, it is possible to write the optimal vectors for the technologies of interest, which will be then analyzed from other points of view.
The optimal vectors, indicated as U for unmanned and M for manned are as follows:

U = (short-haul, 2-seaters, North America and Asia-Pacific, low altitude)
M = (medium-haul, 2-seaters, North American and Asia Pacific, medium altitude).

After reaching this result, the first 2 steps of the model can be considered concluded. Below it is possible to see the tables that summarize the comments and the analysis beforehand drafted.

	HUMAN-PILOTED	
	Pros	Cons
CAPACITY	There are some prototypes 4-seaters, 5 and 7 seaters letting us imagine there could be room for a possible increases in the number of passengers allowed	Most piloted flying cars present a capacity of 1 or 2 seats in many cases including one pilot and one passenger making it difficult to think about widespread commercial use
DISTANCE RANGE	between 80km and 322km (medium to long distances): Manned flying cars can cover large areas and can be on air much more time with respect to a drone.	medium to long ranges require higher robustness for weather conditions and better cyber systems that require higher manufacturing costs with respect to drones
GEOGRAPHY	Manned cars are better suited for large grounds to allow cars with large wings. Suburbs would reasonably take the lead but at the same time the huge costs imply an high-end target that in most cases lives in crowded financial districts. Reduction in costs may change the target and boost the development	Piloted aerial vehicles seem better suited for large ground spaces where there is more room for manual involvement and aircraft space as such leaving a remote possibility for deployments in urban areas
AIR SPACE	Human piloted aerial vehicles along with those addicted to taxi services might use medium aerial space, below 600m	low visibility of the ground is commonly considered one of the most impacting reasons for which many people do not like to fly with actual airplanes. With human-piloted vehicles, these issues would still be present

Tab. 6. Human-piloted table

	SELF-PILOTED	
	Pros	Cons
CAPACITY	reduced capacity actually used and explored allowes drones to be lightweight and as such of great use for professional purposes that require short ranges and easy delivery to people living in crowded cities	Most passenger drones are typically developed to carry just 2 passengers. Flying taxi companies are just stuck to this reduced capacity which can represent a limit for increasing profits. Intercity and airport shuffles can reach 3 and 4 seats
DISTANCE RANGE	short ranges reached are preferred for urban purposes like in the case of professional services with high priority that require lightweight and just a few km to cover	up to 104km (short to medium distances). Freight flying cars may bridge the market gap between the traditional land freight transportation systems and the limited freight delivery offered by drones
GEOGRAPHY	Drones are better suited in small areas and remote locations hard to fly. This is a typical situation that includes big cities like in the case of North America and Asia Pacific, main candidates for this kind of technology. Congested cities can have a better impact by the use of passenger drones	poor regions should find low interest into deploying self-piloted flying cars seen that urban congested areas are typical of North America and Asia-Pacific areas. As such SP cannot be considered a social boosting development means for poor countries lacking ground infrastructures
AIR SPACE	low altitude for which passenger drones are built would allow greater visibility and as such increase the number of people willing to fly for normal commutation	The operational air space for vehicles addressed to commerical use like taxis service would have an aerial space low which means around less than 200m.

Tab. 7. Self-piloted table

The third step of the model can be approached by starting from some considerations with regards to the possible applications and as such the possible industries and markets that may have the need for flying cars.

In order to have a commercial positive outcome, flying cars transportation systems should be designed thinking at their ability to relieve the pressure caused by traffic and congested urban conglomerates also considering the rapid growth faced by global demographic levels.

Human and freight transportation systems are as such the main categories for flying cars, which can be reformulated as public and individual markets. Reduction in transportation costs and reduced pressure on ground infrastructures should ultimately have them in mind as beneficiaries.

Moreover, it is important to talk about in which modalities flying cars will be brought to the markets; we could define two main modes of operational behaviors that are the public transportation mode and the specific transportation mode.

The first one as easily understandable, concerns the integration with the other main public transportation systems, that means integration with underground and on the ground means like buses, trains and subways. This integration, adding the third layer which is the aerial one, should face many issues since political agendas, real estate interests, overload of works to take care, conflicts with preexisting transportation systems and at the same time public utility.

