The future of electric passenger drones

A roadmap towards the Community Integration of Urban Air Mobility

M. Kool

M. (Marcel) Kool

Master thesis – final report

MSc Construction Management and Engineering
Faculty of Civil Engineering and Geoscience
Delft University of Technology
Stevinweg 1, 2628 CN Delft
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Author
M. (Marcel) Kool

Student number: 4303776

Graduation committee

Chairman
Prof. ir. R.J. (Rients) Dijkstra,

1st supervisor
Dr. E.J. (Erik-Jan) Houwing

2nd supervisor
Dr. M. (Martijn) Leijten

Company supervisor
Drs. ing. M.P. (Mark) van Kerkhof

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Delft University of Technology

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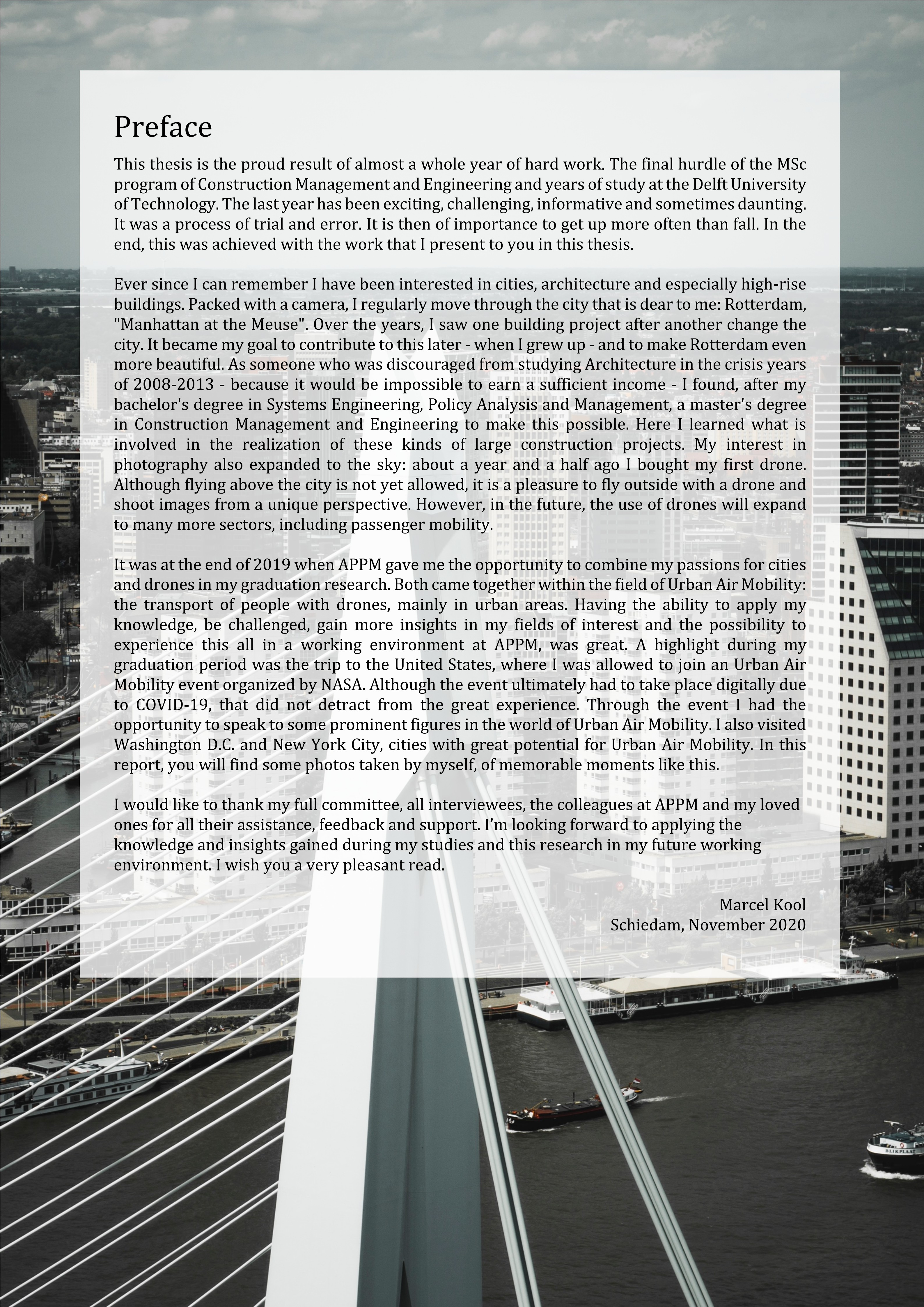


Preface

This thesis is the proud result of almost a whole year of hard work. The final hurdle of the MSc program of Construction Management and Engineering and years of study at the Delft University of Technology. The last year has been exciting, challenging, informative and sometimes daunting. It was a process of trial and error. It is then of importance to get up more often than fall. In the end, this was achieved with the work that I present to you in this thesis.

Ever since I can remember I have been interested in cities, architecture and especially high-rise buildings. Packed with a camera, I regularly move through the city that is dear to me: Rotterdam, "Manhattan at the Meuse". Over the years, I saw one building project after another change the city. It became my goal to contribute to this later - when I grew up - and to make Rotterdam even more beautiful. As someone who was discouraged from studying Architecture in the crisis years of 2008-2013 - because it would be impossible to earn a sufficient income - I found, after my bachelor's degree in Systems Engineering, Policy Analysis and Management, a master's degree in Construction Management and Engineering to make this possible. Here I learned what is involved in the realization of these kinds of large construction projects. My interest in photography also expanded to the sky: about a year and a half ago I bought my first drone. Although flying above the city is not yet allowed, it is a pleasure to fly outside with a drone and shoot images from a unique perspective. However, in the future, the use of drones will expand to many more sectors, including passenger mobility.

It was at the end of 2019 when APPM gave me the opportunity to combine my passions for cities and drones in my graduation research. Both came together within the field of Urban Air Mobility: the transport of people with drones, mainly in urban areas. Having the ability to apply my knowledge, be challenged, gain more insights in my fields of interest and the possibility to experience this all in a working environment at APPM, was great. A highlight during my graduation period was the trip to the United States, where I was allowed to join an Urban Air Mobility event organized by NASA. Although the event ultimately had to take place digitally due to COVID-19, that did not detract from the great experience. Through the event I had the opportunity to speak to some prominent figures in the world of Urban Air Mobility. I also visited Washington D.C. and New York City, cities with great potential for Urban Air Mobility. In this report, you will find some photos taken by myself, of memorable moments like this.

I would like to thank my full committee, all interviewees, the colleagues at APPM and my loved ones for all their assistance, feedback and support. I'm looking forward to applying the knowledge and insights gained during my studies and this research in my future working environment. I wish you a very pleasant read.

Marcel Kool
Schiedam, November 2020

Executive summary

Context of the research

Worldwide, more and more actors have started to speak out their belief in a future with three-dimensional mobility as one of the solutions for congesting and polluted cities. Electric Vertical Take-Off and Landing vehicles – more popularly referred to as drones – are supposed to relieve the current infrastructure network, mainly roads, and quickly transport cargo and people through the sky to their desired location. This new mode of transportation is also called Urban Air Mobility (UAM). To make UAM a reality, three main components are required: the aircraft and aircrew, the management of the airspace and the integration in the community. Over the last years, the industry has made major steps in the first two aspects. However, the community integration of UAM – which is about infrastructure, social acceptance and regulations, among others – has fallen behind, as cities are barely preparing themselves for this new transportation mode. Still, UAM may become a reality much earlier than those cities may expect. When that happens, cities will have to be prepared for this. It is therefore important to explore what it means and takes when UAM is integrated into a community.

Research question

It is the latter which forms the fundament for this research. Where the literature extensively discusses the aircraft and airspace integration, a knowledge gap can be identified on the community integration of UAM. For this reason, the goal for the research was to analyze the required changes in the urban mobility regime, which challenges this will cause and what actions communities can take in preparation for UAM. The goal was also to illustrate the conditions under which UAM can add value to the existing mobility mix of a city.

To contribute to the understanding of the subject and analyze the practical elaboration of UAM Community Integration, the following research question was used for this research:

How can the transition of Urban Air Mobility be realised in communities?

Research approach

To answer the research question, a qualitative approach was chosen, recommended to be used when the investigated phenomenon is new and when the investigator seeks to answer "why" and "how" questions. A combination of different qualitative data gathering methods was adopted: literature reviews and semi-structured interviews. With an extensive literature study data was collected to uncover the dynamics that are at play when considering a transition and what concepts are important to consider in that context. Literature on transitions theory in general and on the MLP framework in particular formed the most substantial and scientific part of the literature. These concepts were placed in the context of the 'Mobility of the Future' and linked to the subject of interest which is the transition of Urban Air Mobility. This was done by analysing literature on these topics, which was complemented by other informative documents. Eventually, these concepts were translated into a main question and sub questions which guide the research.

In order to answer the research questions, in addition to literature, the knowledge of experts and insights from governments was consulted through interviews. Based on the insights on what a future situation, in which UAM is part of the mobility system, will look like, a final picture was retrieved. The basis for these interviews, which are conducted orally, is a semi-structured questionnaire, which made sure that all relevant information would be discussed, while at the

same time providing room for the interviewee to bring up other information. These interviews were complemented with other informative and policy documents, in order to ensure triangulation. The acquired data was analyzed by transcribing the interviews and carrying out a content analysis in order to create a structured narrative in which the results are presented.

Research findings

This research found that UAM will most likely be an addition to the existing mobility regime, instead of becoming the new dominant regime. It can be a sustainable means of transport, but the market is expected to be so small that it is unlikely to be the ultimate solution on the way to a more sustainable urban mobility system. UAM will most likely have a niche role in sustainable mobility and become one of the subaltern mobility regimes, in terms of market share still below regimes like public and active transport. UAM will be a suitable mode of transportation in specific places, for specific people and under specific circumstances. This mostly entails larger and denser urban areas, with a high GDP. The main target group, at least at the start and in the near-term, consists of high-income people. Furthermore, UAM will mainly flourish on longer distances, under circumstances in which much travel time can be saved by bypassing congested or lacking ground connections. Although vertical mobility still holds the promise to relieve some pressure from particularly congested urban hot spots, this will only be some. This means that UAM will, generally spoken, not be the ultimate solution for sustainable urban mobility, which specifically means that it will not solve the congestion problem and will not have a major effect on reducing pollutant emissions. However, this does not mean that UAM will in no case be of added value. It is important to note that it can become a crucial part of an integrated solution to mitigate our growing transportation woes, by improving the connectivity and accessibility of urban areas that adopt this new mobility mode, among others.

This thesis shows that there is a lot involved in the transition from two-dimensional to three-dimensional urban transport, or Urban Air Mobility. Although the emphasis of this research is on the regime level of the MLP, there are also developments at the landscape and niche level that are worth consideration. The transition is driven by large-scale developments such as urbanization, mobility growth and climate change, putting pressure on the mobility regime. Besides, there are technological innovations in development, such as battery and communication technologies and automation, which the development of UAM as a new mode of transportation will depend on. In addition, there are internal frictions in the existing mobility system, such as congestion, which require new, sustainable mobility solutions.

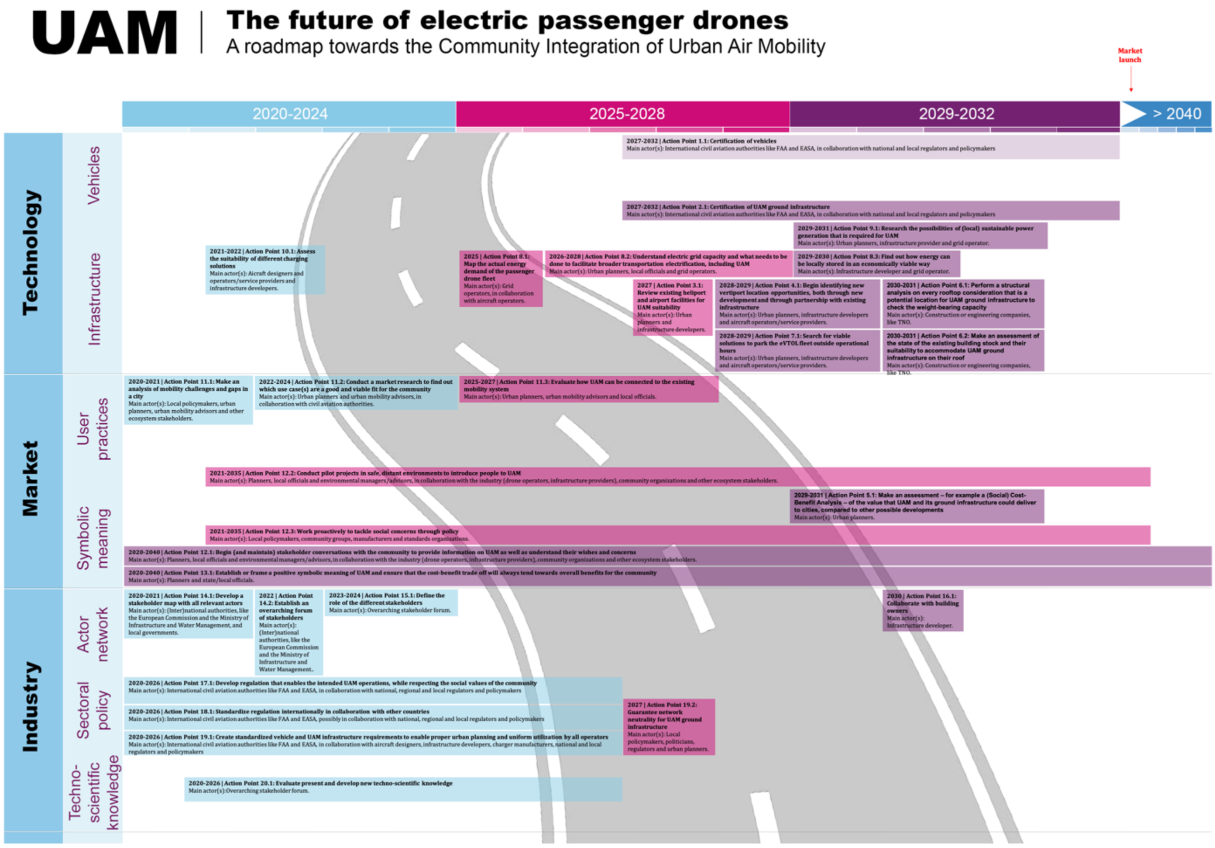
The comparison between the existing and future mobility regime – the latter including UAM – makes clear that the community integration of UAM requires changes in every single dimension in the mobility regime. This is accompanied by various challenges and requires actions from cities. Major challenges are mainly found within the dimensions of sectoral policy, infrastructure and culture or symbolic meaning. The most important actions that cities can take therefore also address these challenges. For example, there are currently a patchwork of rules that restrict or prohibit the use of drones and thus make UAM virtually impossible. This requires standardization of rules, which above all allow the use of drones, while respecting the social impact that drones can have. Furthermore, there is usually a lack of existing infrastructure, which means that new infrastructure must be developed. However, the limited space, suitability of existing buildings, financial feasibility and social value of UAM are some important factors that make infrastructure development within urban centers a challenging task. Cities will have to identify suitable locations for vertiports, taking these types of factors into account. Existing energy capacity can also be an obstacle. Whereas typical passenger vehicle DC fast charging typically ranges from 50kW-350kW, UAM requires charging capacities of up to 600 kW. To provide this, cities may have to make adjustments to their existing energy network. Finally, in terms of noise, horizon pollution, privacy, safety and price, UAM has a significant social impact. The risk of social resistance is therefore high. It is important that cities anticipate this by, among other things, informing and educating the community about UAM, carrying out pilot projects and drawing up social guidelines. Other actions that cities can take to prepare for UAM include the exploration of potential user practices and the definition and division of stakeholder roles, among others.

Conclusion

The realization of UAM in communities is only in its infancy and involves an extensive process of (interdependent) developments and actions. Once the variety of niche-innovations have developed into a more mature state – which can still take several years –, UAM will be able to start its breakthrough into the urban mobility regime. This transition requires changes in all regime dimensions. The integration in the community will have impact in different ways, of which it is assumed that the spatial, energy and social domains will be impacted most. Challenges rise, mainly with regard to the sectoral policy, infrastructure and culture or symbolic meaning within the mobility regime. In order to realise the transition of UAM in communities, these must be addressed. This thesis proposed some of the more important actions that communities can take for the community integration of UAM. These are outlined in the final roadmap on the next page, which should give the final answer on how the transition of UAM can be realized in communities.

Recommendations

This research recommends cities to take up the identified actions for UAM community integration. They provide an insight into what needs to be done to enable the community integration of UAM. This research has taken a first, exploratory step in the right direction, but the identified actions - logically - have no outcome yet. Further research into these actions is therefore required. Cities are therefore recommended to continue with this, so that they can find an answer to the implicit research questions that lie hidden in these actions.



2027-2032 | Action Point 1.1: Certification of vehicles
Main actor(s): International civil aviation authorities like FAA and EASA, in collaboration with national and local regulators and policymakers

2027-2032 | Action Point 2.1: Certification of UAM ground infrastructure
Main actor(s): International civil aviation authorities like FAA and EASA, in collaboration with national and local regulators and policymakers

2029-2031 | Action Point 9.1: Research the possibilities of (local) sustainable power generation that is required for UAM
Main actor(s): Urban planners, infrastructure provider and grid operator.

2021-2022 | Action Point 10.1: Assess the suitability of different charging solutions
Main actor(s): Aicraft designers and operators/service providers and infrastructure developers.

2025 | Action Point 8.1: Map the actual energy demand of the passenger drone fleet
Main actor(s): Grid operators, in collaboration with aircraft operators.

2026-2028 | Action Point 8.2: Understand electric grid capacity and what needs to be done to facilitate broader transportation electrification, including UAM
Main actor(s): Urban planners, local officials and grid operators.

2029-2030 | Action Point 8.3: Find out how energy can be locally stored in an economically viable way
Main actor(s): Infrastructure developer and grid operator.

2027 | Action Point 3.1: Review existing heliport and airport facilities for UAM suitability
Main actor(s): Urban planners and infrastructure developers.

2028-2029 | Action Point 4.1: Begin identifying new vertiport location opportunities, both through new development and through partnership with existing infrastructure
Main actor(s): Urban planners, infrastructure developers and aircraft operators/service providers.

2030-2031 | Action Point 6.1: Perform a structural analysis on every rooftop consideration that is a potential location for UAM ground infrastructure to check the weight-bearing capacity
Main actor(s): Construction or engineering companies, like TNO.

2028-2029 | Action Point 7.1: Search for viable solutions to park the eVTOL fleet outside operational hours
Main actor(s): Urban planners, infrastructure developers and aircraft operators/service providers.

2030-2031 | Action Point 6.2: Make an assessment of the state of the existing building stock and their suitability to accommodate UAM ground infrastructure on their roof
Main actor(s): Construction or engineering companies, like TNO.

2020-2021 | Action Point 11.1: Make an analysis of mobility challenges and gaps in a city
Main actor(s): Local policymakers, urban planners, urban mobility advisors and other ecosystem stakeholders.

2022-2024 | Action Point 11.2: Conduct a market research to find out which use case(s) are a good and viable fit for the community
Main actor(s): Urban planners and urban mobility advisors, in collaboration with civil aviation authorities.

2025-2027 | Action Point 11.3: Evaluate how UAM can be connected to the existing mobility system
Main actor(s): Urban planners, urban mobility advisors and local officials.

2021-2035 | Action Point 12.2: Conduct pilot projects in safe, distant environments to introduce people to UAM
Main actor(s): Planners, local officials and environmental managers/advisors, in collaboration with the industry (drone operators, infrastructure providers), community organizations and other ecosystem stakeholders.

2029-2031 | Action Point 5.1: Make an assessment – for example a (Social) Cost-Benefit Analysis – of the value that UAM and its ground infrastructure could deliver to cities, compared to other possible developments
Main actor(s): Urban planners.

2021-2035 | Action Point 12.3: Work proactively to tackle social concerns through policy
Main actor(s): Local policymakers, community groups, manufacturers and standards organizations.

2020-2040 | Action Point 12.1: Begin (and maintain) stakeholder conversations with the community to provide information on UAM as well as understand their wishes and concerns
Main actor(s): Planners, local officials and environmental managers/advisors, in collaboration with the industry (drone operators, infrastructure providers), community organizations and other ecosystem stakeholders.

2020-2040 | Action Point 13.1: Establish or frame a positive symbolic meaning of UAM and ensure that the cost-benefit trade off will always tend towards overall benefits for the community
Main actor(s): Planners and state/local officials.

2020-2021 | Action Point 14.1: Develop a stakeholder map with all relevant actors
Main actor(s): (Inter)national authorities, like the European Commission and the Ministry of Infrastructure and Water Management, and local governments.

2022 | Action Point 14.2: Establish an overarching forum of stakeholders
Main actor(s): (Inter)national authorities, like the European Commission and the Ministry of Infrastructure and Water Management..

2023-2024 | Action Point 15.1: Define the role of the different stakeholders
Main actor(s): Overarching stakeholder forum.

2030 | Action Point 16.1: Collaborate with building owners
Main actor(s): Infrastructure developer.