The latter concerns professional areas that could find great interest in flying cars developments. We could imagine deployments with regards to police services like patrol, general monitoring for detecting anomalies and being a deterrent for some to act in certain behaviors; deployments in medical services or firefighting services; at the same time tourism could be an optimal deployment like also ground infrastructure aerial inspection, streets mapping. In general, many on-demand queries could find a great solution thanks to flying cars or passenger drones[25].

Other key problems for large scale operations will be described and analyzed.

As it happens for normal streets cars, the paths where flying cars can transit should be accurately analyzed and made clear to people; pre-established paths occur to be planned and the notorious American agency for the space (NASA) is trying to find solutions to what seem the greatest issue behind a real deployment of flying cars.

Because no traffic lights or new aerial streets can be built, other kinds of systems should be identified. Already existing technologies like Wi-Fi and GPS (global positioning system) can be deployed and even improved in their efficacy with the constituency of external control centers possible to be put on the roofs of normal city buildings which can elaborate thousands of navigation algorithms at the same time and are able to give in real time to everyone, while flying with a car, the exact position of other obstacles in a 3D space, given that cars may fly in a certain vertical aerial range and not only on a two-dimensional plane.

Some issues regard the path planning; in particular we may find two different kind of trajectories that should be paid attention to, and these are the fixed trajectories and the dynamic trajectories.

The first ones should be thought about as the already existing dedicated paths for buses and taxes, which are free to go where yellow strips are colored horizontally. In the air, this issue should be addressed for example by instructing all people willing to fly with a car that in some areas they have the precedence. Also, regarding take-off and landing sites, sound pollution and possible safety issues must be analyzed before deciding where to allow cars to stay.

The dynamic trajectories, and as such the adaptive path planning, are those trajectories that should be "freer" in order to address their primary purpose that is the short-distance flight like for example in case of medical aid needed in crowded areas where even short distances can become a hell.

Another point to take into consideration is the one of the support facilities, essential for the maintenance of a good level of services delivery; those are the takeoff and landing sites, all maintenance and related facilities and all kinds of communication systems with the ground.

The last ones connect servers storing every kind of information with all flying cars and the centers of control, the control signal systems through previous trajectory planning, allow an efficient organization throughout the flying time for all car providers to better profiting from the flights, indeed for example a good organization could allow many take-off and landing sites to be well equipped with sanitary instruments and medical stuff in case there has been any accident close to the site; additionally control signal systems can be enough for avoiding that too many aerial vehicles are in the air at the same moment in the same area so avoiding crowds; also reduction of consumed energy would be a result of good working control signal systems like also improved customer experiences.

As per the TOL sites, they should be initially found where rich people could find an interest in using them like financial districts and as such passenger drones seem to be better aligned for growing the market with respect to piloted cars with large fixed wings and other stops could be for example where areas of interest are like where hospitals are or great banks and schools are or where other kinds of transports have their stops (like at interchange with subways and buses stops) and as such, to improve initial profits, premium fees for rich people should be an interesting way to make money; once the service is able to reach an higher scale of users, commercial markets can be developed.

Storage and maintenance facilities are usually of two kinds: specialized and temporary. With that said, the first one concerns sites that must be in charge of maintain the flying cars for every need they could have, from simple refueling to any breakage that might happen in the day-by-day use. The second one refers to small areas that are able to accept just some cars, for a short time, to give the cars what they need for running a little bit more till they are brought to a specific site or anyway till they are completely maintained. These temporary sites should be looked at as we use normal gas stations around the cities, but with more functions able to make a flying car run even in case of communication systems or data communication systems not working; also cleaning of seats, normal refueling, places to eat, offices, rest rooms and other related stuff should be included[25].

Safety issues comprehend a wide range of things, from safety for the passengers related to protection from bad weather conditions like it is for normal cars in case for example of hail and showers, environmental safety and security of the systems behind the correct working of the car.

When it comes to thinking at passengers safety, one obvious thing to catch is that like for normal buses, cars and trains, an aerial vehicle could take fire because of engines failure or because of any kind of breakage; a vehicle could also just stop in the air like normal cars sometimes stop because of various kinds of failures; it is something that can happen and as such safety systems for passengers in the air should be thought like also mechanical systems that could protect people on the ground in case of pieces falling from the sky. Many architectural challenges are nowadays in front of engineers and general designers.

Threats could come from possible collision that should be addressed like nowadays normal airplanes do, with warnings of detection of other vehicles in the same space area and also it should exist some ground-based traffic control system.