2020-2026 | Action Point 17.1: Develop regulation that enables the intended UAM operations, while respecting the social values of the community
Main actor(s): International civil aviation authorities like FAA and EASA, in collaboration with national, regional and local regulators and policymakers

2020-2026 | Action Point 18.1: Standardize regulation internationally in collaboration with other countries
Main actor(s): International civil aviation authorities like FAA and EASA, possibly in collaboration with national, regional and local regulators and policymakers

2020-2026 | Action Point 19.1: Create standardized vehicle and UAM infrastructure requirements to enable proper urban planning and uniform utilization by all operators
Main actor(s): International civil aviation authorities like FAA and EASA, in collaboration with aircraft designers, infrastructure developers, charger manufacturers, national and local regulators and policymakers

2027 | Action Point 19.2: Guarantee network neutrality for UAM ground infrastructure
Main actor(s): Local policymakers, politicians, regulators and urban planners.

2020-2026 | Action Point 20.1: Evaluate present and develop new techno-scientific knowledge
Main actor(s):Overarching stakeholder forum.

Keywords: Urban Air Mobility, community integration, mobility, transitions theory, integral design management

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List of abbreviations

Abbreviation	Description
ATM	Air Traffic Management
Drone	Generic, popular term for UAS or (e)VTOL
EASA	European Aviation Safety Agency
(e)VTOL	(electric) Vertical Take-Off and Landing
FAA	Federal Aviation Authority
FATO	Final Approach and Takeoff Area
NASA	National Aeronautics and Space Administration
PKT	Passenger-kilometers traveled
UAM	Urban Air Mobility
UAS	Unmanned Aircraft System
UTM	Unmanned Aircraft System Traffic Management
VKT	Vehicle-kilometers traveled

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RESEARCH DESIGN

Part I – Research Design

The following sections will elaborate on the context and problem statement of this research. The chapter starts off with a general introduction about urban challenges and Urban Air Mobility (UAM), followed by an insight on the problem this industry is currently facing. To get a better understanding of the problems and required actions a research was set up. The goal and research question for this research can be found in the paragraphs 1.2 and 1.3. The relevance of the research is given in 1.4. Paragraph 1.5 provides a reading guide for the report. Based on these definitions the research design was developed which can be found in chapter 2.

1. Introduction

At this very moment in time, the world is undergoing enormous changes on various fronts. The lives that we, as human beings, have used to live since at least the Industrial Revolution need to change in order to limit the damage caused to our planet. At the same time, the number of people living on Earth is still increasing and 60% of the world's population is expected to live in urban areas by 2030 (Airbus, n.d. b) and 68% by 2050 (United Nations, 2018). This significant population growth is expected to create a real need for all kinds of innovation. One of the major revolutions we are in the midst has to do with our transport. Our ground infrastructure becomes increasingly congested and this asks for expansion. However, the ground infrastructure might approach its limits in the near future and therefore innovative mobility options must be considered. Our transport is becoming cleaner, shared, intelligent, autonomous, connected, etcetera. A part of this is the emergence of electric Unmanned Aerial Vehicles, or more commonly and specifically known as drones. Thousands of companies worldwide are looking at the application of drones, including urban mobility, both for the transportation of goods and people on demand. This is also called Urban Air Mobility (APPM, 2019).

Urban Air Mobility (UAM) is often seen as the holy grail for our mobility systems. It would have the potential to contribute positively to a multimodal mobility system and help build more liveable cities. It leverages the sky and is powered by electricity, which has many benefits. For example, it would help to solve the congestion problems in cities. By 2030, the macroeconomic costs of congestion in the US and Europe are estimated at 300 billion dollars per year. Urban Air Mobility could relieve crowded roads in the cities and facilitate faster transport of both people and goods. In this way, a better link within and between cities and regions can be realised. Also, the transport system becomes more sustainable, when drones are making use of clean energy sources. And so, Urban Air Mobility has the potential to reduce travel time of people and goods and contribute to sustainable city development (Airbus, n.d. a).

However, as with many technologies, UAM will have to be integrated in the community to fulfil its function. While the technology is quickly developing, cities are getting behind and often lack the knowledge about what the community integration of UAM entails (Powell, 2020; Alexander, 2020). Therefore, a plan is needed, containing the necessary actions that cities should consider when they decide to choose to make UAM a part of their urban mobility system. To date, little is known about this, and as far as to the author’s knowledge little research has been done into this topic.

In order to come to a solution for this problem, it is therefore desired to explore which steps these are in order to make urban areas suitable for the integration of UAM. In this way, successful integration of UAM will become more likely, bringing us closer to the realisation of more liveable, more thriving and better-connected cities.

1.1 The Problem

Worldwide, more and more actors have started to speak out their belief in a future with three-dimensional mobility as one of the solutions for congesting and polluted cities. Electric Vertical Take-Off and Landing vehicles are supposed to relieve the current infrastructure network, mainly roads, take cargo and passengers into the sky and (autonomously) transport them through the sky to their desired location. A variety of components is required to execute such operations, because the cities of today lack the framework to accommodate UAM. This will go along with several interferences and challenges in the city. A transition like this must be managed to guide it into the desired direction. Although vehicle manufacturers are quickly progressing in creating a 'ready-to-use' eVTOL vehicle and the airspace is made ready for UAM, the third major brick of the Urban Air Mobility ecosystem, the Community Integration (NASA, 2020), is getting behind, since preliminary research at the Amsterdam Drone Week showed that (local) governments have not been very active on this topic yet. There is very little evidence that (local) governments have already thoroughly thought about the transition, and what it takes to integrate it in cities. For example, the topics 'Urban Air Mobility' and 'drones' are barely part of Dutch municipal policy plans, like the ones from Rotterdam, Amsterdam, Utrecht and The Hague. Only Amsterdam seems to be working on it, but also in the capital city there is still little knowledge about the integration of Air Mobility in the city. This rises the interesting question about what will happen when UAM is integrated in a city, which barriers can rise which actions should be considered.

Based on the described problem, the following problem statement was developed:

Problem statement
Cities of today and cities of the future are facing a variety of challenges, some of which are related to ongoing urbanisation and mobility growth. In order to deal with these challenges, transitions in different fields will be required. One of these is the mobility transition. This transition encompasses a multitude of key factors that can contribute in some way to solving the mobility problems, which will be elaborated on later in this thesis. One of the factors that has gained attention in the search for possible solutions is Urban Air Mobility. The problem with UAM is a lack of available knowledge about what it adds to cities and what it takes from cities to integrate UAM. In other words: knowledge is missing about how and when UAM adds value to a city, which barriers are faced, and which actions can be taken by a city to prepare for UAM Community Integration. Existing studies have not yet addressed these aspects in this field.

1.2 Research objective

The research objective is the goal of the research. It concerns the contribution the researcher wishes to make to solve a problem outside the research itself. That is why the research objective is also called the external aim of the research, the goal of the project. The research objective, in other words, concerns the *use* of the knowledge the research produces, *not* the knowledge itself. Also, it helps to determine the scope of research, because one research is not sufficient to draw extensive conclusions about the chosen project context (Verschuren and Doorewaard, 2010).

As was found out, there is a lack of knowledge about the community integration of UAM. In general, it lacks a framework to do so. With the fast-evolving technology of this time, such a framework might turn out handy in the near future, since the first UAM operations in major cities are already expected around the middle of the 2020's (Porsche Consulting, 2018). Therefore, the objective of this research is to develop a roadmap for the community integration of Urban Air Mobility on the basis of the necessary regime changes that are needed for a mature UAM market, which could be in place around 2050. These are based on a literature review and expert interviews. Based on the gap between the current and future situation, community integration barriers are identified, on the basis of which actions points will be recommended. The research will initially take a holistic approach and later on narrow down on the aspects that turn out to be the more important ones in the community integration of UAM. The research would then allow to identify the required actions to make integration of Urban Air Mobility in the community possible and provide governments insight in the barriers and recommendations to do so. The resulting roadmap can then be used as a guiding tool in order to make the Community Integration a bit smoother, for each city that wants to adopt this new form of mobility in the future.

In short, the main research objective is:

Develop a roadmap for the community integration of Urban Air Mobility and identify the barriers and possible (policy) actions in guiding this transition.

Besides, the subgoal of the research is to:

Assess under which conditions UAM can add value to the existing mobility mix of a city

This goal is included, because UAM will likely be of value in (very) specific cases. It is useful to find out globally under what conditions this is the case.

1.3 Research question

On the basis of the problem statement and the project goal of this research, a research question was composed. This research question will be supported by a set of sub-questions. The following question was formulated:

Main research question:
How can the transition of Urban Air Mobility be realised in communities?

Sub-questions:

1. *How does UAM contribute to the realization of more sustainable urban mobility?*
2. *How does UAM interfere in the current city?*
3. *What challenges or barriers can be identified that must be overcome for UAM to reach the urban mobility regime level?*
4. *Which actions can communities take to prepare themselves for UAM?*

The first sub-question is asked to give notion to the added value of UAM. More specifically, the aim of this question is to identify if, how and when UAM adds value to a city. The second sub-question is asked to identify what kind of impact UAM will have in a city. The third sub-question is related to this and is asked which barriers one may come across on the road to a mature UAM network, when the integration process or project of UAM is going on in a city. Sub-question four is asked to identify the stepwise procedure, strategy or implementation plan that can or must be run through to realise a mature UAM network.

1.4 Research justification

1.4.1 Scientific relevance

This research will provide more insight into the transition from a two-dimensional to a three-dimensional urban mobility system. It will clarify how UAM can be integrated in a city step-by-step by creating a possible pathway or roadmap for this transition. As will be elaborated on in chapter 4 of this thesis, UAM is a complex subject which will redefine certain boundaries. It may radically change the cities as we know them today. It is interesting to find out how this transition can take place and which barriers will be faced on this path, but also which changes in a city are needed or caused. At this moment, there is a knowledge gap in this field: we do not know exactly how we can manage this transition and what the impact on cities will be, while studies of the 'City of the Future' do not yet consider UAM. By diving into this substance, the research aims to contribute to science by creating a possible pathway for this transition and providing a set of recommendations regarding the necessary steps to enhance the community integration of UAM.

1.4.2 Societal and practical relevance

As was stated before, UAM will have a certain impact on communities and face a variety of barriers, while there is a long way to go to integrate this new form of mobility in cities as well. For communities, and municipalities in particular, it is important to have knowledge about what awaits them in the upcoming years and what needs to be done to integrate UAM in a city. At the moment this is not the case and municipalities barely take UAM into account in their policy.

Furthermore, this research is conducted for APPM Management Consultants. As is described on their website, 'the more than 100 employees of APPM work with passion, courage and vision on planning, developing and restructuring urban and rural areas'. The company manages and organizes complex projects, which focus on better accessibility, infrastructure and mobility. Their goal is a future for the Netherlands that is climate-proof, abundant in water and sustainable. The employees of APPM are involved in a broad range of multidisciplinary projects, categorized into five different areas of activity, namely (1) Mobility, (2) Area development, (3) Water, (4) Energy and (5) Infrastructure. The topic of UAM is more or less related to four of the five areas, except water. APPM wants to dive into the world of drones and specifically UAM. As an important player in the field of advice on electric transport, charging infrastructure and urban area development and mobility, this subject has their special interest - and certainly also the way municipalities deal with this and what they can do to be ready for this revolution. This research can help APPM in finding the necessary steps to integrate UAM in the Netherlands. This knowledge can be used well in helping municipalities with this transition.

1.5 Reading guide

In the next chapter, the research strategy and methods that will be used in the Master Thesis are discussed. Thereafter, in chapter 3, theories and concepts will be introduced that were acquired while conducting the literature study prior to this research. The chapter has been divided into multiple sections, discussing sustainability transitions and MLP framework that has been used to understand and explain the dynamics that are at play in the transition of UAM.

In chapter 4, the issues of the existing mobility system are discussed first. Subsequently, it is elaborated on the variety of options that cities can apply towards a more sustainable urban mobility system. After the shortcomings of these strategies are discussed, UAM is introduced as a potential addition to the mobility regime. The chapter provides a definition of UAM and discusses the advantages and disadvantages and the market potential.

This chapter will be followed by chapter 5, which will elaborate on the methodology that has been used. The general research design will be described, as well as the data approach that has been used in collecting and analyzing data.

The body of this thesis is introduced by chapter 6 and 7. In chapter 6, it is described which pressures are at play on the current mobility regime, from above and below, in relation to the transition of UAM. Besides, a comparison is made between the current and future regime, resulting in de required regime changes for the transition of UAM. In chapter 7, the challenges that rise from these changes are elaborated, partially based on a case study: a square kilometer in the heart of Rotterdam. Based on these challenges, actions are recommended. These can be applied by cities to prepare themselves for the community integration of UAM.

In chapter 8, the research is concluded by answering the research questions that have been posed at the start of this thesis. The second part of this chapter is dedicated to reflection, discussing the strengths and limitations of the research. The chapter will be concluded with suggestions for future research.

2. Research strategy

A clear knowledge of the research method gives a working framework for the thesis. Thus, after understanding the problem domain, the research strategy and methods that will be used in the Master Thesis are discussed in this chapter. The chosen strategy is explained of their relevance regarding this study.

2.1 Methodology

To fulfil the research objective and answer the research question, an approach is needed to develop a strategy to reach the conclusion (Verschuren et. al, 2010). The research method that is followed is a qualitative research, recommended to be used when the investigated phenomenon is new and when the investigator seeks to answer "why" and "how" questions (Yin, 2014). This section consists of the methodology to be followed for this research.

2.1.1 Exploratory research

Literature study

The research consists of multiple parts. First, a literature study of previous research was done in three main areas. The first concerns the theory of transitions. Given that the mobility domain will or must undergo a transition to more sustainable mobility in the coming years, with possible room for UAM, it is important to know how transitions work. This theory helps to understand all kinds of issues that come with UAM's Community Integration, including the changing systems, barriers and, as a result, what actions can be taken upon them. The second area is the 'City of the Future', which includes studies of what future cities may look like. The emphasis for this thesis is on the 'Mobility of the Future', because UAM is mainly related to this domain. The main focus was on how cities (can) fill in their mobility mix, what options they have for a transition to a more sustainable mobility system and what still falls short. Subsequently, the link was made with the value that UAM can add, the third research area. The literature study on this has contributed to both defining the concept and to the synthesis in this report.

Initial interviews

After finding relevant information regarding these concepts, study towards the required steps to integrate UAM in cities was executed. The empirical study started with talks with a diversity of stakeholders at the Amsterdam Drone Week. Here, an initial idea could be obtained about UAM and its current state, from which the lack of knowledge about Community Integration was confirmed.

2.1.2 Empirical data collection

Detailed interviews

Thereafter, it was determined what it takes to integrate UAM in communities. Semi-structured, detailed interviews were executed with a variety of experts from the industry and with representatives of cities that have started an UAM initiative, some of which are part of the European UAM initiative launched by the European Commission. A list of participants can be found in Appendix C. The general feeling among the interviewees was that they did not focus blindly on UAM as the 'holy grail', but also put firm, critical notes on the concept. This gave sufficient confidence that a correct picture of UAM was being obtained. With these interviews, information could be acquired which helped to answer the research questions.

Roadmap preparation

With the collected data a good picture could be obtained of the Community Integration of UAM, in terms of the required (system) changes, possible challenges and required actions. Based on this, a strategy could be set up consisting of these steps, which resulted in the final roadmap. This roadmap consists of a stepwise procedure, that cities can use for successful integration of UAM in communities.

Conclusion

The result is an answer on the question how Urban Air Mobility can be successfully integrated in communities of today, consisting of recommended actions for further steps to take towards Community Integration of UAM.

All of this can be illustrated in a research framework (fig. 1). In short: the exploratory research provided the theoretical framework. The empirical data collection provided insight in the current situation, the desired situation, the gap between both and the challenges that the desired situation will have within the context of the community. The analysis and conclusion should then lead to a proper stepwise procedure of integrating UAM in communities.

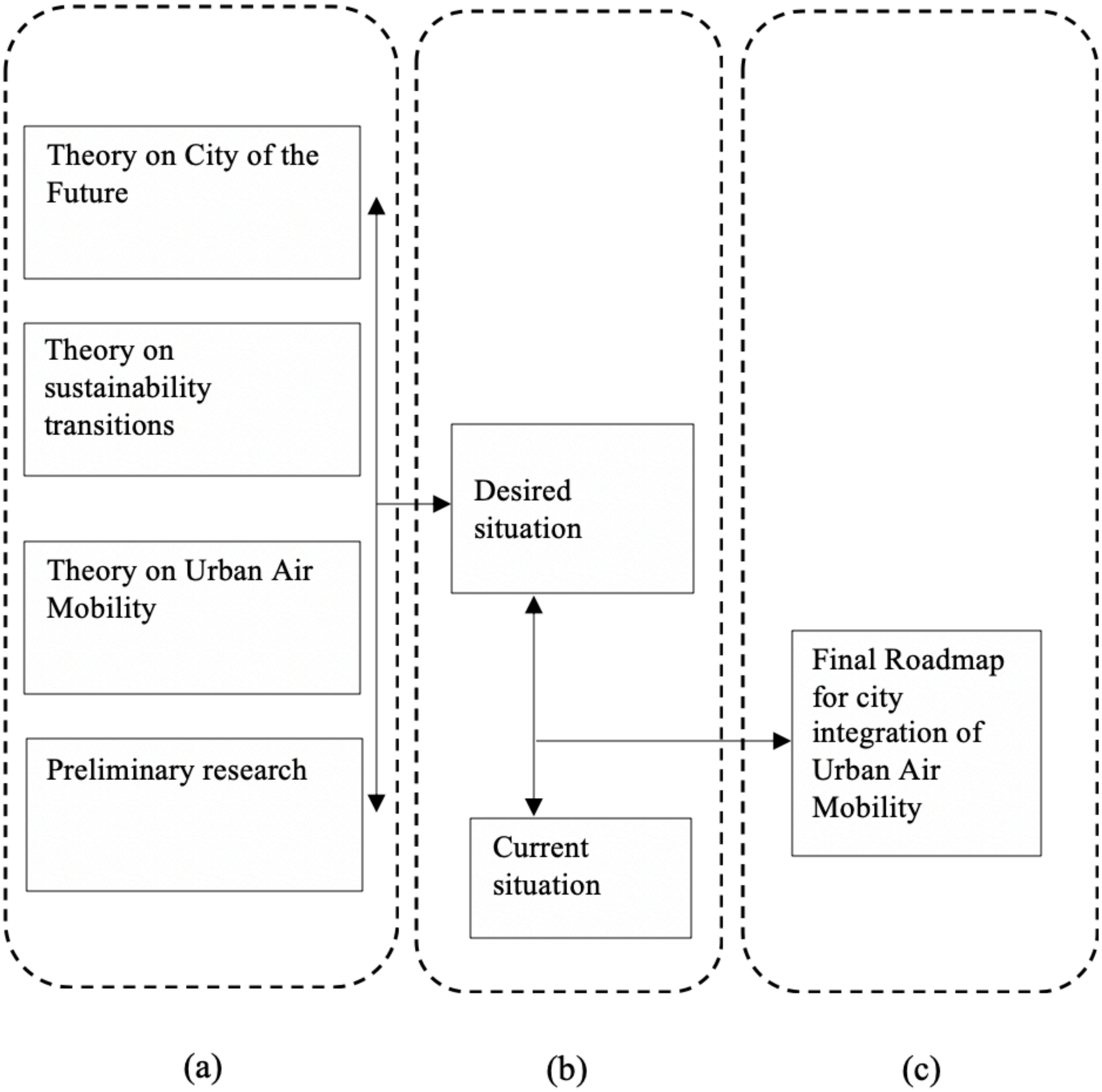


Figure 1 | Research framework.

(a) An analysis of the theoretical concepts of 'City of the Future', sustainability transitions and UAM provides insight in both the desired situation of UAM in future cities and the research perspective that is used throughout the research. On the basis of (b) empirical data collection, the current situation of UAM in cities and the gap between the current and the desired situation are determined, and barriers can be identified. From this, (c) recommended actions towards further Community Integration of UAM can be given, and a roadmap can be constructed.

2.2 Scope of the research

UAM is a complex topic and a system of systems. Broadly, it exists of three major bricks: vehicles, airspace integration and community integration (fig. 2) (NASA, 2020). The first two parts have already had a lot of attention, but the latter one has been underexposed. Besides, the latter brick fits best with the author's field of knowledge. The scope of the research therefore consists of this part, which is about bringing the technology and their services into the community. This encompasses a variety of physical and social topics, like infrastructure integration, sectoral policy and social acceptance of UAM operations (NASA, 2020b). As was mentioned before, initially a holistic approach was used to explore the matters of community integration of UAM. During the empirical research, this was narrowed down to parts of this community integration that are considered more important. Based on existing literature on UAM, the time period that will be used in the research, generally runs until 2050 and starting right now. While there is a large variety of actors that will have their stake in the field of UAM (Appendix F.1), the stakeholders that are mainly concerned when it comes to the Community Integration of the concept are governments and especially municipalities. They will need to know what kind of actions they should follow to successfully integrate the UAM network in their communities. Therefore, these are considered as the problem owners.