Commercial issues are another point: too high manufacturing costs are actually posing a wall to scale but at the same time new technologies, new materials like the new composites go into a new direction also for appreciable reduction of costs.

At least in the near future pilots need to in a sufficient number seen that many flying cars are based upon the human-piloted technologies but also pilots are needed for emergency situations even on the ground; pilots wages are normally higher than those of delivery hires and taxi drivers, as such costs of work are high too.

Issuing licenses could also be a major impacting factor binding the commercialization of flying cars seen that flying licenses should comprehend tests for flying in many different situations, alike normal driving licenses, more affordable from an economic and a practical point of view.

Environmental issues are related to pollution and to what concerns noise pollution that may cause ecosystems disturbance of birds but also of ground animals. Restricted areas could be a solution.

Human privacy could be invaded by a large and uncontrolled use of flying cars; a reasonable solution should be again given by flying bans for some areas over exposed.

The third step of the model begins with finding main industries that could find some kind of interest into using, better deploy and develop flying cars.

Four main industries have been selected:

a. Military
b. Private
c. Commercial
d. Professional

The commercial sector is the one that could be represented by more subsectors but for the scope of this thesis work, just two categories have been selected: the normal B2C and the B2C for sharing.

The first one concerns what we commonly refer to with deliveries: when customers order stuff of any kind, trucks or trains or vans could not be used anymore giving space to flying cars which should reduce times and people involved, in the case of drones, and as such reduce costs.

B2C for sharing should be used instead of normal car sharing schemes, which are anyway used for distances that the customer looks at as feasible, not too long and not too costly, showing then a first but big problem for a large deployment in this subsector.

In the case of professional use, the flying cars would be used for emergency purposes like medical services or the already stated police services or fire extinguishing services, in order to reduce intervention time, increase social enthusiasm and improve general welfare.

Considering four parameters for each of these industries or market segments has been the second point for the construction of an evaluation matrix: cost, security&safety, environment and social acceptance can be considered major parameters that change their value in relation to a particular market proposition.

INDUSTRY	MARKET SEGMENT	PARAMETERS
MILITARY		COST
		SECURITY&SAFETY
		ENVIRONMENT
		SOCIAL ACCEPTANCE
PRIVATE		COST
		SECURITY&SAFETY
		ENVIRONMENT
		SOCIAL ACCEPTANCE
COMMERICIAL	B2C	COST
		SECURITY&SAFETY
		ENVIRONMENT
		SOCIAL ACCEPTANCE
	B2C FOR SHARING	COST
		SECURITY&SAFETY
		ENVIRONMENT
		SOCIAL ACCEPTANCE
PROFESSIONAL	FIREFIGHTING, POLICE AND MADICAL AID SERVICES	COST
		SECURITY&SAFETY
		ENVIRONMENT
		SOCIAL ACCEPTANCE

Tab. 8. Industries of interest, market segments and parameters of evaluation

Weights from 1 to 5 can be assigned to them for each market scenario; some considerations have been drafted for each parameter in every market outlook allowing to put numbers as a result.