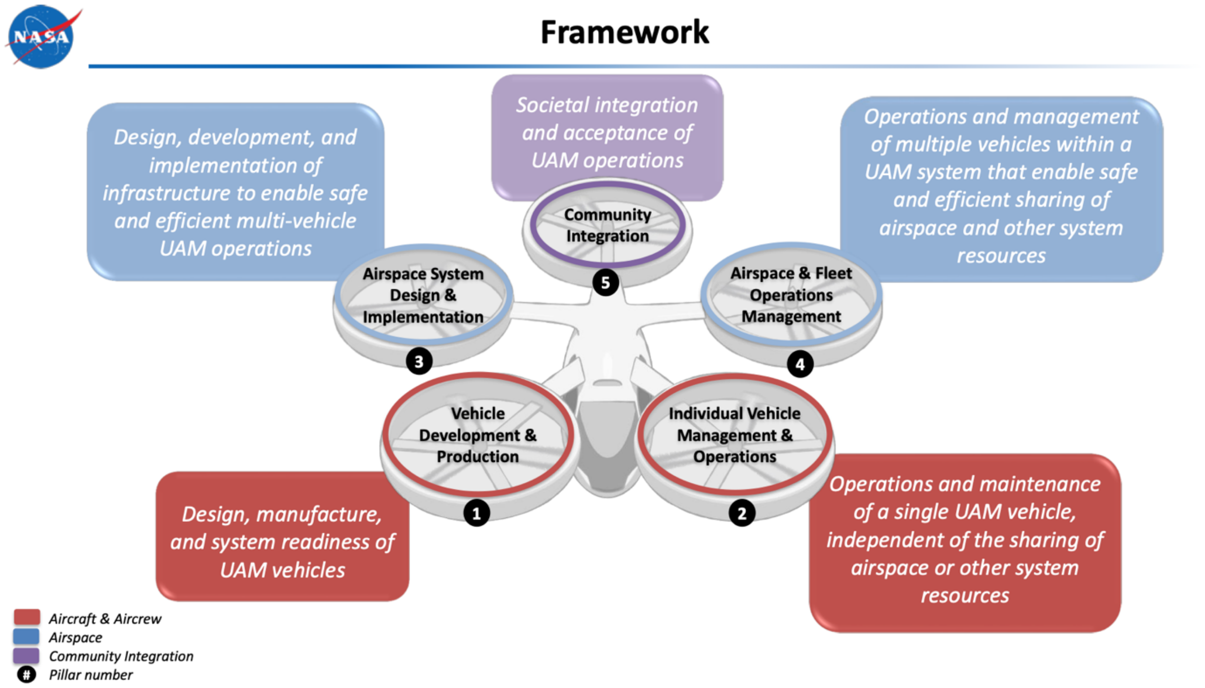


Figure 2 | Urban Air Mobility framework as considered by NASA. This research focusses on the Community Integration pillar, which consists of aspects like supporting (ground) infrastructure, operational integration, public acceptance and local regulatory environment and liability.

II

LITERATURE STUDY

Part II - Literature study

This part of the research will introduce the theories and concepts that have been the foundation for the research on the community integration of Urban Air Mobility. The first concerns the theory of transitions. Given that the mobility domain will or must undergo a transition to more sustainable mobility in the coming years, with possible room for UAM, it is important to know how transitions work. This theory helps to understand all kinds of issues that come with UAM's Community Integration, including the changing systems, barriers and, as a result, what actions can be taken upon them. The second area is the 'City of the Future', which includes studies of what future cities may look like. The emphasis for this thesis is on the 'Mobility of the Future', because UAM is mainly related to this domain. The main focus was on how cities (can) fill in their mobility mix, what options they have for a transition to a more sustainable mobility system and what still falls short. Subsequently, the link was made with the value that UAM can add, the third research area. The literature study on this has contributed to both defining the concept and to the synthesis in this report.

3 Transitions theory

Just as the automobile once managed to establish itself in our mobility mix, so could UAM too. However, in order to achieve this, (drastic) changes are usually required in the existing systems, also referred to as a transition. The theory of transitions forms a useful framework that can be used to map out what is involved in the development of a transition, in this case UAM. It helps to provide insight into the necessary changes. From this it can be determined what challenges there are and what actions cities can take to make the transition possible. In this way, the theory systematically contributes to answering the research question.

3.1 Sustainability transitions

Socio-technical systems can be described as a cluster of elements, including technology, regulation, user practices, markets, cultural meaning, infrastructure and maintenance and supply networks (Geels, 2005). Linkages between the different heterogeneous elements within the system are crucial. Without, societal functions cannot be fulfilled well (Geels, 2004).

The relevant socio-technical system in this thesis is transportation. Interaction between the different elements enables the provision of services to society, like the possibility to travel from one place to another (Markard et al., 2012). Figure 3 gives a graphic overview of the socio-technical system of land-based road transportation, which includes the automobile. This system functions because all the different social and technical elements are aligned with each other, and together fulfil the societal function of transportation.

A socio-technical system does not function autonomously. It is shaped through the agency of certain actors. Social groups, such as car owners and oil companies, actively create, (re)produce and refine a socio-technical system (Geels, 2005). Interactions between different groups lead to changes within the system, consisting of either incremental improvements of the existing technology or the introduction of a novel technology. The latter affects actors. For example, policymakers will have to introduce new rules and users will have to adjust their behavior (Geels, 2004). These dynamics lead to the co-evolution of different elements within the socio-technical system. However, despite the existence of these dynamics in a socio-technical system, radical technologies are struggling to break through as all elements are dedicated to the existing technology (Geels, 2002). Therefore, when a new technology is introduced, it often results in a mismatch with the established system, which is characterized by stability (Geels and Kemp, 2007). Because of path dependency and lock-in, established technologies have an advantage over new technologies in terms of economies of scale, learning, networks and increasing returns (Geels, 2005). This stability presents a challenge to new and more sustainable technologies that break with the existing regime and require, among others, new infrastructure, different regulations and social acceptance.

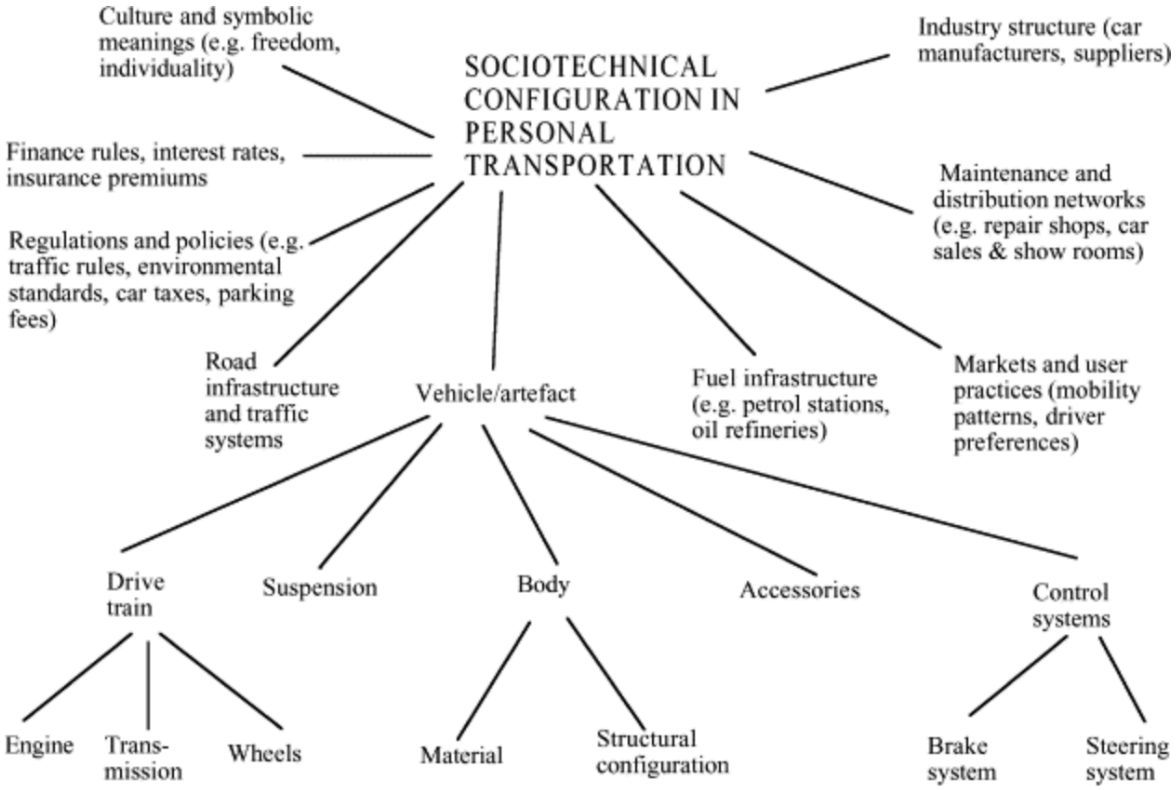


Figure 3 | Elements from the sociotechnical configuration in transportation (Geels, 2002).

However, if a shift from one socio-technical system to another does occur, it is called a transition (Geels, 2005). A transition can be described as a gradual and continuous change process. In this, the structure or a complex sub-system of society undergoes a transformation (Farla et al., 2010). A distinction can be made between general and sustainability transitions. The latter concerns the transformation of a system within a society towards more sustainable ways of production and consumption. Transitions generally take place over longer periods, of 50 years and more. Radical changes take place in various dimensions, and several actors are involved. In addition, not only does the structure of the system in question change, but related domains can be affected as well (Markard et al., 2012). This can be illustrated by electric driving. Due to EV-drivers connecting their car to the grid, they affect the energy domain and create a peak demand. Depending on the magnitude of such an effect, it may also require changes in the related domain: in this case, for example, using a smart-grid approach (Nijland et al., 2012). In the past there have been various transitions, including the transition from candle and gaslight to electrical light (Smith, Voß & Grin, 2010), the transition from horse-drawn carriages to a transport system based on the automobile (Geels & Kemp, 2007) and the gradual transition from sailing ships to steam ships (Geels, 2002). Box 2 elaborates on the latter example.

Box 1: From sailing ships to steamships (Geels, 2002)

Previously, the socio-technical shipping regime was dominated by sailing ships with a wooden construction. However, as a result of the 'canal boom' in which countries started to form interconnected networks of waterways, experiments were started with steamships in Britain, France and America in the late 18th and 19th centuries. Steam tugs were used to maneuver ships through these waterways and into ports. Gradually, the use of these steamships was scaled up from harbors to crossing small seas. However, the downside to using steamships was that they required large amounts of fuel. As a result, there was little capacity to transport goods and they were mainly used to transport passengers and mail. The latter contributed to a strong improvement in telecommunications. A number of experiments with steamships took place on oceans, but steam engine technology was mainly used as an add-on to sailing ships. This brought a solution at times without wind. As trade expanded, the shipping regime began to change. Despite transporting an increasing number of emigrants, steamship technology remained inefficient. As the ships began to travel longer distances, greater amounts of coal were required. The attention therefore shifted to technological steamship developments. At this point a change from wooden to iron ships began to take place. New challenges presented themselves as new skills and competences were required. Iron ships were initially used on a small scale, after which the benefits were gradually discovered. When freight transport increased further due to liberalization, the number of shipbuilding innovations also quickly took off. Eventually all technological trajectories, aimed at improving individual components of steamships, came together and gradually resulted in a steamship regime.

Lastly, the actual shift to steamships was incentivized by a landscape factor, namely the expansion of trade. In the transportation regime, climate change has been the driver on the macro-level, emphasizing the need for more sustainable types of mobility. Another implication of this shift to other technologies is that new skills and competencies are required. In the shipping regime this encompassed the change from using wind to using steam, and from wood to iron. A similar shift is witnessed concerning EVs, as electric engines differ from the conventional ICEs.

Where in this section examples of previous transitions were given and linked to the transition to electric automobiles, the same link can be made with the transition of Urban Air Mobility. The emergence of electric Vertical Take-Off and Landing (eVTOL) vehicles will potentially encompass a similar transition in the transportation regime. Later chapters (4, 6 and 7) in this thesis will elaborate on the transition of Urban Air Mobility.

The above-mentioned examples already give some insight into the internal dynamics of a socio-technical system, which play an important role regarding transitions. One way of analysing these internal dynamics is by using the Multi-Level Perspective (MLP), which will be explained in the next section. Besides describing the three identified levels and how they work together, attention will be given to how this framework is relevant in analysing sustainability transitions.

3.2 Multi-Level Perspective

As mentioned in the previous section, the Multi-Level Perspective is a useful tool to better understand socio-technical transitions. These transitions result from multidimensional interactions at three different levels, consisting of niches, socio-technical regimes and an exogenous landscape. Together, these concepts help understand the dynamics involved in socio-technical change (Geels, 2002). Figure 4 graphically illustrates the three levels of the MLP, which can be seen as a nested hierarchy.

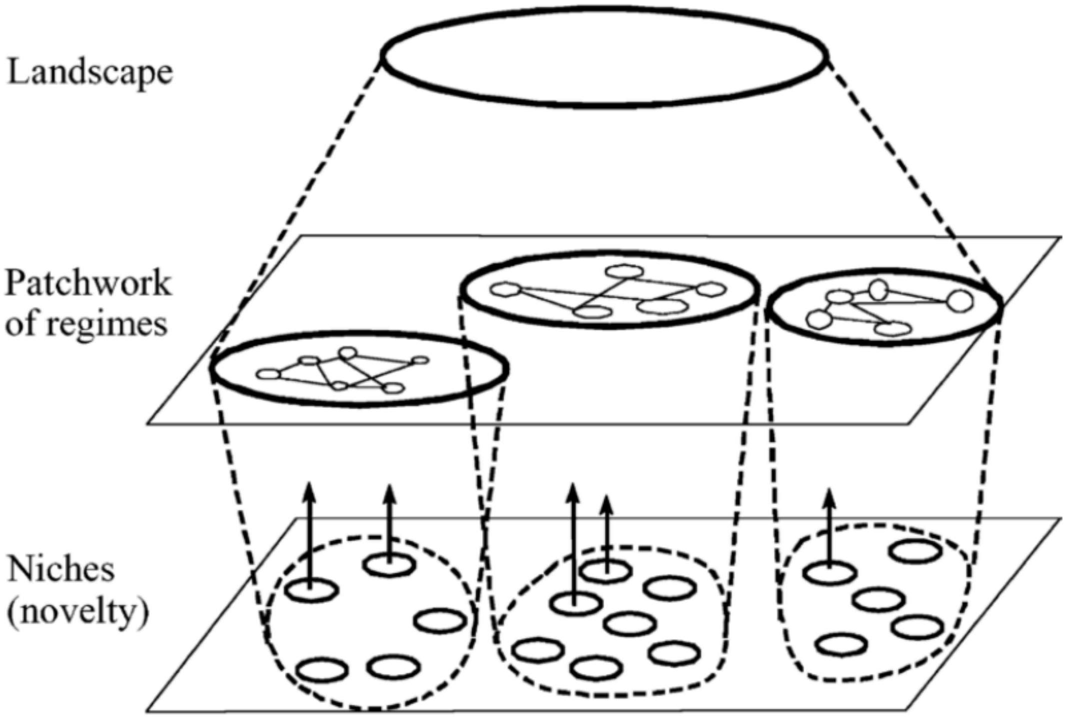


Figure 4 | Multiple levels as a nested hierarchy (Geels, 2002).

In addition to the three levels, there are a number of elements that are characteristic of the MLP (Geels, 2012). First of all, it has a co-evolutionary approach. As indicated earlier, transitions are not driven by isolated factors, but take place through developments in different dimensions. Second, the approach is actor-based, which means that it focuses on strategies, perceptions and interactions. Furthermore, the MLP includes both stability and change. It studies the lock-in of the existing regime, but also looks at the radical changes appearing in the niche. Finally, the MLP captures all complex dynamics that take place in the system. In particular, it looks at how certain developments reinforce each other. We will now turn to the three different levels, and the section will be concluded on the interactions between these analytical concepts.

3.2.1 Nested hierarchy and its dynamics

3.2.1.1 Niche-innovations

The micro-level within the MLP is represented by niches. These provide the ‘seeds for change’ and are therefore essential for a transition to occur (Geels, 2002). Niches can be viewed as "protected spaces" or "incubation chambers" in which different selection pressures prevail, as the performance of these novel technologies is not yet competitive given the selection pressures of the regime (Smith et al., 2010). This protection gives niches the opportunity to grow until they are sufficiently developed to compete with the incumbent technology. The protection can be formed in many ways, for instance through subsidization for demonstration and learning, or a specific environment for adoption and experimentation, such as living labs. Due to this protection, niches mainly produce radical innovations, whereas more incremental innovations usually develop within regimes (Geels, 2002). Sometimes niche innovations can stay at the micro level for a longer period of time before they break through. For example, a case study on organic land use shows that this remained a small niche for a long time, but could break through because various elements at the regime and landscape level changed (scandals and price drops in regular agriculture, other government regulations, more critical consumers, strategic positioning from supermarkets like Albert Heijn). The niche of organic farming could suddenly catch up with developments at regime and landscape level and break through as a result. The multi-level conceptualization of figure 4 is thus able to explain the delay or acceleration of (technical) developments by looking at links between developments at multiple levels (Geels and Kemp, 2000). However, despite the protection measures, many niches are not successful in trying to expand themselves or in surviving for such a long time (Smith et al., 2010), because they often face several challenges that may hinder their development. For example:

a) niche innovations are often more expensive than existing technologies, because they have not (yet) been able to benefit from economies of scale, learning curves and decades of incremental improvements;
b) there is no ready-made market for niche innovations and there is strong uncertainty about the preferences of the end users (Geels, 2019);
c) they do not match with existing regulations;
d) they lack sufficient infrastructure (Geels, 2012);
e) radical innovations often suffer from the 'liability of newness', and may be perceived as strange, unreliable, or unfamiliar. This reduces their cultural legitimacy, social acceptance, and access to funding (Lounsbury and Glynn, 2001).
f) different, fragmented but complementing innovations tend to remain isolated or short-lived. This prevents them from coming together, and ultimately reduces their potential for lasting and wide-ranging change (Turnheim et al., 2018).

Promising niches are radical, innovative alternatives that have emerged in the transition process to achieve improved regimes, like (more) sustainable mobility systems. This is an important condition for niches to develop: they must add value to or solve a problem of the existing regime (Geels and Kemp, 2000). Niches are developed and tried by pioneers, entrepreneurs, social movements and other relative outsiders (to the existing regime). They could be related to management innovations (like integrated transport systems, sustainable urban planning, sharing schemes, de-mand management and public transport innovations) or may rise from technological innovations (like ICT or green propulsion technologies, hybrid and battery electric vehicles, hydrogen fuel cells and biofuels). According to Geels (2012), the main drivers of niches often concern the level of niche support from government and international policies as well as the supports by incumbent actors, and the power of niche actors. The main problems and cracks are also formed by the low level of supports by incumbent actors and government, uncertainties about the economic productivity and niche performance. Niche innovations gain higher degrees of momentum, are more likely to be nurtured, and emerge as a new regime of mobility when they have the support of more actors and receive more resources. However, the high price of innovation and the long development period often make the chance of success for technological niches small. That is why many policymakers often opt for management innovations that seem more probable as they need less funding (Moradi and Vagnoni, 2018).

3.2.1.2 The socio-technical regime

The socio-technical regime represents the meso-level of the MLP and can be described as the current and dominant way of doing things in order to realize a societal function (Smith et al., 2010). Nelson and Winter (1982) first introduced this term and talked about 'technological regimes'. They argue that these regimes originate from engineers and firms who share the same routines. If such a community of engineers guides their search in the same direction, the regime can grow out to become a technological trajectory (Geels, 2002). Because socio-technical regimes are known for their stability, mainly incremental improvements take place along these trajectories.

Rip and Kemp (1998) widened the concept of the technological regime by adding 'rules' as a dimension. Although Nelson and Winter (1982) also included some form of rules, they argued that these shared rules were solely embedded in the practices of engineers. The broadening of the regime concept by Rip and Kemp (1998) resulted in more social groups, such as policymakers and end users, influencing the technological trajectories, instead of just engineering communities (Geels, 2002). The prevalent rules act as guidance regarding research activities, and also influence the strategies that different actors will undertake (Hoogma, Kemp, Schot & Truffer, 2002). This guidance can be described as blinding, since social groups tend not to look at developments outside of their focus (Grin, Rotmans & Schot, 2010). Therefore, rules account to a large extent for the stability and lock-in that characterizes socio-technical systems.

Nowadays, the regime-level is characterized by multiple dimensions, which have internal dynamics and may cause tensions. Geels (2002) distinguished seven of these dimensions: technology, user practices and application domains (markets), symbolic meaning of technology, infrastructure, industry structure, policy and techno-scientific knowledge. They are described in table 1. Together these dimensions form a socio-technical system.

Table 1 | The regime dimensions of the MLP and their description.

Dimension	Description
Actor network	Networks of (social) groups or actors that are involved in the functioning of the socio-technical regime. Part of this network are often producers, suppliers, user groups, societal groups, public authorities, research network and financial network.
Techno-scientific knowledge	The necessary (scientific) knowledge that is needed in the socio-technical regime.
Sectoral policy	The public policy pursued with regard to the socio-technical regime involved, including regulation. Government guidance may be necessary in the event of, for example, market failure or external effects related to social efficiency, equity and sustainability.
Markets and user practices	The scope or market of the product. It includes aspects such as market niches, user preferences and competencies.
Technology	Physical artefacts and the technological knowledge associated with their use. Technology consists of a hardware and a software component. The hardware relates to a physical artefact and the software includes the information necessary to use this object. It also focuses on technological developments.
Infrastructure	The material infrastructure that is needed for the functioning of the socio-technical system.
Symbolic meaning	Material objects not only have a function for people, but also a symbolic meaning. In the latter, objects are associated with certain "end values" that people pursue in their lives, such as health, relationships, leisure, nature, freedom (or control) and pleasure. The symbolic meaning is important for how we see ourselves and how we see others. One can think of identity, values, status, belonging to a group, and stereotypes. The symbolic meaning of a technology is expressed, among other things, in public opinion regarding a technology (the acceptance of a technology by citizens). This can be influenced by social groups such as nature and environmental organizations, consumer organizations and by the media.

Regime dynamics are forces that drive mobility systems to be more sustainable and less carbon intensive; the existing drivers and barriers to the transition process are described as lock-ins and cracks in the transition literature. The incumbent regime is stabilized by lock-in forces, while it can be opened up for promising niches to emerge at the regime level by cracks, which are weak points that create tension in the existing regime. Incumbent actors tend to be locked into existing regimes, the automobility (private car) regime being the dominant one in the socio-technical system of transportation (Elzen et al., 2004, Elzen et al., 2003; Geels, 2005; Hodson et al., 2015). The aim of transport and mobility plans is to shift this regime to more sustainable ones, like active (e.g. walking, cycling) and public transport (e.g. train, tram, bus), but due to several reasons, as discussed in 4.2.1, they have generally remained relatively small regimes. These transport modes have been around for many decades, are carried by specific communities of actors that have developed institutionalised practices, beliefs, capabilities, etc. It makes no sense to call these transport modes 'niches' in the sense of being radically new and precarious innovations. However, these transport modes capture only a small percentage of total mobility (in terms of passenger kilometres), and in that sense occupy small market niches. Therefore, these transport modes can be called subaltern regimes in contrast to the dominant auto-mobility regime (Geels, 2012).

There are several factors that lock in the automobility regime (see also table 2 in 4.1.1). These are mainly linked to vehicle manufacturing industry, the huge investments in skills, factories and infrastructure, market share, and user preferences. While, it is possible to argue that tensions mainly emerged from landscape pressure on market variables, traffic problems (congestion and parking problems) and the strategies and plans to reconfigure the existing regime (like pollution limits for vehicles). Nevertheless, there are also some factors that help the existing automobility regime to be reconfigured to become cleaner and more sustainable like the competition between the vehicle manufacturers to apply the environmental standard certificates (Chiarini, 2014a, 2014b) and support the promising niches of clean propulsion technologies (Moradi and Vagnoni, 2018).

3.2.1.3 Landscape developments

The socio-technical landscape, the macro-level of the MLP, provides the structural context for the in which the other two levels, the socio-technical regime as well as the niches, are embedded (Smith et al., 2010). It can be seen as an exogenous environment that consists of a set of connected trends, which can largely be divided in economic, political, industrial, and social trends, deep structures and events (Moradi and Vagnoni, 2018; Hoogma et al., 2002):

- Economic variables: trends in demand and supply, economic growth and crisis, international fuel and energy markets;
- Political variables: political coalitions, international debates and policies for climate change, greenhouses gases and CO2 reduction strategies and agreements; policy supports, rules and regulations;
- Industrial variables: physical infrastructure and manufacturing base, technological revolutions and R&D trends;
- Social variables: demographic factors, values and ideologies, climate change awareness and behaviour change (Moradi and Vagnoni, 2018; Geels, 2002).

The landscape itself is not influenced directly by the success of innovation processes within the niche or the regime, but rather acts as a source of pressure for change on the level of the socio-technical regime (Smith et al., 2010). On the one hand, landscape processes can reinforce existing technological trajectories, but on the other hand they can also exert pressure on the dominant regime. As a result, a window of opportunity can open, creating space for the consideration of niche alternatives. Furthermore, landscapes do change, which can eventually be the result of a novel, dominant technology, but this happens at a slower pace than the change within socio-technical regimes and could take several decades (Geels, 2002; Grin et al., 2010).

3.2.1.4 Transition dynamics

Despite the fact that three different levels can be distinguished, there are a lot of dynamics going on between these levels. The MLP suggests that transitions result from the interplay between processes at the niche, regime and landscape level. Although transitions may differ somewhat between domains and countries, the general multi-level dynamics are characterized as follows:

a) niche-innovations develop over time and gradually build up internal momentum. They can either break through and compete with the regime, or they can turn out to be failures;
b) niche-innovations and landscape changes create pressure on the system and regime, the latter being characterized by multiple dimensions, which have internal dynamics and may cause tensions. and
c) destabilization of the regime creates windows of opportunity for niche-innovations. Niche innovations with sufficient internal momentum then diffuse and disrupt the existing system (fig. 5) (Geels, 2019).

Whether a shift from one socio-technical system to another will occur depends on the alignment of developments within the three levels. There is no guarantee that the dynamics will take place. If niches fail to generate momentum and if there are only small tensions within a regime, or from the landscape, windows of opportunity will not emerge.

Socio-technological transitions can take several decades and can be divided into four phases, in which different core activities and barriers play a role. The first phase is characterized by experimentation and trial-and-error learning with radical niche-innovations (Geels and Schot, 2008; Sengers et al., 2019). R&D laboratories, real-world experiments and demonstration projects serve initialy as carriers of niche innovations (Geels and Raven, 2006). This gives pioneers the opportunity to learn about the techno-economic performance, socio-cultural acceptance and political feasibility of radical innovations in real-life settings (Kemp et al., 1998). The first phase is characterized by much uncertainty, competing claims and promises, and many failures and pioneer burn-outs (Olleros, 1986).

In the second phase, innovations set a foothold in one or more market niches, resulting in a more reliable flow of resources. The innovation stabilizes into a 'dominant design' when sequences of projects build on each other through the circulation of experiences, learning processes, and dedicated aggregation activities such as codification, standardization, and model building, which articulate best practices, product specifications, and design guidelines (Geels and Raven, 2006). Engineering communities, standardization committees or industry associations, who operate on behalf of the entire field, are often responsible for the circulation and aggregation of technical knowledge. This can also be done by 'intermediary actors' (Kivimaa et al., 2018) as energy agencies or innovation agencies, as they are usually involved in several projects and therefore have comparison material. This way they can extract and codify general lessons and provide these as inputs for new projects. Such socio-cognitive activities help to gradually stabilize innovation trajectories (fig. 6) (Geels, 2019).

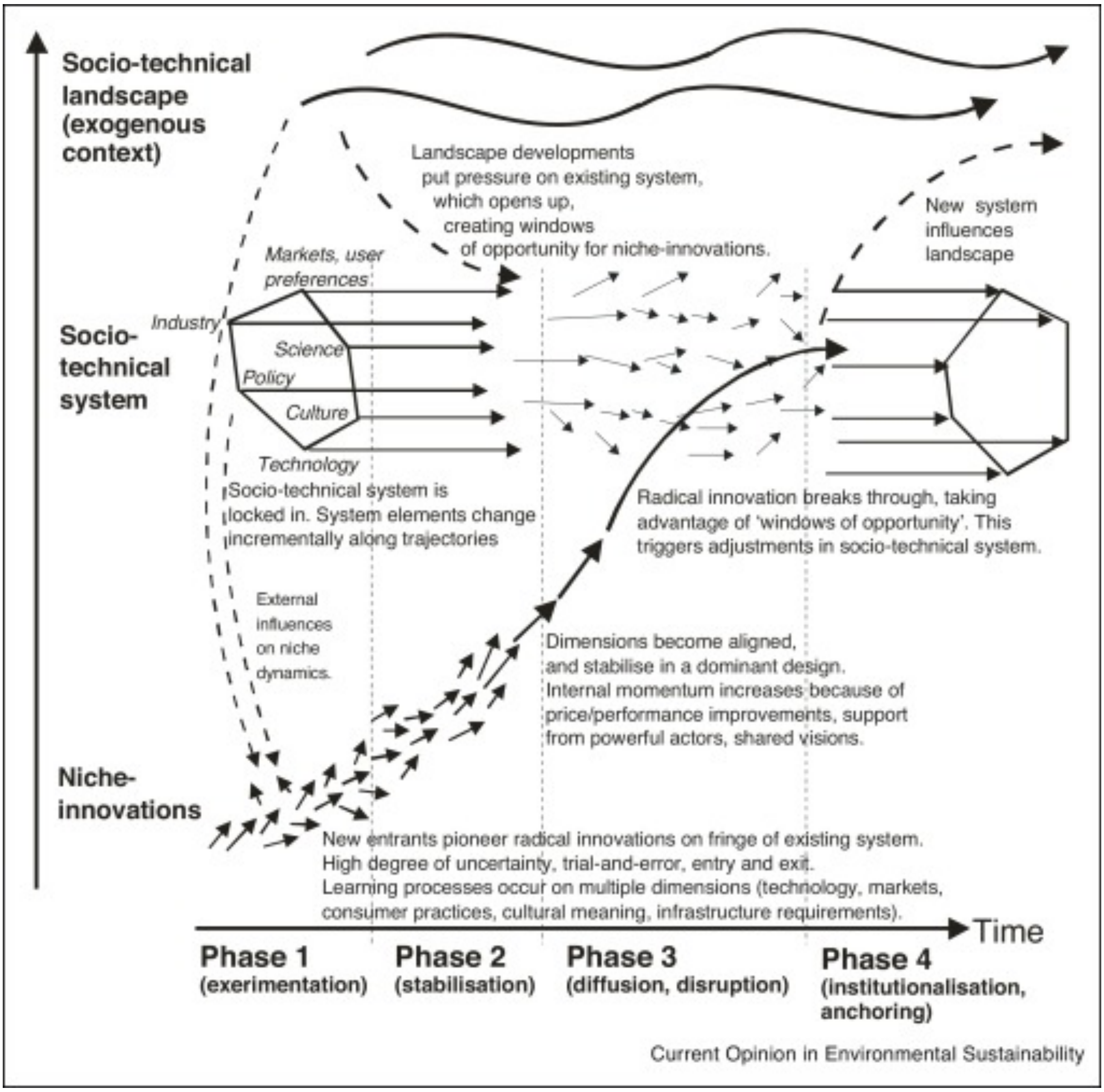


Figure 5 | A dynamic multi-level perspective on socio-technological transitions (Geels, 2019).

Innovation can also take place in the user practices, as consumers 'domesticate' radical innovations and change them from unknown things into familiar objects that find a place in everyday life (Lie and Sørensen, 1996). Expressing positive, cultural visions is also important in legitimating innovations and in creating further support. Innovations may, however, also be opposed by social groups who experience negative side effects, do barely benefit from the innovation or feel insufficiently consulted in decision making. Such opposition may result in high social resistance, which can hinder further progression, as happened with biofuels, onshore wind turbines and carbon capture and storage (in some countries) (Devine-Wright et al., 2017).

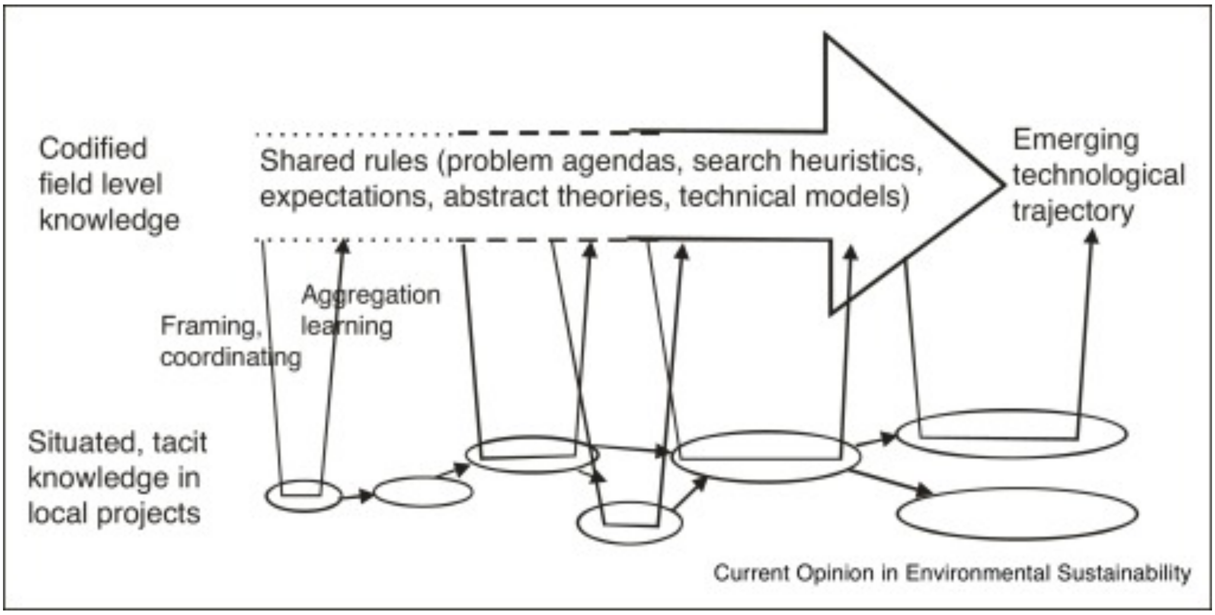


Figure 6 | Innovation trajectory emerging from sequences of local projects (Geels, 2019).

In the third phase, the radical innovation diffuses into mainstream markets. This is enabled by drivers from two directions. On the one hand, the innovation is driven upwards by drivers from the niche itself, such as price/performance improvements, economies of scale, development of complementary technologies, and support from powerful actors. On the other hand, the landscape from above creates a structural window of opportunity by putting pressure on the existing regime, which leads to tensions and destabilization of the regime (represented by diverging arrows in fig. 5). This phase is often characterized by struggles between niche-innovations and the existing regime on multiple dimensions. There is economic competition between new and existing technologies, which is influenced by the institutions that make up the market and economic frame conditions. There are typically struggles between new entrants and incumbents, which in some cases can lead to the demise of existing businesses (Christensen, 1997). There may be political conflicts and power struggles over agenda setting, problem framing, and adjustments in subsidies, taxes, and regulations (Meadowcroft, 2009). These struggles involve policy actors (bureaucrats, ministers, advisory committees, political parties, parliaments), but also wider interest groups, which often have varying degrees of access to policy networks. Cultural struggles over framing problems and solutions are likely, as social groups often view and interpret things differently. This is usually expressed in contested public debates (Roberts and Geels, 2018).

There is no guarantee that niche innovations will ultimately win this battle. For example, radical innovations could fail to build sufficient momentum, or experience setbacks. It may also happen that tensions may be contained in existing regimes, for example due to actions by incumbent actors. In that case, a ‘window of opportunity’ for niche-innovations will not (sufficiently) materialize (Geels, 2019).

In the fourth phase, the new socio-technical system replaces or complements (parts of) the old one, and becomes institutionalized and anchored in regulatory programmes, user habits, views of normality, professional standards, and technical capabilities (Geels, 2019).

This process can follow different pathways, depending on the nature of the relationships between niche-innovations and landscape developments on the one hand and the regime on the other hand. These relationships can either be reinforcing or disruptive. From this, Geels and Schot (2007) developed four different transition pathways, an additional fifth proposition that addresses a possible sequence of transition paths and a ‘zero proposition’ about stability and reproduction:

P0) Reproduction process
P1) Transformation path
P2) De-alignment and re-alignment path
P3) Technological substitution
P4) Reconfiguration pathway
P5) Sequential pathway

Pathway 4 (P4) (fig. 7) will best suit the transition of Urban Air Mobility. Here it is about symbiotic innovations, which developed in niches and are initially adopted in the regime to solve local problems. As UAM will probably fill in a niche market (Kasliwal et al., 2019), fulfilling specific use cases, within (urban) mobility, it connects quite well to this description. The innovations may subsequently trigger further adjustments in the basic architecture of the regime (Geels and Schot, 2007).

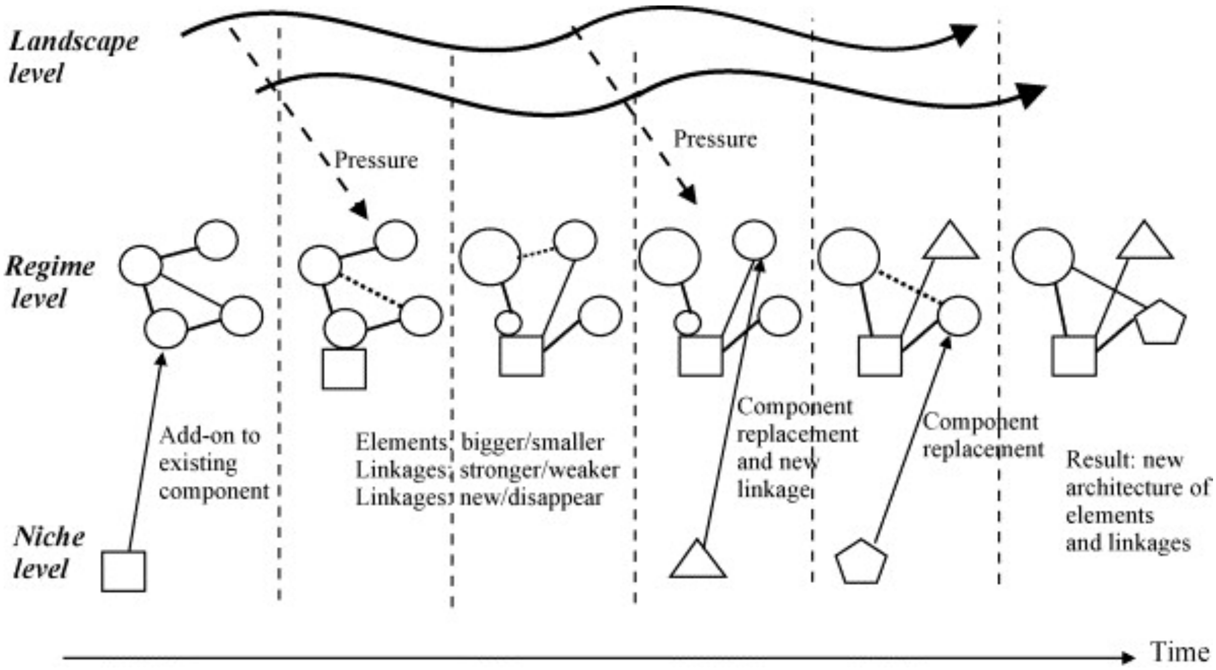


Figure 7 | Reconfiguration pathway (Geels and Schot, 2007).

An example illustrating the ongoing dynamics within a socio-technological system concerns the transition from horse-drawn carriages to automobiles (Geels, 2005). This transition started as a result of landscape developments such as industrialization and urbanization, which resulted in changing travel patterns. The horse was introduced to cover longer distances, but this mode of transport was characterized by several negative aspects. For example, horse manure on the street caused all kinds of diseases and maintenance and operational costs were very high. These disadvantages created a window of opportunity and enabled the emergence of novel transportation modes, like the electric tram and the bicycle. A cultural shift happened as well, as driving became associated with fun and entertainment and streets became transport arteries instead of social meeting places. However, both the bicycle and the electric tram did not become the dominant way of transportation. Instead, the former one grew out to a children's toy, while the latter one became a type of transportation in urban surroundings. Automobiles emerged as a radical new transport option, in which the gasoline car won over steam and electricity. Eventually, this niche transformed the existing regime and a 'car culture' emerged. This example shows that the success of a technology like the car does not depend on a single factor or level. There are socio-technical processes at play, which co-evolve within niches and regimes, and which are subject to an exogenous landscape with certain trends and events.

In our current era, all kinds of landscape developments are driving the need, but the opportunity as well, for more sustainability transitions. Factors like urbanization, mobility growth and climate change are some developments why we may need to consider alternative mobility modes to add to our mobility mix, like Urban Air Mobility. In the initial phase of such a transition, niche technologies play an important role. As illustrated by the example from Geels (2005), niches incorporate the shortcomings of the regime and present a solution, introducing a technology which improves current practices. For example, bicycles emerged in a niche due to the need for a more hygienic and healthier environment. However, as long as the different dimensions are aligned to the current regime, it will be difficult for the niche to establish itself. This shows that niches, as well as the related dimensions of the socio-technical system, are important in achieving a transition.

It has been acknowledged that we need to escape lock-in of current regimes and avert path dependencies if we want to move in a more sustainable direction (Smith et al., 2010). The MLP proves to be a helpful tool in this, as it is able to simplify complex transformations and map ongoing dynamics in a straightforward way.

3.2.2 MLP in sustainability studies

Several studies have used the MLP as a theoretical framework for studying transitions. Geels (2005) has emphasized the importance of the MLP, compared to other frameworks such as large technical systems (LTS) and innovation literature. The former mainly looks at the emergence and development of systems, whereas the latter concerns different analytical levels such as innovation at the national or sectoral level. However, both of the frameworks lack an explanation of how change takes place from one system to another. This is where the MLP has an added value, as one of the aspects of this concept is how transitions to new socio-technical systems come about. Furthermore, it is argued that existing literature primarily looks at path dependency and lock-in, while there is no answer to the question how we can understand 'lock-out' or change (Geels, 2005). Besides, approaches usually only take into account technologies and markets, while aspects such as policies and regulations, user preferences, infrastructures and cultural and symbolic meanings are ignored (Geels, 2005).

The example presented in the previous section, on the transition from horse-drawn carriages to automobiles, shows the strength of the MLP with regards to how transitions take place. Using a substitution approach, this case study is often seen as a case in which horse-drawn carriages were replaced by cars following a technological substitution pathway. However, when the MLP is applied to this case, it can be seen that innovations such as the electric tram and bicycle actually served as stepping stones in achieving the eventual transition towards car-based transportation. Therefore, the MLP adds great value as a tool in analyzing internal dynamics and historical transitions, uncovering processes at the micro-, meso, and macro-level.