INDUSTRY	MARKET SEGMENT	PARAMETERS	COMMENTS ABOUT PARAMETERS	WEIGHT
MILITARY		COST	high manufacturing production costs for a normal company might be smoothed by the certainty of buyers willing to pay for the product. The military sector can be considered as a major sector able to absorb the production capacity of manufacturing firms.	3
		SECURITY&SAFETY	security issues are of great importance for the military sector: in case of wars, the possibility for cyber intrusion from the enemy can lead to dangerous situations. Safety issue is also a major concern.	5
		ENVIRONMENT	the environmental issue should not be considered as of major concern once that generally war areas suffer from noise pollution. Electric engines anyway should guarantee a reduction of noise pollution	2
		SOCIAL ACCEPTANCE	War related vehicles and general technologies are usually kept secret by officials for security reasons. As such the rights on this particular aspect, like in general ethical aspects, are not considered to be of major interest for this particular market segment	2
PRIVATE		COST	The need for flying licenses and driving licenses may increase the price of getting licenses	5
		SECURITY&SAFETY	What if landowners would like to prevent or impose their rights to safety and security? Will it be possible to set rules like the no fly zone in certain areas and times? Will any stakeholder like associations of people from a same area be able to have rules about no fly zones? Will these associations be able to impose their rights and at what cost? Will it be feasible to restrict take-off and landing areas? Will it be possible for these associations to decide the timings for taking passengers on and off? (https://www.[illegible]/IH18334.html).	5
		ENVIRONMENT	environmental issues can be overcome once the recent developments of electric power	5
		SOCIAL ACCEPTANCE	For a Deloitte insight, taking pilotless vehicles has been shown to be acceptable when a flying vehicle is able to bring people to shops or to the beach, like a normal car would, moreover psychological barriers are too important when it comes to people thinking that many aerial vehicles fly above their heads with high frequency, at low altitude, making them afraid of crashes possibilities.	5
COMMERICIAL	B2C	COST	About a B2C market, like taxi services or delivery services, the cost may become less important when it comes to big companies offering these kinds of services.	4
		SECURITY&SAFETY	regulatory regimes should be a must before seeing an increase in aerial B2C fleets. As such regulatory boards should find a complex and systematic way for organizing aerial traffic control which is still not completed anywhere (NASA projects still have to be completed)	5
		ENVIRONMENT	environmental issues are of major concern for these services as shown by the recent sustainability directions undertook by many companies to increase their market shares	4
		SOCIAL ACCEPTANCE	flying transportation systems might be a great way to challenge the recent congested cities issues.	4
	B2C FOR SHARING	COST	the cost for flying vehicles should not be of great importance since it is amortized over time because of the business model	3
		SECURITY&SAFETY	safety issues are the major concern, as such, aerial traffic controls and regulations are a big issue which will be faced in the long run.	5
		ENVIRONMENT	environmental sustainability is of great importance for companies to raise their market share	4
		SOCIAL ACCEPTANCE	flying transportation sharing systems might be a great way to challenge big cities traffic issues.	4
PROFESSIONAL	FIREFIGHTING, POLICE AND MADICAL AID SERVICES	COST	cost acceptance would be higher once that the it should be the public sector to bear the costs; and considered the economic cycles repeating themselves through the years, because the coming years are those following the recession periods, normally governments tend to spend more to make a turnover of assets and follow positive economical parameters	3
		SECURITY&SAFETY	as higher speed would allow police officials to earlier services and better performances. A flying ambulance would be faster reaching the sick, police could faster make operations and firefighting would improve intervention times	5
		ENVIRONMENT	environmental issue may be overcome by electric power improvements for vehicles	3
		SOCIAL ACCEPTANCE	social acceptance would be at peak levels once the improved service with improved times to operate	5

Tab. 9. Relative comments and considerations with weights

Below, the comments drafted for all parameters and the related weights, given as results of the considerations made.

high manufacturing production costs for a normal company might be smoothed by the certainty of buyers wiling to pay for the product. The military sector can be considered as a major sector able to absorb the production capacity of manufacturing firms.	3
security issues are of great importance for the military sector: in case of wars, the possibility for cyber intrusion from the enemy can lead to dangerous situations. Safety issue is also a major concern.	5
the environmental issue should not be considered as of major concern seen that currently war areas suffer from noise pollution. Electric engines anyway should guarantee a reduction of noise pollution	2
War related vehicles and general technologies are usually kept secret by officials for security reasons. As such the lights on this particular aspect, like in general ethical aspects, are not considered to be of major interest for this particular market segment	2

Tab. 10. Comments and weights for military

The need for flying licenses and driving licenses may increase the price of getting licenses	5
What if landowners would like to prevent or impose their rights to safety and security? Will it be possible to set rules like the no fly zone in certain areas and times? Will any stakeholder like associations of people from a same area be able to have rules about no fly zones? Will those associations be able to impose their rights and at what cost? Will it be feasible to restrict take-off and landing areas? Will it be possible for those associations to decide the timings for taking passengers on and off? (https://www.everycrsreport.com/reports/IN10934.html).	5
environmental issues can be overcome seen the recent developments of electric power	5
for a Deloitte insight, taking pilotless vehices has been shown to be acceptable when a flying vehicle is able to bring people to shops or to the beach, like a normal car would, moreover psychological barriers are too important when it comes to people thinking that many aerial vehicles fly above their heads with high frequency, at low altitude, making them afraid of crashes possibilities.	5