However, the usefulness of the MLP has not only been illustrated with many historical case studies of transitions, such as in land transport (Geels, 2005a), shipping (Geels, 2002), cargo handling (Van Driel and Schot, 2005), as well as in sewers and sanitation, clean water (drinking, washing, bathing), aviation, highway systems, and industrial production. The MLP has also successfully been applied in studies of contemporary and future transitions to sustainability, e.g. in electricity systems (Verbong and Geels, 2007; Verbong and Geels, 2010; Hofman and Elzen, 2010), mobility and 'green' cars (Nykvist and Whitmarsh, 2008; Van Bree et al., 2010; Geels et al., 2011), biogas and co-combustion (Raven, 2004), organic food and sustainable housing (Smith, 2007), and animal welfare in pig farming (Elzen et al., 2011). Many of these contemporary studies explain the ups and downs of 'green' niche-innovations by analyzing the learning processes, network dynamics, and struggles against existing regimes on multiple dimensions (Geels, 2011).

A different paper by Geels (2012) also applies the MLP and introduces it into transport studies. Using the framework, he identifies promising 'green' niche developments, like inter-modal travel, deviating cultural and socio-spatial niches such as sustainable urban planning, car and bike sharing, behavioural-change oriented initiatives, improvements in public transport services, ICT and niches of green propulsion technology. In his paper, Geels (2012) also focusses on the corresponding (in)stabilities within the socio-technical regime, and landscape developments. Taking automobility as an example, the destabilizing landscape pressures of climate change and Peak Oil have a big influence on the regime, since the majority of cars run on polluting petrol. However, despite these destabilizing pressures, he argues that the current regime is kept in place by, among others, the physical landscape that has been shaped around the car, macro-economic growth in especially developing countries and the cultural preference for speed and time saving, since the car is often the fastest transport mode. In a time of increasing urbanisation and congestion, it is argued that UAM can be an answer to both these stabilizing and destabilizing pressures. On the one hand it has the potential to make transportation even faster than automobility does, while on the other hand it is aimed at making the mobility regime more sustainable as it is not reliant on fossil fuels. As such, UAM may be an answer on the question how we can keep our cities both liveable and accessible. This shows that the research of this thesis on UAM and its community integration is valuable in realizing a sustainable mobility transition.

The insight into the use of the MLP in transport studies reveals that transportation systems are highly complex, with many internal dynamics and developments. Furthermore, each case illustrates that there is a lock-in of the automobile regime, which is kept in place by the dimensions that are aligned to this situation. This thesis will explore what may happen when UAM becomes part of the urban mobility regime. By using the MLP as a framework, a possible pathway for this transition, together with the challenges that will rise, will be created and the broader impact on the city will be qualitatively assessed. Also, policy measures to guide the transition should be part of this research. As such, the research should help local governments in dealing with a possible transition to three-dimensional urban mobility.

Transitions theory, and the MLP in particular, have shown that they can be a useful framework to lay out a path for the transition of Urban Air Mobility. In the next sections, it will be used to describe the dynamics of alternative mobility solutions for the car and the transition of Urban Air Mobility. It can help to uncover the gap between the current and future urban mobility regime. On the basis of this gap, barriers between these two situations are identified, and a variety of action points is recommended.

4. Urban Air Mobility as a potential improvement for the mobility system

Currently, our (urban) mobility system relies heavily on the private car. It is the most dominant mode of transport: according to Eurostat (2019), passenger cars accounted for 82.9 % of inland passenger-kilometres in the EU in 2016, while half of all European citizens use a car every day (50%). For comparison, this is more than the proportion who cycle (12%) or use public transport (16%) combined (European Commission, 2013b). Although the car is on average less dominant in cities, this dominant role turns out to be more and more problematic and causes a variety of problems in and around cities (European Union, 2020; European Union and UN-Habitat, 2016; Ministerie van Infrastructuur en Waterstaat, 2019). Two of them are in contradiction: congestion in the urban areas and a dissolving network in the countryside (Roosien and Bussink, 2018). Being stuck in traffic is a global phenomenon that has serious negative consequences. It causes a waste of time, increased fuel consumption leading to higher emissions, and loss of property and human life (Porsche Consulting, 2018). This chapter goes into the urban mobility problems and discusses how the main issues are expected to develop into the future. Subsequently, various solution directions are discussed that cities can deploy in order to achieve their sustainable urban mobility goals. Finally, it will be described how Urban Air Mobility could contribute to the solution of the urban challenges that are faced.

4.1 Urban mobility problems

4.1.1 Dynamics of private car-based regime (automobility)

In the previous chapter, it was explained how transitions can be achieved or prevented. This has to do with dynamics at and between the three different levels of the MLP: niche, regime and landscape. Based on these concepts, a brief overview can be given that explains why the car is the dominant mode of transport in the mobility regime (lock-in), despite the fact that it knows several crack and tensions (table 2).

Apparently, the stabilizing factors of the car regime have the upper hand over the destabilizing factors, while it is precisely the latter that demand sustainable changes in the mobility regime. In the next paragraph, some of the main cracks and tensions of the automobility regime are discussed in more detail.

Table 2 | Dynamics of private car-based regime (automobility).

Lock-in (stabilizing forces)	Cracks and tensions (destabilizing forces)
- Taxe incomes for governments (Van der Eerden, 2013)	- Energy security and affordability (Foxon et al., 2010; Geels, 2012; Geels et al., 2011)
- Increasing returns to adoption (Arthur, 1989)	- Liberalized energy markets (Foxon et al., 2010)
- Household income growth (Elzen et al., 2003; Floricel et al., 2009; Freund and Martin, 2000; Geels, 2012)	- Fuel price (Hillman and Sanden, 2008; Hodson et al., 2015; Rip and Kemp, 1998)
- Increasing demand for personal mobility (Castells, 2011, Castells, 2010; Geels, 2012);	- Economic crisis- declining sales (Hodson et al., 2015)
- Land development policies (Elzen et al., 2002)	- Market saturation (Geels, 2012)
- Government strategies to support industry (Ngar-yin Mah et al., 2012)	- Environmental policies (Turnheim et al., 2015)
- Diversity of models and prices	- Pressure from EU and national policy makers (Geels, 2012; Hodson et al., 2015; Turnheim et al., 2015)
- Large market segment (Turnheim et al., 2015)	- Carbon trading policies (Hillman and Sanden, 2008) and CO2 labeling strategies (Turnheim et al., 2015)
- Existing resources for infrastructure, manpower, machinery (Arthur, 1989; Geels, 2012; Geels et al., 2011; Hodson et al., 2015; Rock et al., 2009)	- Weakening commitment of policymakers to car regime (Geels, 2012)
- Vehicle efficiency (user interface, convenient, entertainment, safety and comfort) and better environmental performance (Turnheim et al., 2015)	- Concerns about road and car safety
- Symbolic representation of cars (Hodson et al., 2015; Van der Eerden, 2013)	- Anti-car discourse (Hodson et al., 2015)
- Manufacturing base, technological innovation and reconfigurations (Geels, 2012; Hodson et al., 2015; Ngar-yin Mah et al., 2012; Rogge et al., 2015; Turnheim et al., 2015)	- Traffic plan limitations for cars (Elzen et al., 2004; Geels, 2012; Hodson et al., 2015; Turnheim et al., 2015)
- Powerful manufacturing companies	- Public transport regime improvements (Geels, 2012; Hodson et al., 2015; Kim, 2015; Turnheim et al., 2015)
- Alternative fuels (Moradi and Vagnoni, 2018)	- Congestion problems (Hodson et al., 2015; Turnheim et al., 2015)
	- Citizen awareness of pollution threats (Hodson et al., 2015)
	- Parking availability and rates (Elzen et al., 2004)
	- Competition for environmental standard certification
	- Environmental management system in the industry (Chiarini, 2014)
	- Limited traffic zones in cities
	- Interest of local government to clean mobility
	- Urban form and structure (Moradi and Vagnoni, 2018)

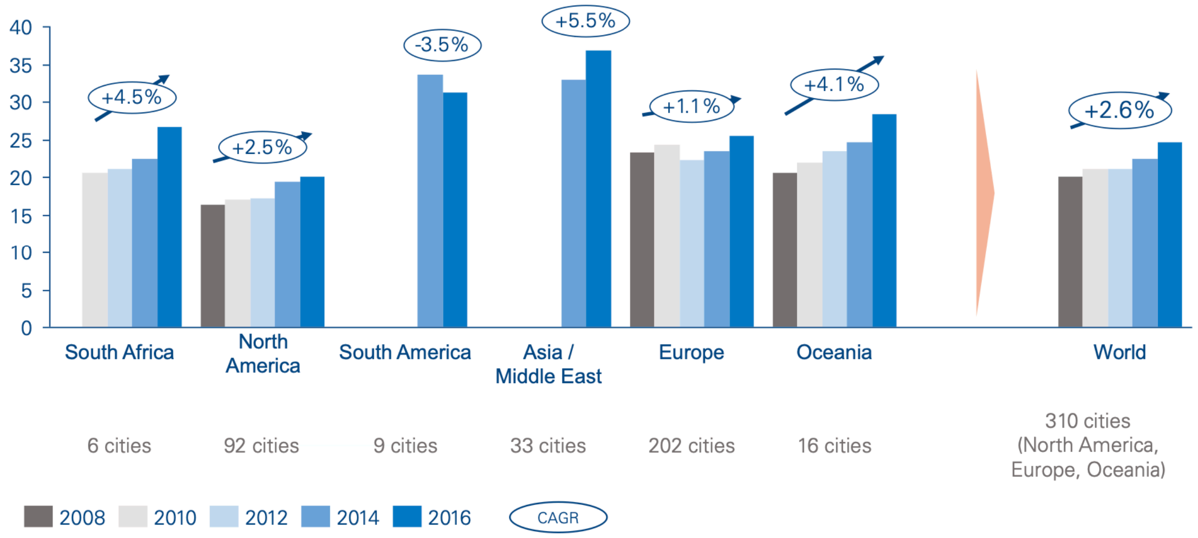
4.1.2 Current state of urban mobility

4.1.2.1 Congestion

Today, the world population exists of more than 7 billion people. Since 1950, the urban population of the world became more than four times larger, reaching an estimated 4.2 billion citizens in 2018 (United Nations, 2018). The infrastructure that must facilitate and process the ever-increasing transport flows in the cities has in many cases reached its limit. Common causes of this are a lack of funding, space or both. It has simply become too expensive and complex to build new roads and highways. Moreover, more roads have a negative impact on the quality of life of citizens (Porsche Consulting, 2018). In fact, analyses show that the number of vehicle-kilometers traveled (VKT) and the total amount of road surface (i.e. asphalt) generally grow at the same speed. In other words, the ratio between the two, which is congestion, remains unchanged. This result recalls, on a global level, the classical work by Downs (1962; 2004), which is known as the “fundamental law of peak-hour congestion”. It states that, on urban commuting axes, after every investment in road capacity, the roads over time become just as congested as they were before, as newly constructed roads will only invite additional traffic flows to fill them. Clearly, the problem of urban traffic congestion will not be solved by simply building new roads.

Therefore, there appears to be a strong need for an irreversible paradigm shift in the organization of urban mobility. In many urban areas, the quality of mobility services is declining. While this may not apply to every urban center, there is strong evidence that in all megacities a point has been reached where incremental changes will not be enough to provide the required improvement and respond to the challenges ahead (Arthur D. Little, 2018).

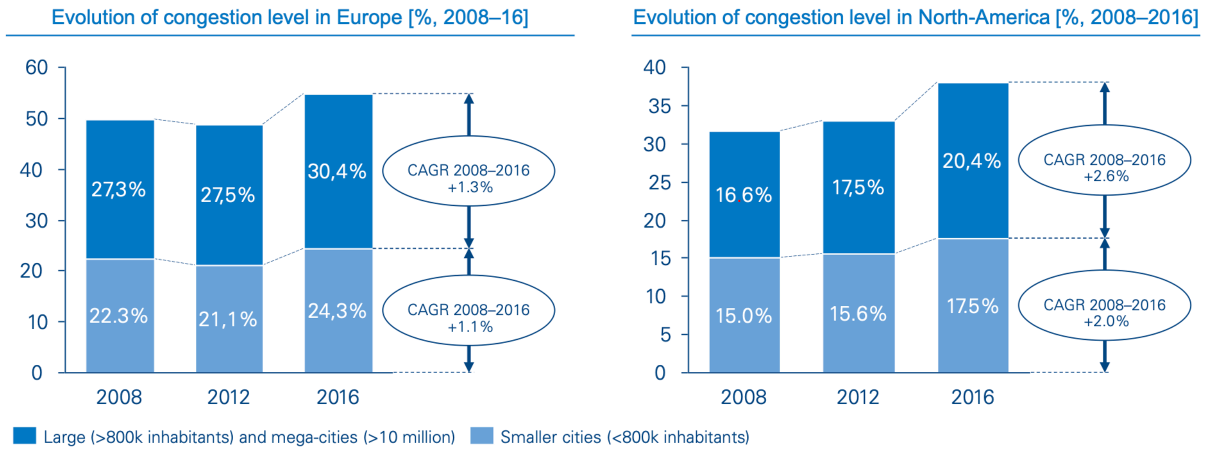
While the movement of people and goods is a precondition for economic development, a lack of it – i.e. congestions – poses a serious burden on households and businesses. In recent years, traffic congestion in urban areas around the world has been constantly increasing (fig. 8) (Arthur D. Little, 2018).



TomTom measures the congestion level (%) as the increase in overall travel times when compared to a free-flow situation

Figure 8 | Evolution of congestion level per region [%, 2008-2016] (Arthur D. Little, 2018).

When looking at the regional spread of congestion, it is found that congestion levels are (slightly) higher in large cities (>800k inhabitants) and megacities (>10 million) than in smaller cities, as is illustrated in fig. 9. Congestion growth has also been greater in larger cities (Arthur D. Little, 2018).



Source: Source: TomTom traffic index 2016, Arthur D. Little analysis

Figure 9 | Average congestion levels in Europe and North America (Arthur D. Little, 2018).

In sparsely populated areas, on the other hand, mobility is not constrained congestion, but rather by a lack of facilities. This is further exaggerated due to the increase of people leaving the countryside for the city. At the same time, existing solutions such as railways are expensive to build and maintain: above ground metro lines can cost 15 to 30 million dollars per kilometre (Flyvbjerg et al., 2008).

4.1.2.2 Safety

Furthermore, the number of road fatalities remains very high. The number of road traffic deaths keeps increasing and reached a total of 1.35 million in 2016 (fig. 10). This makes it the 8th leading cause of death for people of all ages. On the other hand, the death ratio has stabilized and even decreased slightly to around 18 deaths per 100,000 people, relative to the world population and the number of motor vehicles. This means that the safety of mobility does not deteriorate. However, the world is not yet even getting close to achieving SDG target 3.6, which calls for a reduction in the number of deaths by a half by 2020. This makes clear that insufficient progress is being made (World Health Organization, 2018).

As a result of a decreasing trend, 22,660 people died on European roads in 2019 (fig. 11), meaning that European roads are the safest in the world. However, according to the figures, the gap between the actual number and the target number is growing. Therefore, more efforts are required to make a big step forward. Urban areas account for 37% of Europe's road fatalities, with vulnerable users such as pedestrians being particularly exposed. Progress in reducing road fatalities has been below average in urban areas (European Transport Safety Council, 2020).

Figure 1: Number and rate of road traffic death per 100,000 population: 2000–2016

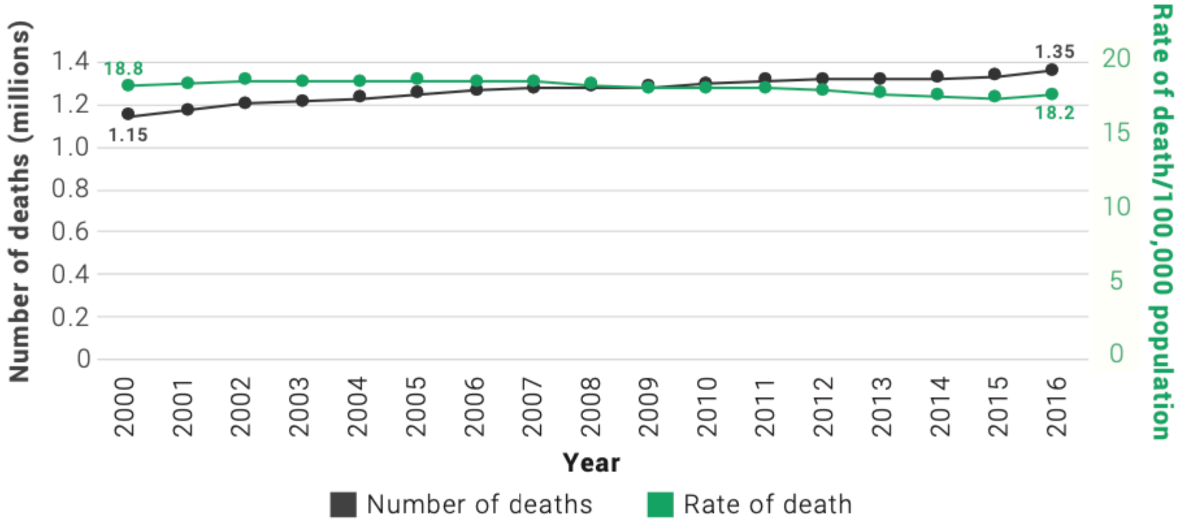
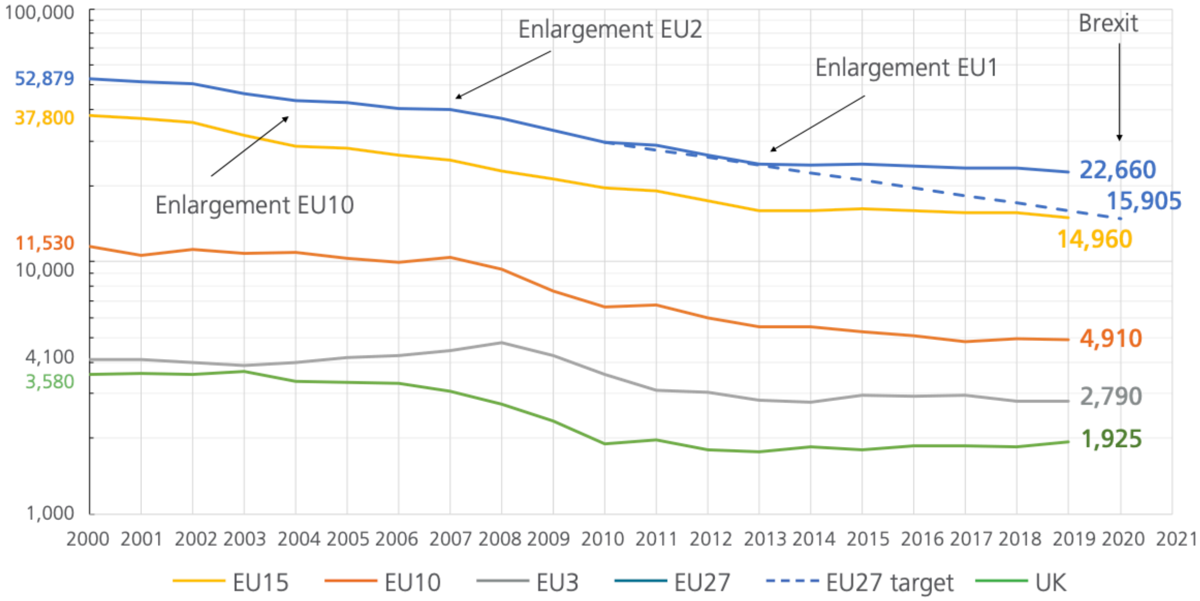


Figure 10 | Number and rate of road traffic death per 100,000 population: 2000-2016 (World Health Organization, 2018).



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[16] The EU14 were the first fifteen countries to join the EU minus the United Kingdom: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden.
The EU10 were the group of countries that joined the enlarged EU in 2004: Cyprus, Czechia, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia. The EU3 includes the latest three countries to join the EU: Romania and Bulgaria in 2007 and Croatia in 2013.

Figure 11 | Reduction in road deaths since 2000 in the EU27 (blue line), the EU14 (yellow line), the EU10 (red line), the EU3 (grey line) and the UK (green line). The logarithmic scale is used to enable the slopes of the various trend lines to be compared (European Transport Safety Council, 2020).

4.1.2.3 Urban space

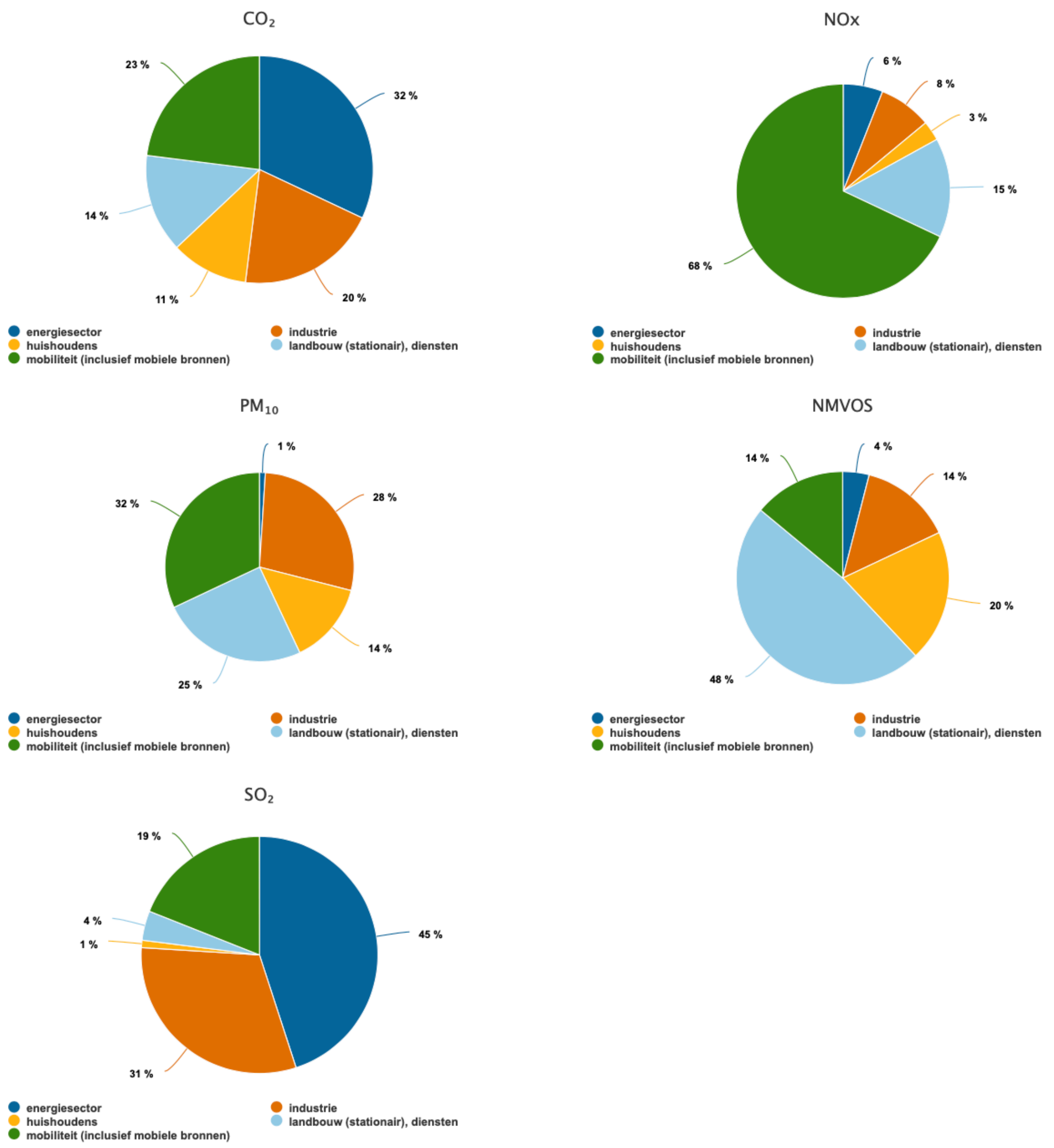
A lot of space in cities is used for transportation. Up to 60 percent of a metropolitan area may be used for transportation, an result of the over-reliance on some forms of urban transportation like the space consuming automobile. This includes the road themselves, but also parking facilities in the streets and in garages. Yet, this land consumption also underlines the strategic importance of transportation in the economic and social welfare of cities (Rodrigue et al., 2013).

However, the challenges facing cities, including ongoing urbanization, mean that the available space is becoming increasingly scarce. The destination of this space will have to be considered more and more carefully. It is possible that less and less priority should be given to the private car, all the more so because more asphalt does not so much solve any urban problems.

4.1.2.4 Environment

The traffic and transport sector also account for a significant part of global emissions (fig. 12), like NOx and CO2. In the Netherlands, for example, it is the largest source of NOx emissions (68%). Via NOx emissions, the traffic and transport sector contributes approximately 10% to the total nitrogen deposition in the Netherlands (RIVM, 2019). In 2015, 852.3 million tonnes of CO2 were emitted by road transport in the EU-28, which is more than 70% of emissions from all modes of transport (European Commission, 2017).

Transport is also one of the main, and increasing, contributors to air pollution. In particular, it is estimated that road transport is responsible for up to 30% of small particulate matter (PM) emissions in European cities and is the main cause of air-pollution-related deaths and illnesses (World Health Organization, 2015). Road transport is responsible for most of the emissions (Ministerie van Infrastructuur en Waterstaat, 2019).



Figuur E5.2.1: Relatieve bijdrage van de sector verkeer en vervoer (inclusief zeescheepvaart op het Nederlands Continentaal Plat en luchtvaart in de LTO-fase) aan de totale emissies van CO_2, NO_x, PM_{10}, NMVOS en SO_2 in Nederland in 2018. Bron: CBS Statline.

Figure 12 | Relative contribution of the traffic and transport sector (including shipping on the Dutch Continental Shelf and aviation in the LTO phase) to the total emissions of CO_2, NO_x, PM_{10}, NMVOC and SO_2 in the Netherlands in 2018 (Ministerie van Infrastructuur en Waterstaat, 2019)..

4.1.3 Developments

In the meantime, the world population is still increasing, and cities are still attracting people. According to the United Nations (2019), by 2050 almost 70% of the global population will live in urban areas (table 3). For the ‘High-income countries’ this figure is already at more than 80% and will rise to almost 90%.

Location	2015	2020	2025	2030	2035	2040	2045	2050
World	53.9	56.2	58.3	60.4	62.5	64.5	66.4	68.4
High-income countries	80.9	81.9	82.8	83.9	85.0	86.2	87.3	88.4

Table 3 | Annual percentage of population residing in urban areas (United Nations, 2019).

Also, cities will become bigger, as is illustrated in fig. 13. Cities of all sizes will grow in number, with the number of cities with at least 1 million inhabitants growing from 1,146 in 2018 to 1,416 in 2030. The majority of this growth will happen in Africa and Asia (table 4) (United Nations, 2019). This brings with it new challenges and opportunities for more efficient and sustainable mobility solutions.

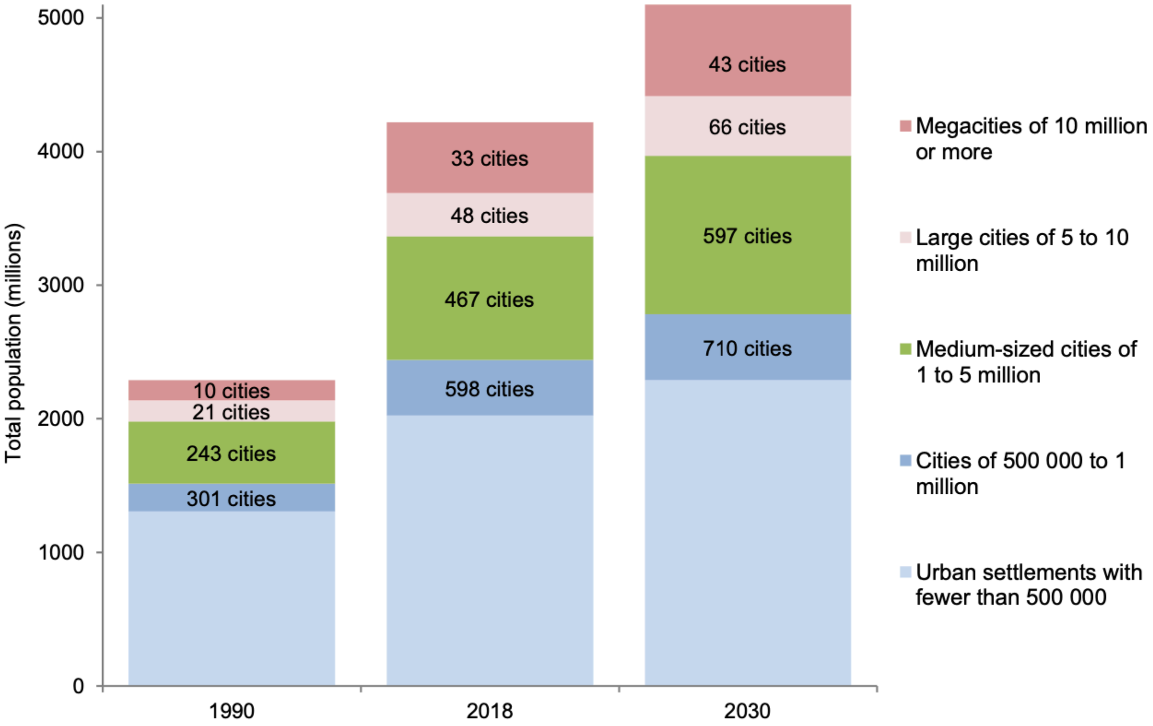


Figure 13 | Population and number of cities of the world, by size class of urban settlement (United Nations, 2019).

2015	2025	2035
1. Tokyo (37M)	1. Tokyo (37M)	1. Delhi (43M)
2. Delhi (26M)	2. Delhi (35M)	2. Tokyo (36M)
3. Shanghai (23M)	3. Shanghai (30M)	3. Shanghai (34M)
4. Mexico City (21M)	4. Dhaka (25M)*	4. Dhaka (31)
5. São Paulo (21M)	5. Cairo (23M)	5. Cairo (29M)
6. Bombay (19M)	6. São Paulo (23M)	6. Bombay (27M)
7. Osaka (19M)	7. Mexico City (23M)	7. Kinshasa (27M)*
8. Cairo (19M)	8. Beijing (23M)	8. Mexico City (25M)
9. New York-Newark (19M)	9. Bombay (22M)	9. Beijing (25M)
10. Beijing (18M)	10. New York-Newark (19M)	10. São Paulo (24M)

* = new entrant

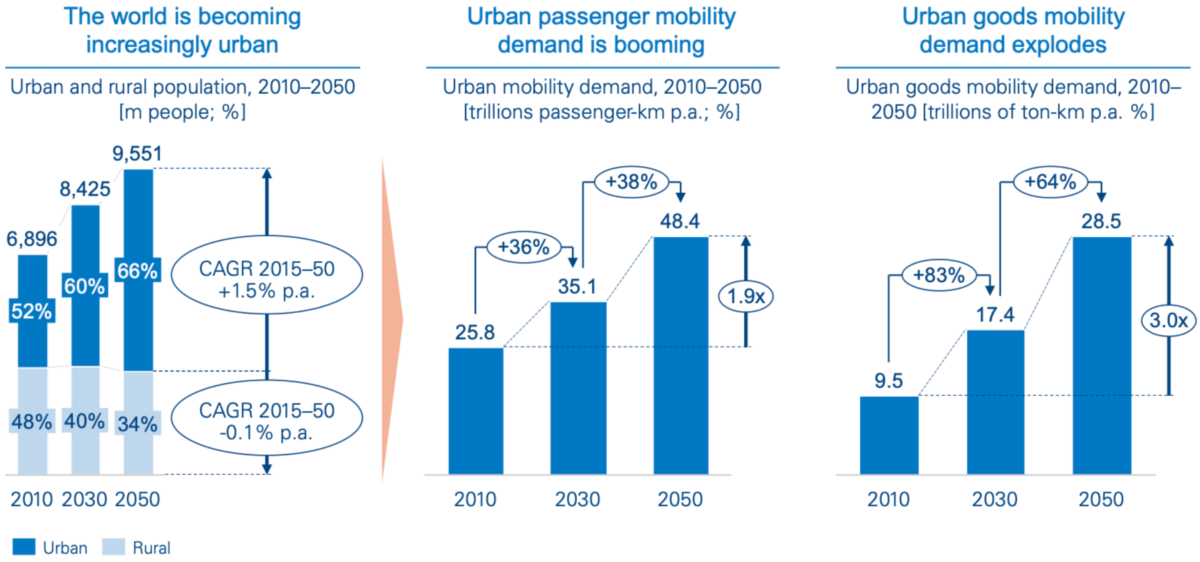
Table 4 | Top 10 largest cities (United Nations, 2019).

With the Earth's population expected to grow by almost a third between 2010 and 2050, already crunching mobility systems in our expanding cities will come under significant pressure. In such a context, innovation is crucial and yet research by Arthur D. Little (2011) shows that, instead of being advocated, innovative approaches are all too often stifled.

4.1.3.1 Relevance of urban mobility

With urban population growing from around 4 billion in 2020 to 6.6 billion in 2050, there are few issues set to become more challenging than the provision of well-developed and sustainable urban transport. As existing urban mobility systems are already facing breakdown in many regions, this presents a critical problem for policymakers worldwide, as the earlier mentioned problems will likely become worse if no intervention is taken (Arthur D. Little, 2011).

The problem is exacerbated by the fact that city workers are responsible for creating a significant amount of global GDP. By 2025, it is expected that they will contribute 86%. In such a context, it is vital that urban residents are able to move around freely. Meanwhile, it is expected that urban mobility – in terms of passengers-kilometers travelled per year – will almost double between 2010 and 2050, while it accounts for 'only' 64% of overall mobility today. Besides, the number of individual journeys taken on a daily basis has grown significantly since 2010. Even larger growth is expected in the field of goods mobility, especially in dense urban areas, due to the growing importance of e-commerce and the accompanying growth in demand for last-mile delivery (fig. 14) (Arthur D. Little, 2018). This emphasizes the increasing relevance and importance of urban mobility (Arthur D. Little, 2011).



Source: UN Department of Economic and Social Affairs, OECD/ITF, Arthur D. Little

Figure 14 | The future of mobility will be urban (Arthur D. Little, 2018).

4.1.3.2 Triple bottom line impact of urban mobility systems

If current trends continue, urban mobility systems will face a serious breakdown and exact a heavy toll. Mobility will especially grow until 2030, with road transport maintaining its dominant role in our mobility system. These developments concern both the transport of people and goods. The latter sector, however, is growing faster and is therefore more closely following economic developments. Passenger transport will also grow after 2030, but less quickly. This is mainly the result of an almost stagnant population after 2040 and saturation effects that limit the growth of car traffic. A similar picture exists for freight transport, as a result of the shift from economic activities to services and limits to distant sourcing and offshoring. The growth will be only slightly higher than that of passenger transport in the period between 2030 and 2050 (European Commission, 2016). Specifically, road passenger transport is estimated to grow with 16% during 2010-2030 and with 30% for 2010-2050. Road freight transport is projected to increase by 33% by 2030 and 55 % by 2050 (fig. 15).

Until 2050, and probably beyond, it is expected that road transport and in particular passenger cars will maintain their dominant role in transporting people. However, they will grow at lower pace relative to other modes (0.8% and 0.5% p.a. for 2010-30 and 2030-50, respectively, compared to growth rates of 1.0% and 0.7% for total transport activity). As a result, the modal share of passenger cars is expected to gradually decrease over time (from about 73% in 2010 to 70% in 2030 and 67% in 2050) (European Commission, 2016).

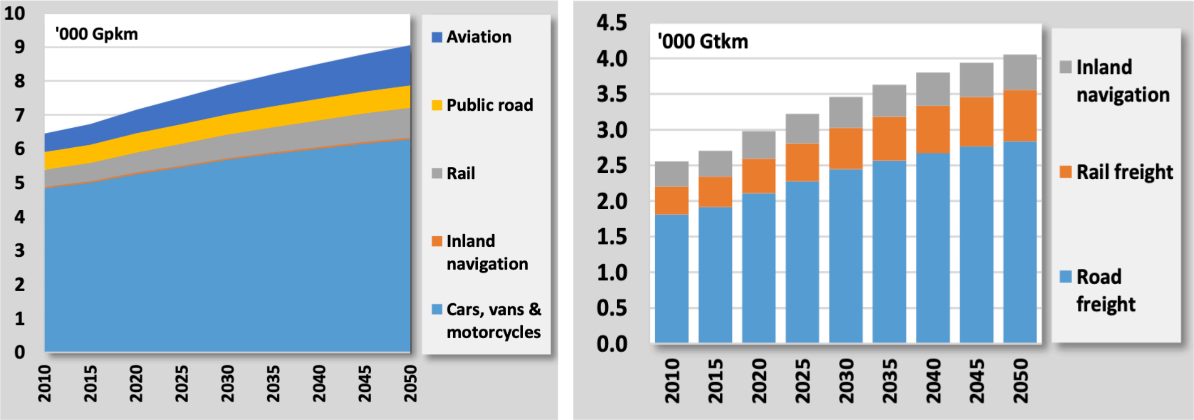
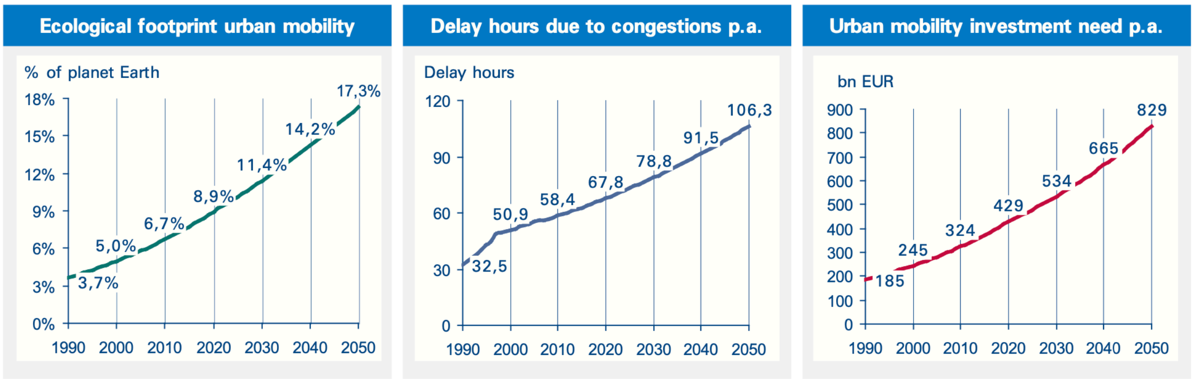


Figure 15 | Passenger transport activity by mode (left). Note: the figure reports the aviation related to the domestic and international intra-EU flights to maintain comparability with usual reported statistics. Freight transport activity by mode (right). Note: the figure reports freight transport activity excluding international shipping. Source: European Commission (2016).

Box 2: Car use in urban areas

It is uncertain whether we will see the same development on the city level. Here, both car ownership and the number of trips by car vary strongly per city, from 10% in Paris to 70% in Nicosia. It is uncertain whether we will see an increase or decrease of car use in urban areas. Past trends have shown a diminishing role for the car in some cities, like Vienna and Berlin, while in others it has increased (European Union and UN-Habitat, 2016). Some sources expect that car traffic in urban areas will keep growing (Kennisinstituut voor Mobiliteitsbeleid, 2017), while others expect it will decrease (Vandecasteele et al., 2019; European Union and UN-Habitat, 2016). In general, it might be expected that the dominance of the car will decrease in developed urban areas and increase in developing cities (Arthur D. Little, 2018; Alonso Raposo et al., 2019). However, it is doubtful if this will cause reducing congestion levels in urban areas, since past trends show worsening congestion in most cities (European Union, 2020; TomTom, n.d.).

The so-called triple bottom line – people, planet, profit – could seriously suffer from these developments (see fig. 16). For example, a citizen by 2050 could on average suffer some 100 hours of congestion-related delays a year, which is triple the number in 1990 (middle). These overloaded transport infrastructures will present a major obstacle to economic growth, requiring annual investment in urban mobility to quadruple to some €829bn worldwide by 2050 (right). This will cause a large increase in demand for energy and raw materials. As a result, 17.3% of the planet's bio-capacities will be needed to make urban mobility possible in 2050, which is five times more than in 1990 (left). Also, air and noise pollution will see a major increase. Given this, sustainability will become an increasingly key factor in the way the urban mobility systems of the future are designed (Arthur D. Little, 2011).



Source: Stockholm Environment Institute, US Census Bureau, UN Population Division, Schäfer/ Victor 2000, Siemens, Bureau of Transport Statistics, Arthur D. Little

Figure 16 | Tripple bottom line impact of urban mobility (Arthur D. Little, 2011).

4.1.4 Conclusion

This paragraph has shown that (urban) mobility will in all likelihood continue to increase in the coming decades - with a continuing important role for the private car - if we continue as it currently does. This entails all kinds of possible consequences: including increasing congestion, less space available for qualitative developments, safety risks and an increasing burden on the environment. Although in some developed countries and cities the share of car use has declined somewhat and a further decline is foreseen, these problems have persisted. Action will therefore have to be taken to realize a more sustainable and efficient mobility system, and thus more livable cities.

In order to achieve this, demand, i.e. the transport of persons and goods, should be limited as much as possible first. However, intervening in the development of mobility is difficult due to the complex whole of (relatively autonomous) economic, social and cultural factors that play a role in this. The next step is to fill in the remaining demand as sustainably and efficiently as possible. To this end, cities can follow different strategies. The key factors that will play a role in this are discussed in the next section.

4.2 Solutions for urban mobility

4.2.1 A range of (new) mobility options

Today, new visualisations of how our future cities should look like exist. The reasoning behind those studies is the fact that cities will have to deal with a diverse set of broad challenges, like healthy urbanization, social inclusion, the new economy, accessibility and climate adaptation. Part of these are also the mobility issues discussed in the previous paragraph. They arise from various developments, such as urbanization, mobility growth, climate change and growing socio-economic fragmentation. Facing all these challenges at the same time will become a challenge in itself for cities.

To address them, transitions in areas such as energy, climate, circularity, digitization and mobility are necessary. They can help to better balance the natural systems of which we are part. These transitions will most probably take place in the not too far future. The transitions require a great deal of space, while the pressure on public space is already rising. A challenging task, but this turbulence also offers opportunities to link various challenges and encourage new perspectives on the City of the Future (De Boer & Van der Wouden, 2019).