Tab. 11. Comments and weights for private

About a B2C market, like taxi services or delivery services, the cost may become less important when it comes to big companies offering those kinds of services.	4
regulatory regimes should be a must before seeing an increase in aerial B2C floats. As such regulatory boards should find a complex and systematic way for organizing aerial traffic control which is still not completed anywhere (NASA projects still have to be completed)	5
environmental issues are of major concern for those services as shown by the recent sustainability directions undertook by many companies to increase their market shares	4
flying transportation systems might be a great way to challenge the recent congested cities issues.	4

Tab. 12. Comments and weights for commercial B2C

the cost for flying vehicles should not be of great importance since it is amortized over time because of the business model	3
safety issues are the major concern, as such, aerial traffic controls and regulations are a big issue which will be faced in the long run.	5
environmental sustainability is of great importance for companies to raise their market share	4
flying transportation sharing systems might be a great way to challenge big cities traffic issues.	4

Tab. 13. Comments and weights for commercial B2C for sharing

cost acceptance would be higher seen that the it should be the public sector to bear the costs; and considered the economic cycles repeating themselves through the years, because the coming years are those following the recession periods, normally governments tend to spend more to make a turnover of assets and follow positive economical parameters	3
an higher speed would allow police officials to earlier servicesand better performance. A flying ambulance would be faster reaching the sick, police could faster make operations and firefighting would improve intervenence times	5
environmental issue may be overcome by electric power improvements for vehicles	3
social acceptance would be at peak levels seen the improved service with improved times to operate	5

Tab. 14. Comments and weights for professional

Once given the weights for all parameters in each case studio, the trends for each line have been analyzed: this means that each for each parameter, manned and unmanned flying cars (human-piloted and self-piloted) show trends which can suffer from modifications while the technologies evolve and are better deployed as such both the technology clusters will present values ranging from 1 to 5 as results of the commented trends. The consequence of this kind of analysis is evaluating the final scores for both as the product of their trends and the weights before given for each parameter in each case studio.

Making simple summations for each of the 2 technologies analyzed, 2 numbers will come out. Surely one will be higher, less or equal to the other showing a relative winner for a certain market segment or industry.

As shown in the following table, the unmanned kind, unproperly identified as flying cars but better addressed to as passenger drones, emerges as the most likely to be used in every single segment.

This result should not surprise given the above stated considerations about actual deployments and the usage modes that have been thoughts for them by regulatory institutions and product makers.

Passenger drones seem better equipped for addressing sustainability issues and in particular, congested cities issues.

Much of these results should be due to how passenger drones are produced: apart from the relative reduced costs with respect to human-piloted cars because of redeployments of already existing autonomous driving technologies which are fast reaching scales, they seem better addressed to the optimal vectors before considered, especially thinking at their deployment areas (urbanized North America and crowded Asia-Pacific cities, struggling with pollution issues) and their architecture, indeed most human piloted flying cars should present large wings just in some cases retractable but anyway cumbersome.

Below the tables beforehand commented.

TREND FOR MANNED AND UNMANNED	M	U	M-score	U-score	WINNER
Although a possible employment of flying cars in this sector, it seems that the military sectors find drones a better fitting occasion in order to reduce soldiers on the grounds while at the same time keeping control of war areas like if currently on the ground, thanks to remote control technologies. The cost issue seems then to be better controlled in the case of drones than in the case of manned flying cars	2	5	6	15	UNMANNED
While for drones, safety and security standards can be always improved, for normal piloted flying cars the issues remain unsolved seen the compromise of having light cars able to fly and robust vehicles able to fight and be protected on the ground. Flying cars do not seem to be the best feet from security standards point of view for the military sector.	2	5	10	25	
electic power performances encourage environmental sustainability for both final technologies	4	4	8	8	
drones would be better approved seen the ultimate goal of reducing men on ground levels	4	4	8	8	
			32	56	
this problem might be slightly overcome by unmanned technologies. At the same time the cost for having a flying car is actually unfeasible on a large scale, like it is for unmanned aerial vehicles.	1	1	5	5	UNMANNED
safety levels would be especially enhanced by the eVTOL passenger drones technology which are considered more secure and easier for human control	3	4	15	20	
in any case better fitting the unmanned type seen that it is preferred for short distances	3	4	15	20	
An unmanned passenger drone is then seen as a better fitting way for the private use but considering the above considerations, it is improbable for both manned and unmanned vehicles to be ok for a successful market boom.	2	3	10	15	
			45	60	
It remains an issue anyway for both aerial types of vehicles. Unmanned aerial vehicles should be better fitting anyway a business model based on cost reductions	2	3	8	12	UNMANNED
drones should be advantaged seen the easier maintenance with respect to manned flying cars that still have problems regarding safety of the materials used and appropriate security systems	2	2	10	10	
both vehicles should not present environmental issues seen electric power advancements	4	4	16	16	
In this case, the unmanned aerial vehicles, because better fitting crowded cities environments, are better suited for becoming the new way of offering B2C services	3	4	12	16	
			46	54	
the cost should be addressed to drones	2	3	6	9	UNMANNED
for both vehicles environmental problems should not be of concern	2	3	10	15	
for both vehicles there should not be environmental issues not addressed by both technologies	4	4	16	16	
In this case, the unmanned aerial vehicles, because better fitting crowded cities environments, are better suited for becoming the new way of offering B2C services but license issuance problem remains something not allowing a soon explosion of the market	3	4	12	16	
			44	56	
drones are better aligned for the purpose of reducing transportation costs for professional services and for reducing the time to patients	1	3	3	9	UNMANNED
drone technologies would be better fitting speed needs	1	4	5	20	
environmental issues shoud not be of concern for none of the technologies	4	4	12	12	
both vehicles would see high social acceptance but drones would not see that high acceptance seen that the necessity for having professionals managing their services could be considered a must	5	4	25	20	
			45	61	