The transition that is particularly relevant for this thesis is the mobility transition, which is partially connected to the energy transition because many mobility modes require some sort of energy source for propulsion. With the mobility transition, cities aim to change existing mobility habits (e.g. less car use) in order to achieve more sustainable urban mobility systems. If the world fails to, and innovative mobility ecosystems fail to deliver on their promises, the future could be bleak. In response to the urban mobility challenges, so called Sustainable Urban Mobility Plans (SUMP) may prove particularly valuable. Such a plan, that contains a mix of urban mobility strategies, can help cities to deal with these challenges. Its central goal is to improve accessibility of urban areas and provide high-quality and sustainable mobility and transport to, through and within the urban area. It regards the needs of the 'functioning city' and its hinterland rather than a municipal administrative region. In pursuit of this goal, a SUMP aims to contribute to the development of an urban mobility system which, as cited from the European Commission (2013):

a) is accessible and meets the basic mobility needs of all users;
b) balances and responds to the diverse demands for mobility and transport services by citizens, businesses and industry;
c) guides a balanced development and better integration of the different transport modes;
d) meets the requirements of sustainability, balancing the need for economic viability, social equity, health and environmental quality;
e) optimises efficiency and cost effectiveness;
f) makes better use of urban space and of existing transport infrastructure and services;
g) enhances the attractiveness of the urban environment, quality of life, and public health;
h) improves traffic safety and security;
i) reduces air and noise pollution, greenhouse gas emissions, and energy consumption and
j) contributes to a better overall performance of the international transport system as a whole.

In theory, cities of today and cities of the future have a variety of options to make up such a SUMP to accommodate their mobility needs. These options can generally be divided into four key factors (fig. 17): cities can apply a variety of governance measures, but can also promote active and public transport, innovation and introduce new mobility services (Vandecasteele et al., 2019).

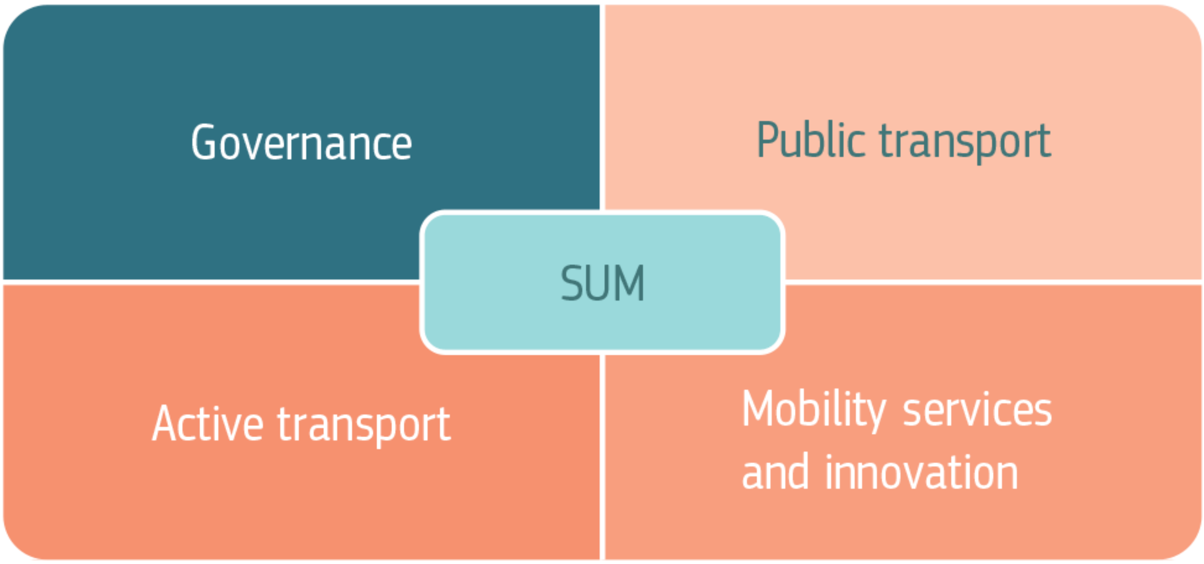


Figure 17 | Key factors to enable sustainable urban mobility (SUM) (Vandecasteele et al., 2019).

4.2.1.1 Public transport

The first and most important measure towards sustainable urban mobility is the correct optimisation of public transport. Reliable, affordable, safe, fast and frequent public transport will be key to compete with the car and enhance sustainable mobility in cities (Alonso Raposo et al., 2019). It can decrease energy consumption and pollutant emissions and reduce congestion, which can improve traffic flows and reduce travel times. Cities are in the unique position to provide optimised and efficient public transport networks (bus, metro, train or alternative systems) to meet the needs of their citizens. An example of good practice is the expansion of bus rapid transit (BRT) worldwide, particularly in Asia and Latin America (Zottis, 2014). Some cities are even introducing free public transport systems (e.g. Dunkirk and Tallinn). However, substantial efforts are still required to increase satisfaction with public transport across Europe (Vandecasteele et al., 2019), which faces many challenges (table 5) (European Union, 2020; Alonso Raposo et al., 2019). First, it generally remains more time-efficient to use a private vehicle than public transport. Public transport is often considered as slow and infrequent, while waiting time is also a factor (European Union, 2020; Moradi and Vagnoni, 2018; Turnheim et al., 2015). Also, highly subsidised public transport systems have always represented a significant cost for urban administrations (Alonso Raposo et al., 2019; Moradi and Vagnoni, 2018; European Union, 2020). The financial challenges involved are reflected in the age of the vehicle fleet (Moradi and Vagnoni, 2018). In Naples and Palermo, for example, aging vehicle fleets caused unavailability of vehicles, reliability problems and eventually an increase in car use (European Union, 2020). Besides, the (poor or moderate) last-mile connection is usually an important factor preventing the use of public transport (Alonso Raposo et al., 2019). Related to this is the factor of a sometimes lacking coverage of public transport, mostly in the peripheral commuting zones. This, together with a radial public transport layout and an increasing number of trips between different suburbs, contributes to the higher modal share of private vehicles there than within cities (European Union, 2020). Security, safety, tidiness (Alonso Raposo et al., 2019), comfort (Alonso Raposo et al., 2019; European Union, 2020; Institute for Mobility Research, 2016) and a negative cultural representation (Turnheim et al., 2015) are other elements that discourage the use of public transport in favour of individual mobility options.

Table 5 | List of cracks and tensions of public transport systems. These are causes of the relatively small (i.e. lower than desired) share in the modal split and of the preference for other transport modes, mostly the (private) car.

Cracks and tensions of public transport
- Negative cultural representation: 'people transport', slow, infrequent, etc. (Hodson et al., 2015; Turnheim et al., 2015a; Van der Eerden, 2013)
- Lack of security and safety (Alonso Raposo et al., 2019; Institute for Mobility Research, 2016)
- Lack of tidiness (Alonso Raposo et al., 2019)
- Lack of comfort or convenience (Alonso Raposo et al., 2019; European Union, 2020; Institute for Mobility Research, 2016)
- Negative or challenging public debates and opinions (Turnheim et al., 2015)
- Fleet age (European Union, 2020; Moradi and Vagnoni, 2018)
- Travel time (slower than car) (European Union, 2020; Moradi and Vagnoni, 2018; Institute for Mobility Research, 2016)
- Waiting time (Xin et al., 2005)
- Poor first- and last-mile connections (Alonso Raposo et al., 2019)
- Lacking coverage and accessibility (European Union, 2020; Institute for Mobility Research, 2016)
- Upstream rules and regulations (Moradi and Vagnoni, 2018)
- Not beneficiary in low population density zones (Moradi and Vagnoni, 2018)
- Significant costs for (local) government (Alonso Raposo et al., 2019; Moradi and Vagnoni, 2018; European Union, 2020)
- Limited operating hours (Moradi and Vagnoni, 2018; Institute for Mobility Research, 2016)
- Low financial support from government (Moradi and Vagnoni, 2018)

Moreover, public transport innovations, which can also be scaled under 'mobility services and innovations' (see below), encounter various barriers (table 6). They are considered expensive and unattractive in low density areas and require greater focus on spatial planning strategies. Also, significant alterations to regulations and taxes would be needed (Geels, 2012). Besides, they would require continuous data updates (Moradi and Vagnoni, 2018).

Table 6 | Potential problems and barriers of public transport innovations.

Problems and barriers of public transport innovations	
Public transport innovations – Special bus lanes – Real-time information panels – Short-distance radio systems – alternative fuels	- Expensive and unattractive in low density areas - Require greater focus on spatial planning strategies - Significant alterations to regulations and taxes (Geels, 2012) - Need continuous data updates (Moradi and Vagnoni, 2018)

4.2.1.2 Active transport

Walking and cycling are also important alternative transport modes in European cities, and especially suitable for distances up to two and 15 kilometres respectively (Millward et al., 2013; Planbureau voor de Leefomgeving, 2019). They promote a healthier lifestyle, increase accessibility and make the urban environment more attractive (Stevenson et al., 2016). Meanwhile, they contribute to a reduction of noise and polluting emissions. Some cities have been very successful in promoting these modes of mobility. In Copenhagen, Helsinki, Amsterdam and Vienna, more than 40% of the trips are made on foot or by bike. Many other cities can encourage walking and cycling by making such modes more attractive and convenient and by improving traffic safety (Vandecasteele et al., 2019). However, active transport still faces quite some cracks and tensions that prevent those mobility modes from growing to a larger modal share, as presented in table 7.

Table 7 | List of cracks and tensions of active transport systems. These are causes of the relatively small (i.e. lower than desired) share in the modal split and of the preference for other transport modes, mostly the (private) car.

Cracks and tensions of active transport
- Non-existent, incomplete, and poor quality sidewalks and crosswalks (Moradi and Vagnoni, 2018; European Union, 2020; Institute for Mobility Research, 2016) - Not supported by transportation agencies (Litman, 1994) - Poorly designed infrastructure (Moradi and Vagnoni, 2018; European Union, 2020; Institute for Mobility Research, 2016) - Lack of participation in policy design (Kim, 2015) - Bike theft (Replogle and Mundial, 1992; Institute for Mobility Research, 2016; Turnheim et al., 2015) - Slow modes (Moradi and Vagnoni, 2018) - Inadequate lane space for cyclists (Moradi and Vagnoni, 2018; European Union, 2020; Institute for Mobility Research, 2016) - Walking and cycling considered travel modes of last resort (Litman, 1994) - Accident risk (for cyclists) (Hatfield et al., 2015; Institute for Mobility Research, 2016; Turnheim et al., 2015)

- Physical environment (such as the weather or topography) (Moradi and Vagnoni, 2018; Institute for Mobility Research, 2016)

4.2.1.3 Mobility services and innovation

Both the private sector and cities themselves can incentivise the use of multimodal transport and new alternative modes of transport by introducing and operating new mobility services and making them easier to use. In the future, more integrated urban transport solutions will make use of dedicated digital platforms to bring together all available means of transport. This will combine, for example, public transport with autonomous electric-car sharing and short-term bicycle rental applications to offer Mobility as a Service (MaaS) (Vandecasteele et al., 2019). Ride-sharing and ride-hailing services can also both help to better connect the existing modes and solve the last-mile connection, which is usually the most important factor preventing the use of public transport (Alonso Raposo et al., 2019). A recent study for the Greater Dublin Area showed that such a combination of shared mobility and light rail services could significantly help to reduce the need for private cars (International Transport Forum, 2018a; Vandecasteele et al., 2019). Vehicle sharing is growing in popularity and its wider adoption in cities could help reduce the need for parking, thereby freeing up space for other developments, like new housing or green areas. Although integrated transport and sharing schemes have the potential to contribute to more sustainable urban mobility, both still face several problems to develop into the mobility regime (tables 8 and 9), which is why they have not utilized their potential yet.

Table 8 | Potential problems and barriers of integrated transport innovations.

Problems and barriers of integrated transport

- Time losses in transfers
- Low support from regime players
- Absence of powerful advocacy coalition
- Low economic interests (Geels, 2012)

Table 9 | Potential problems and barriers of sharing schemes.

Problems and barriers of sharing schemes

- Requires significant reconfiguration in conceptions of users, business model, tracking, monitoring and payment infrastructure and a mix of new and incumbent regime actors (Geels, 2014; Moradi and Vagnoni, 2018)
- Trust
- Less flexibility
- Not suitable for everyday use (Moradi and Vagnoni, 2018)

Also, car sharing alone would probably offer little relief for congestion in peak hours, when the majority of commuters have similar times of arrival and departure. Demand management has the potential to deal with this. It aims to reduce car use and includes initiatives like workplace and school travel plans, personalised travel planning, public transport information and marketing, travel awareness campaigns, residential and leisure travel plans, and urban cycling initiatives (Geels, 2012). Online platforms can offer their users important incentives as they increase the perceived reliability of the service by providing real-time information on congestion, vehicle arrival times and occupancy rates. This can help them to find the best way of getting from one place to another (Alonso Raposo et al., 2019; Vandecasteele et al., 2019). Also, technological advances, such as GPS tracking or automatic registration-plate identification, could provide opportunities for dynamic road pricing which, in turn, could help steer mobility choice and reduce congestion (Vandyck and Rutherford 2018, Cramton et al., 2018). With a system like this Gothenburg (SE) was able to reduce traffic by over 10%, in 2013, and increase the use of public transport (Vandecasteele et al., 2019). However, several barriers show why these behavioural-change oriented initiatives have not been the ultimate solution yet (table 10).

Table 10 | Potential problems and barriers of demand management.

Problems and barriers of demand management
- Still in the early stages - Limited momentum - Dependent on good intentions (Geels, 2012; Moradi and Vagnoni, 2018) - Changes of decision makers at local and municipal level - Depend on the interest of local government - Not obligatory for all cities - Lack of funds - Non feasible goals - Need for data and R&D - Absence of clear targets (Moradi and Vagnoni, 2018)

Connected and automated vehicles (CAVs) could help improve road safety, energy efficiency, urban accessibility, social inclusion and reduce congestion (Alonso Raposo et al., 2018). However, by lowering travel costs, vehicle automation could, in the absence of advanced road-governance schemes, compete with public transport and result in more trips – for both passengers and goods – and make traffic congestion and pollution worse (Alonso Raposo et al., 2019 and Vandecasteele et al., 2019). Other problems on the road to CAV deployment are outlined in table 11.

Table 11 | Potential problems and barriers of connected and automated vehicles.

Problems and barriers of connected and automated vehicles
- Recent severe and fatal accidents (Claybrook and Kildare, 2018) - Delays over the ambitious targets set by certain key players in the field (Hawkins, 2017). - Significant technological challenges to making fully automated driving a reality remain (Marshall, 2017), with training algorithms considered a crucial step towards ensuring safe and efficient vehicle operation in every driving situation (Nash, 2018).

The use of alternative fuels, and the electrification of road transport in particular, can help to diminish our dependency on fossil fuels and reduce pollutant and greenhouse gas (GHG) emissions. However, if combined with fossil-fuel-based electricity generation, electric mobility will only move the emissions upstream: from the road to the power plant. This does not necessarily reduce overall pollution. Significant investments in charging infrastructures will also be needed to enable the mass adoption of such technology (Tsakalidis & Thiel, 2018 and Vandecasteele et al., 2019). Besides, other factors play a role that could hinder the uptake of green propulsion technologies (table 12), while these technologies will not have an effect on the congestion problems.

Table 12 | Potential problems and barriers of green propulsion technologies.

Problems and barriers of green propulsion technologies	
General	- Experienced several ups and downs (hype disappointment cycles) Depend on: - Taxes or subsidies, - Tougher CO2 regulations - Technical improvements - Public investments in infrastructure (Geels, 2012)
Hydrogen fuel cell vehicles	- Repeated hype cycles (Geels, 2014; Turnheim et al., 2015b) - Technical and cost difficulties (Geels, 2014)
Biofuels	- Traceability and scope for sustainably scaling up (Turnheim et al., 2015b) - More expensive than fossil fuels (Geels, 2014)
Plug-in hybrid Electric vehicles	- Technical compromise (Turnheim et al., 2015b) - Purchase power
Battery electric vehicles	- Multiple hype/disappointment cycles - Need for interoperability of charging opportunities (Turnheim et al., 2015b) - Issues of vehicle range and cost (Geels, 2014) - Purchase power - Low travel range per charge - Lack of charging points - Not supported by administrative bodies - Long refueling time

4.2.1.4 Governance

While technological innovation and the development of alternative transport modes have the potential to cut travel time and increase mobility in cities, alternative governance approaches are trying to decrease the overall need for personal travel by:

Redesigning cities: Certain cultural and socio-spatial niches deviate from ‘normality’ and challenge basic assumptions of the automobility regime. Some examples are: sustainable urban planning, e.g. compact cities, smart growth, clustering of important destinations around public transport hubs and Transit Oriented Development to make public transport more efficient (Alonso Rapose et al., 2019), Complete Streets/Liveable Streets and homezones which include soft edges, a staggered street axis, and visual narrowing of the space. These practices are supported by social movement networks and community organisations which draw on counter-discourses that challenge the dominant order (e.g. sustainability, health, anti-consumerism) (Geels, 2012). Also, a new work - live - play urban model is promoted, whereby all the necessary services/housing/entertainment are within walking distance (De Boer & Van der Wouden, 2019;

Vandecasteele et al., 2019). Although these practices have contributed to the emergence of a new discourse of 'sustainable mobility', Sheller (2012) states that "it still remains questionable to what extent these cultural shifts will impact the overwhelmingly automobile-centred pattern of the majority of mobility". Some of them (e.g. liveable streets and homezones in the Netherlands) have existed for decades without much wider impact (Geels, 2012). The barriers that are related to such initiatives are outlined in table 13.

Table 13 | Potential problems and barriers of sustainable urban planning.

Problems and barriers of sustainable urban planning
- Unexpected and often counterproductive results on sustainable mobility: no lasting improvement, but halting more negative development (Turnheim et al., 2015b) - Very low techno-economic momentum (Geels, 2012; Turnheim et al., 2015b)

Bringing services to the people: the emergence of ICT into our daily life may create an information society with new practices such as tele-working, tele-shopping and tele-conferencing. For example, a growing proportion of workers can now work away from the office, e.g. at home or at flexible workplaces nearby. In 2017, 14% of the EU's urban population teleworked at least once a week (Vandecasteele et al., 2019). A recent JRC study provides a rough estimation of around 25% of employment in teleworkable sectors in the EU as a whole (Joint Research Centre, 2020). Since the outbreak of the Covid-19 pandemic, this percentage has increased strongly. Working from home has become the 'new normal' for millions of workers in the EU and worldwide. Early estimates from Eurofound (2020) suggest that close to 40% of those currently working in the EU began to telework fulltime as a result of the pandemic. Video conference platforms like Microsoft Teams and Zoom have seen a large growth. They have proven a great job and turned out very helpful in working remotely. On the other hand, the number of homeworkers declined again as the pandemic receded somewhat, which resulted, among other things, in increasingly busy roads and even the return of traffic jams. This could indicate that many people still prefer to work in the office..It will be interesting, yet uncertain, to see how this development will continue in the more distant future. Nevertheless, some of these practices may diminish the need for actual travel (Vandecasteele et al., 2019), but there are also problems that can be faced (table 14).

Table 14 | Potential problems and barriers of information and communication technologies.

Problems and barriers of information and communication technologies
- Internet security, privacy, integrity and the protection of human rights - Data authorization and usage (Johm et al., 2015) - Lack of the right ICT infrastructure - Tele-working not always (technically) feasible or desired - Productivity and working conditions may deteriorate for many workers (Joint Research Centre, 2020) - 'Digital panopticon' with centralised planners using travel information for surveillance and control of people (Dennis and Urry, 2009) - Generation of new mobility needs (e.g. making new friends through cyberspace and then deciding to visit them) (Geels, 2012) - Generation of trips for 'fun and entertainment' by enabling passengers to watch videos, use the (mobile) Internet, or communicate with the home or office inside a vehicle (Geels, 2012)

Recently, online shopping has dramatically increased as well, leading to fewer 'shopping trips'. However, a decline in the need for personal transport has been offset by an increase in the number of trips made by last-mile delivery vehicles. The use of electric drones and autonomous pony express for last-mile delivery could replace traditional delivery trucks and reduce congestion and emissions. Recent work has identified that up to 7.5% of the EU population could have access to home-delivery services (dispatched from drone beehives) if such services were legally authorised (Aurambout et al., 2019 and Vandecasteele et al., 2019). Related barriers in this area will be part of this thesis and discussed further in this report (chapter 7).

Adapting working hours: peak traffic hours often coincide with commuting trips. Thus, initiating dialogue with major employers to introduce more flexible working hours may help to redistribute traffic and lower congestion during peak hours (De Boer & Van der Wouden, 2019; Vandecasteele et al., 2019). See table 10 for related problems that can hold back this initiative.

4.2.2 Conclusion

The previous sections discussed a variety of existing and emerging key factors that cities can implement to deal with their mobility challenges and move towards more sustainable urban mobility. When these factors come together, the City of the Future arises, specified on the mobility domain, as we would like to see it. The design of the city is changing in that City of the Future. We are moving from a monocentric to a polycentric city, with multiple, compact city districts and neighborhoods that are situated around public transport hubs as much as possible. By taking proximity as a core principle and allowing each city neighborhood to be as self-sustaining as possible in terms of living, working and recreation, the need for mobility is limited. Digitization of work in particular also plays an important role in this. The remaining mobility needs can largely be accommodated by active transport (on foot or by bicycle); for longer distances between the various districts or cities, we use integrated transport, in which public transport, shared mobility, self-driving vehicles and, possibly, passenger drones play a central role.

In practice, however, every city is unique. How mobility evolves will depend on a city's current state (network and physical features) and its capacity to adopt new technologies and change behaviour. Whilst large infrastructure investments, such as the implementation of new, expensive public transport systems, may be possible in capital cities or cities which are growing very quickly, cheaper options, like optimising existing infrastructure and sharing, will be more feasible in others (Vandecasteele et al., 2019).