Tab. 15. Trends, scores and winners

this problem might be slightly overcome by unmanned technologies. At the same time the cost for having a flying car is actually unfeasible on a large scale, like it is for unmanned aerial vehicles.	1	1	5	5	UNMANNED
safety levels would be especially enhanced by the eVTOL passenger drones technology which are considered more secure and easier for human control	3	4	15	20	
in any case better fitting the unmanned type seen that it is preferred for short distances	3	4	15	20	
An unmanned passenger drone is then seen as a better fitting way for the private use but considering the above considerations, it is improbable for both manned and unmanned vehicles to be ok for a successful market boom.	2	3	10	15	
			45	60	

Tab. 16. Trends, scores and winner for military

It remains an issue anyway for both aerial types of vehicles. Unmanned aerial vehicles should be better fitting anyway a business model based on cost reductions	2	3	8	12	UNMANNED
drones should be advantaged seen the easier maintenance with respect to manned flying cars that still have problems regarding safety of the materials used and appropriate security systems	2	2	10	10	
both vehicles should not present environmental issues seen electric power advancements	4	4	16	16	
In this case, the unmanned aerial vehicles, because better fitting crowded cities environments, are better suited for becoming the new way of offering B2C services	3	4	12	16	
			46	54	

Tab. 17. Trends, scores and winner for private

the cost should be addressed to drones	2	3	6	9	UNMANNED
for both vehicles environmental problems should not be of concern	2	3	10	15	
for both vehicles there should not be environmental issues not addressed by both technologies	4	4	16	16	
In this case, the unmanned aerial vehicles, because better fitting crowded cities environments, are better suited for becoming the new way of offering B2C services but license issuance problem remains something not allowing a soon explosion of the market	3	4	12	16	
			44	56	

Tab. 18. Trends, scores and winner for commercial B2C

the cost should be addressed to drones	2	3	6	9	UNMANNED
for both vehicles environmental problems should not be of concern	2	3	10	15	
for both vehicles there should not be environmental issues not addressed by both technologies	4	4	16	16	
In this case, the unmanned aerial vehicles, because better fitting crowded cities environments, are better suited for becoming the new way of offering B2C services but license issuance problem remains something not allowing a soon explosion of the market	3	4	12	16	
			44	**56**	

Tab. 19. Trends, scores and winner for commercial B2C for sharing

drones are better aligned for the purpose of reducing transportation costs for professional services and for reducing the time to patients	1	3	3	9	UNMANNED
drone technologies would be better fitting speed needs	1	4	5	20	
environmental issues shoud not be of concern for none of the technologies	4	4	12	12	
both vehicles would see high social acceptance but drones would not see that high acceptance seen that the necessity for having professionals managing their services could be considered a must	5	4	25	20	
			45	**61**	

Tab. 20. Trends, scores and winner for commercial professional

Further analyses should be made with regards to market dimensions.

Availability of data regarding dimensions have been difficult to find because of small data sets comprehensively showing all possible markets involved in possible technology deployments.

It was anyway possible to draft data about markets of interests in the U; it can be considered a good approach for defining quantitatively dimensions able to give some ideas about what the future could be like.

Normal transportation systems for each sector of interest can be given approximate numbers not so far from reality; it has emerged that in the military sector for the US, all trucks, airplanes, drones, cars employed used during one year in war conditions like it has been in the recent years amount to approximately 0.73 billion USD.

With regards to military deployments, another kind of analysis has been conducted because different sources show that research and development money spent related to finding new sustainable ways for conducting wars and general defense inside the country are considerably higher with respect to commercial and institutional funds and investments. As such it should be worth of note that 57.69 billion USD are yearly spent for new findings, of which a high percentage is mainly related to transportation issues (almost 20 billion USD, which means about 33% of the expenditure). This high number related to future developments should be considered as an important factor potentially able to give a boost for deployments of flying cars in the military environments.

Same kind of analysis has been conducted for the private sector in US. Acquiring cars for private use in US amounts to almost 65 billion USD.

For commerce B2C, meaning assets bought by taxi service companies and similar or buses bought by travel companies, in US the market amounts to almost 19 billion USD.

For B2C for sharing, meaning all cars and scooters rented by share companies (mainly situated in big cities and metropolitan areas), the US market amounts to 49 billion USD.

For professional use, mainly related to state owned assets or anyway state regulated companies in charge of medical, police and firefighting services, data seem just a small fraction of public expenditure and in general seem to insignificant with respect to the other industries and market segments.

Below the data founded:

SECTOR	MARKET VALUE
US military	0,73
Private	64,43
Commerce B2C	18,17
Commerce B2C sharing	49
Professional	Irr

1. Irr: irilevant
2. R&D US military: 57.69
3. Transport R&D military: 19.23

Tab. 21. Data about market dimensions in US

3.1.2 Results of the analysis

As a first impact, the private sector is the one that actually dominates the insight. It is followed by distance by commerce B2C and commerce B2C for sharing while military and professional, state-oriented, seem to be far away from a large deployment of the new technologies.

Numerical data in the table anyway do not consider which is the expenditure made per capita: they are just sizing industries and markets not considering how much is spent per person, then missing a fundamental aspect which is the one about market saturation, even if a niche market.

Previous data instead were suggesting that a well-defined set of basic technologies and/or architectural components can be defined. It concerns the capacity they could deploy which is mainly going towards a common standard which should be the 2-seaters capacity; it concerns the distance range that can be covered, and air space allowed where to fly.

The aerial space allowed and, better say, preferred by the markets, should be the near ground space that is mainly related to really crowded urban contexts, while the ranges covered should be those normally reached by passenger cars and human-piloted cars, short and medium hauls.

Geographical areas mainly interested in those two new technologies are North America and Asia-Pacific as it should had been easy to foresee. Developed countries and industrialized ones (US, Germany, South Korea and China) should be the ones in charge of building and developing innovations since they would be the main interested groups for a large deployment of flying cars.

It should result that passenger drones would be mostly used for commercial use even more than for normal day to day commutation.

CONCLUSIONS

Conclusions about the analyses made can be drafted.

As already stated beforehand, this thesis work suffers from lack of big amounts of data, while it is built upon data found through personal research on companies' websites and related released press conferences; furthermore, it is commented also based on outsiders' insights.

The lack of data has brought the work onto qualitative judgments in many situations that have even been the base on which numbers have been drafted. The scope of this thesis work should not be anyway giving any kind of strategic advice concerning flying cars, while it should represent just a way to seizing and modelling possible future developments for most promising technologies, building upon widely used methods for other manufacturing related like the quality function deployments.

Regarding data and comments made beforehand, skepticism towards a large deployment of flying cars to solve sustainability issues of modern cities should be raised. Both manned and unmanned cars present several issues that are not actually finding any solution (like the fear of seeing flying vehicles all days long flying above heads and possible privacy violations), if not including other areas of analysis (like it could be the case for psychological, legal and social sciences). Positive communication towards flying cars would also be a major impacting factor to make a large deploy of them.

Based on the tables analyses, it should be foreseen that some passenger cars would be adopted as an alternative way for all the commercial-related world.

Not any further positive comments could be made towards flying cars seen that pros and cons most always balance each other not giving real numerical insights in favor of a commonly agreed technology cluster to be successfully deployed.

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