Although these factors have the potential to make a major contribution to making mobility more sustainable, they also face their barriers. In general, it appears that the mobility problems persist. Despite significant investments, there has been no significant reduction in private car usage (European Union, 2020) which may be due to different reasons as discussed in the previous sections. It can therefore be considered doubtful whether this change will take place in the future (i.e. the coming decades) or whether the dominant role of the car will decline and thus whether mobility problems - and mainly congestion - will decrease, let alone disappear, with help of the key factors discussed in previous sections. Therefore, it cannot be assumed that this is the case and cities will have to keep looking for alternatives. In this way, the end customer can be offered a variety of mobility choices and a contribution can be made to good connectivity and accessibility of the city.

4.3 Urban Air Mobility as part of the urban mobility solution

Contemporary cities are rich in technology, and that technology has always been used to address urban challenges. Due to the large number of inhabitants and high population densities, implementation costs in cities are lower, making them interesting locations to introduce new technologies. However, certain technologies on which cities rely heavily have barely changed over time. For example, most people still travel using a manually controlled car with an internal combustion engine. Something that we have been doing since the early 20th century (Vandecasteele et al., 2019).

A new technological revolution awaits us, due to developments in sensors, (mobile) internet and computer technology. The Internet of Things (IoT), Artificial Intelligence (AI), the high- resolution global positioning system (GPS), big data, and new building materials and techniques are likely to change cities' core functioning elements and affect every aspect of our lives. Many new technologies have had a positive impact, but some caused unintended negative effects. For example, the advent of the car caused an increase in mobility, congestion and air pollution. New, emerging technologies will also bring changes for cities, their core systems and their inhabitants. The only question is how (Vandecasteele et al., 2019).

The implementation of new technologies has resulted in important improvements in our quality of life, greater productivity, higher levels of public service provision, less need for commuting and extra leisure time. Smart highways and the deployment of 5G technologies along roads are now being planned (the Munich-Bologna corridor (Lupi, 2018)) and will greatly improve traffic information and management. Drones can be the kind of mobility services that will become part of the key factors to enable sustainable urban mobility (fig. 17). They will greatly assist emergency services, reduce delivery costs and eventually will even transport people (International Transport Forum, 2018b). In Paris alone, it has been projected that drones will account for almost 20,000 flights per hour by 2035 (Jasper, 2018 and Vandecasteele et al., 2019).

4.3.1 Defining Urban Air Mobility

Moving from A to B with a 'flying car' has always been one of people's greatest imaginations. Over the last few decades, some forms of vertical flight have existed using conventional helicopters and limited existing heliport infrastructure. However, their scopes are considerably narrower than the concepts of operations (ConOps) envisioned by proponents of what today is called Urban Air Mobility. Nor have they always been equally safe and economically successful. The next generation of UAM will ultimately be a mix of transformative technologies (6.1.2) – from electric propulsion systems to artificial intelligence and communications networks – and operational models (6.2.3 and Appendix D.4). These, together with the earlier mentioned urban challenges - like urban population growth, traffic congestion and air pollution - open a window of opportunity (6.1) into what will be possible in the near future. These developments will soon enable commercial passenger drone services and thus add a third dimension to the urban transportation mix of the future, changing the dream into reality. For the first time ever, cities will be able to leverage the sky for their mobility needs (Porsche Consulting, 2018).

Vertical mobility is making steady progress in research labs and companies around the world. It has the potential to become a piece in the everchanging puzzle called mobility. Novel ride-hailing and ride-sharing services on the ground have demonstrated that there are new ways to transport goods and people more efficiently and more economically (Porsche Consulting, 2018).

Urban Air Mobility (UAM) is an appearing concept that represents a significant paradigm shift. NASA defines UAM as "a safe and efficient system for air passenger and cargo transportation at a maximum height of 1,500 metres within an urban area, inclusive of small package delivery and other urban Unmanned Aerial Systems (UAS) services, that supports a mix of onboard/ground-piloted and increasingly autonomous operations". Most of the time, UAM is envisioned as on-demand air transportation within and between core urban areas and residential suburban destinations outside city centers. However, it can also play an important role in connecting rural areas. UAM has the potential to provide rural-urban connectivity in a more efficient and cost-effective way and can guarantee small communities adequate access to transportation options by certificated air carriers. The mission generally occurs over relatively short distances (typically less than 100 km), and most UAM concepts use new, electric-powered, vertical takeoff and landing (eVTOL) aircraft of some configuration (Appendix D.1). The vehicles are sometimes popularly referred to as air taxis, passenger drones or just ‘flying cars’ (Booz Allen Hamilton, 2018; NATA, n.d.).

The UAM concept can become an integral part of overall urban mobility (fig. 18) and is supposed to utilize uncongested, low-altitude airspace. This should be achieved through a fully integrated shared transportation system that seamlessly integrates surface and air transportation, where UAM can be connected with first- and last-mile transport modes or serve as one itself. They are an attractive and competitive way to cover distances of at least 15 to 25 kilometres and more, since they require relatively few infrastructure investments and can serve secondary and tertiary routes (NATA, n.d.; Porsche Consulting, 2018).

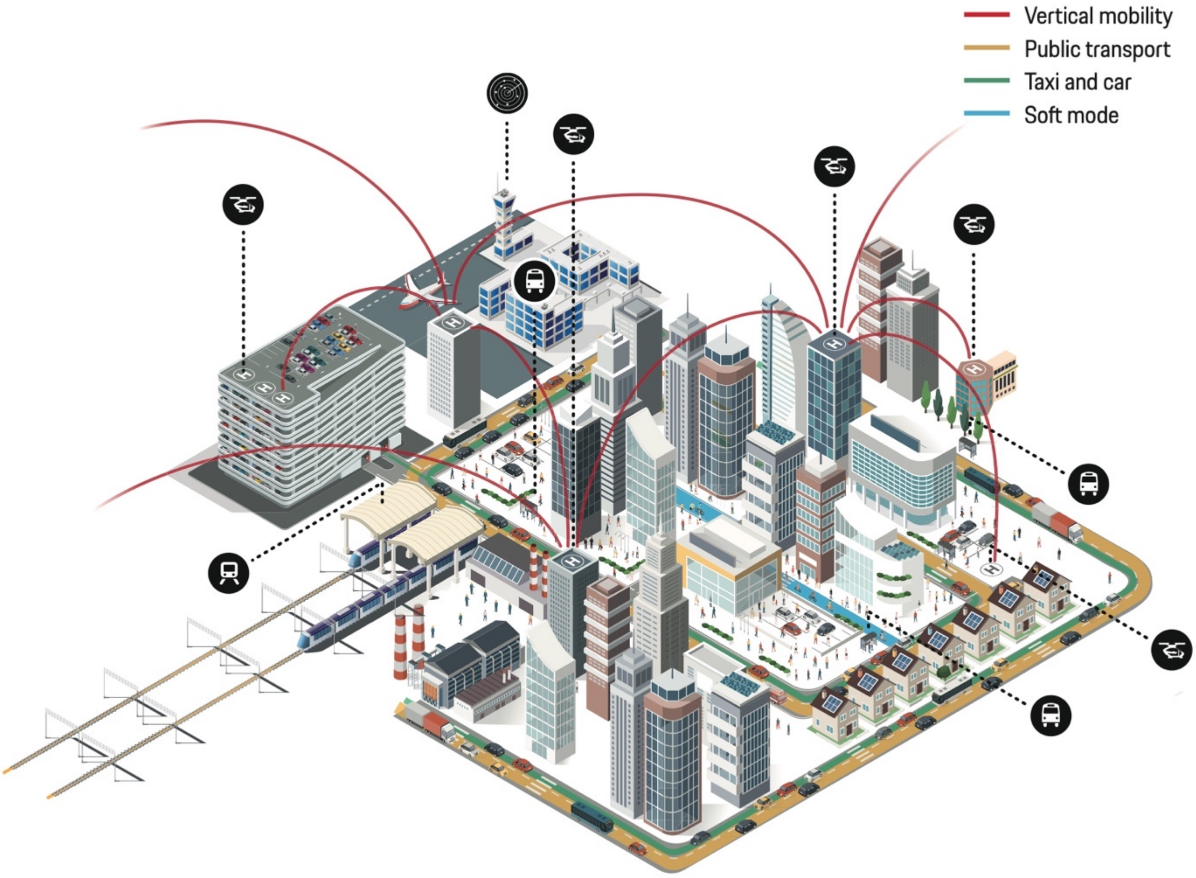


Figure 18 | Pieces of an integrated puzzle: air taxis can make a significant contribution to urban transport networks (Porsche Consulting, 2018).

Due to the emerging nature of the UAM concept, there exists no single business model, but one could be loosely defined as:

- On-demand: Generally speaking, UAM ConOps envision on-demand flights, similar to many of today’s ridesharing companies. However, UAM providers may seek to explore scheduled flights in the early stages before full scale demand justifies a more fluid flight schedule. Also, some use cases will always be better off with scheduled flights, regardless of the market stage (NATA, n.d.; Roland Berger, 2018; Crown Consulting, 2018).
- Vertical Takeoff and Landing: To minimize the required space for ground infrastructure, vertical take-off and landing aircraft are required to operate in dense urban cores that ask for a high degree of maneuverability (NATA, n.d.).

- Electric Propulsion: Most vehicle concepts use electric propulsion. Although it is not the only possible propulsion technique (6.1.2.1), the idea is that the low noise profile of electric propulsion might enhance social acceptance (NATA, n.d.).
- Value proposition: Every year, millions of hours of productivity are wasted through chronic road congestion (4.1.2 and 4.1.3). Some people, mainly commuters (4.3.4), are likely to pay a premium for early UAM operations. This could ultimately provide a (small) level of reduction in road congestion and thus encourage local policymakers to collaborate with UAM companies (NATA, n.d.).
- Reduced seat-mile cost: The ultimate goal of UAM operators is to reduce ride-share air transportation costs to that of ride-share surface transportation costs and seamlessly integrate both transportation modes (NATA, n.d.).

4.3.2 Why now?

The idea of UAM is not new, but the developments in the field have accelerated over the last few years. Major investments in technology (>$1 billion) lead to advances in batteries and computer controllers for electric motors. Moreover, the lessons learned from drone technology allowed for the development of vehicles that were less expensive and more efficient than helicopters. While not very long, the resulting range is acceptable for urban operations. A vehicle that is build-up out of basic components and software is economically more efficient to operate. Besides, it no longer runs a hydrocarbon combustion engine, making it more environmentally friendly and more quiet (Wright, 2018; Hirschberg, 2018).

4.3.3 Promises

Vertical mobility has the potential to create wide-ranging social benefits by addressing earlier mentioned mobility challenges at hand. As an integrated part of future urban mobility, passenger drones offer significant advantages (fig. 19 and table 15). They are an innovative, sustainable, safe and fast transportation mode that only requires a point-based infrastructure network. This means that limited amounts of space and low infrastructure investments are needed, because “air roads” are almost cost-free and lack traditional limiting factors such as intersections. By using renewable energy sources, they can fly energy neutral as well. Besides, they are supposed to enhance safety because autonomy must exclude human errors. Drone flights provide extra flexibility because they are easy to configure and adopt second- and third-tier connections in a city. The basic precondition for this market to develop, is improved transportation efficiency. UAM could revolutionize the way people move within and around cities by shortening commute times, bypassing ground congestion, and enabling point-to-point flights across cities. And, drones can improve the connectivity in less populated areas with lacking facilities (Porsche Consulting, 2018; NATA, n.d.).

Customers already have a wide choice of transportation modes in which passenger drones must find their appropriate place. On the one hand, there are fixed line modes like the subway, train, or commercial airlines that predictably go from point A to B. On the other hand, there are individual modes, like the bicycle and private car. A seamless experience of on-demand mobility (fig. 20) via personal flight will take customers from quickly putting together their itinerary, ordering their fly-ride, catching ground transport to a vertiport, boarding the eVTOL flight, and, once landed, having a ride-hailing service waiting to cover the last mile. Navigating this multipart journey also allows for the more efficient use of existing bottlenecks on the ground by unburdening congested infrastructure. UAM can alleviate pressure from the existing transportation system and make public transport and MaaS more accessible (Porsche Consulting, 2018 and Roosien & Bussink, 2018).

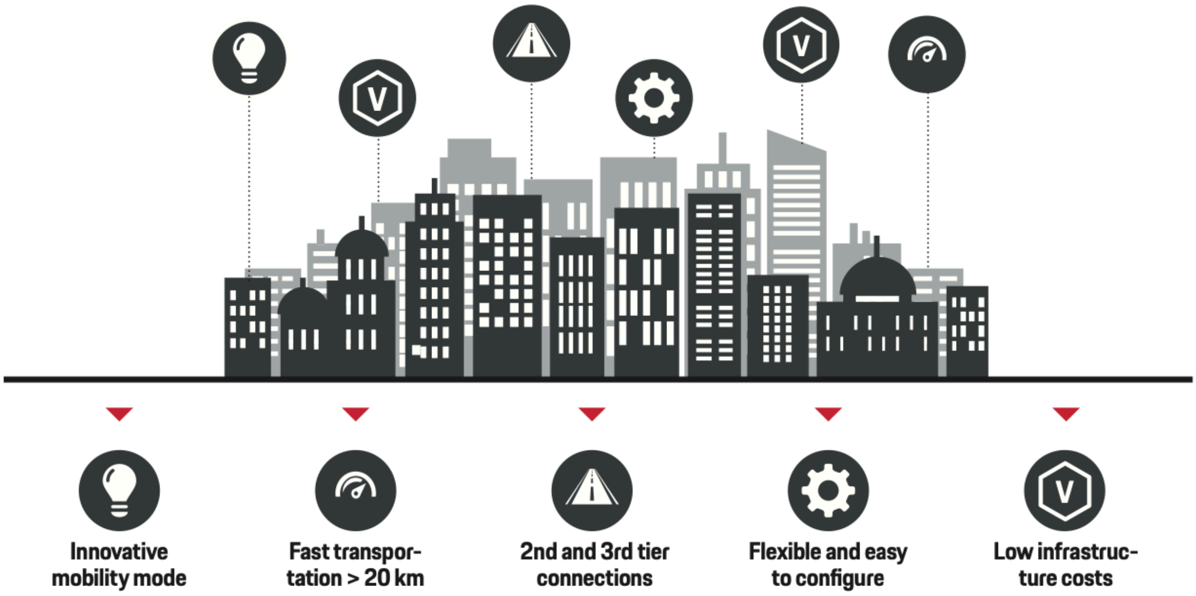


Figure 19 | Winning on time, space and cost: passenger drones can become an integral part of future urban mobility (Porsche Consulting, 2018).

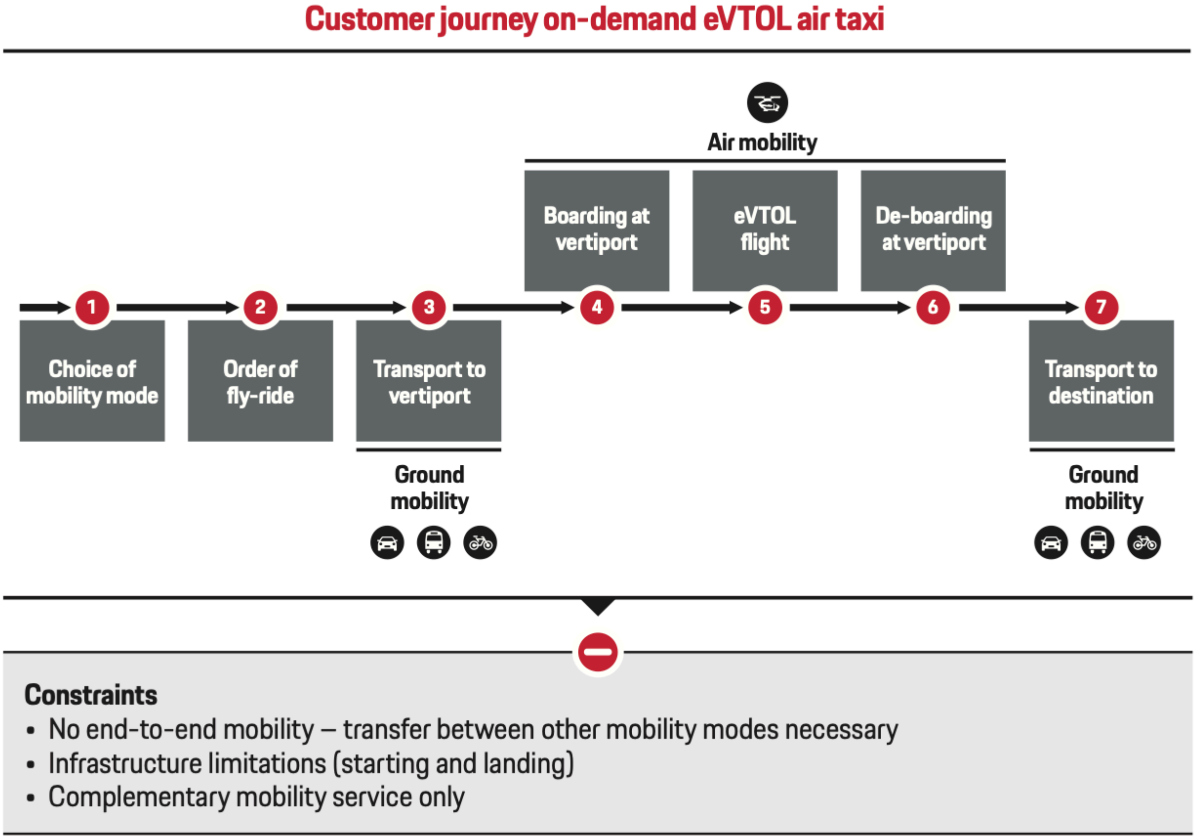


Figure 20 | From click to lift-off: eVTOL mobility services offer an end-to-end journey that combines ground with air transport (Porsche Consulting, 2018).

Table 15 | List of potential advantages that UAM is able to offer.

Potential advantages of Urban Air Mobility
- UAM will often enable faster and shorter point-to-point connections than its alternatives, especially on longer distances (> 20 km) (Crown Consulting, 2018; Roland Berger, 2018; Porsche Consulting, 2018; Kasliwal et al., 2019) - High predictability of travel times (Kasliwal et al., 2019) - Increased electrification for lower in situ emissions (Community Air Mobility Initiative, 2020a; Porsche Consulting, 2018; Roland Berger, 2018) - Relatively little ground infrastructure needed (Porsche Consulting, 2018) - Autonomy must improve safety levels higher than those of helicopters and cars (Porsche Consulting, 2018; Roland Berger, 2018) - Possible improvement for integrated transport and MaaS (Porsche Consulting, 2018; Roland Berger, 2018) - Quieter than helicopters (Crown Consulting, 2018; Porsche Consulting, 2018) - More reliable than helicopters (Porsche Consulting, 2018) - Less expensive than helicopters (Porsche Consulting, 2018; Roland Berger, 2018) - Reduced need for ground vehicle traffic within urban core - Reduced emergency response times - Increased range of access to the urban core - Additional transportation demand management options - Urgency-trip pairing with commuter transit - Stronger connection of rural areas to urban opportunities - Increased utility of GA airport infrastructure - Additional disaster response capabilities - Elimination of transportation deserts (Community Air Mobility Initiative, 2020a)

4.3.4 Disadvantages

In addition to advantages, Urban Air Mobility certainly has disadvantages (table 17), which keep the market potential relatively limited and make it unlikely that UAM will become the ultimate solution for sustainable urban mobility. While the ideal has always been that "flying cars" will shift mobility flows to the air and ground transportation becomes obsolete, market demand for UAM makes this unlikely for at least some decades to come (Porsche Consulting, 2018; Roland Berger, 2018; KPMG, 2019). This can be explained by various adverse factors.

A first disadvantage is related to economics and refers to the high price level of UAM (table 16). The expected initial price levels are roughly between \$1.86 and \$5.55 per VKT or between \$6.25 and \$18.75 per minute, assuming an average speed of 200 km/h (KPMG, 2019; Porsche Consulting, 2018; Uber Elevate, 2016). With an average of three paying passengers per vehicle (Kasliwal et al., 2019; Uber Elevate, 2016; Crown Consulting, 2018), this amounts to \$0.62 to \$1.85 per passenger-kilometer traveled (PKT) or \$2.08 to \$6.25 per passenger-minute traveled (PMT). Expectations for medium to long-term price development as the market scales vary: from a price level comparable to that of a taxi (Roland Berger, 2018; KPMG, 2019) to a price level well below, namely less than \$1 per VKT (Uber Elevate, 2016).

Table 16 | Expected price levels for UAM services. It is assumed that on average, each flight will have three paying passengers.

Study	Price per VKT [$]	Price per PKT [$]
Porsche Consulting (2018)	$2.40-$5.40	$0.80-$1.80
KPMG (2019)	$1.86-$3.11	$0.62-$1.04
Uber Elevate (2016)	Initial: $3.90-$5.55 Near-term: $1.29-$1.83 Long-term: $0.63-$0.87	Initial: $1.30-$1.85 Near-term: $0.43-$0.61 Long-term: $0.21-$0.29

In the latter case, the air taxi would actually become accessible to a wider public. However, some critical notions can be made to this assumption. Firstly, the question is whether people are willing to step into an (autonomously flying) drone. Some inventories seem to indicate that there is (ex ante) a group of people that dares to do so. But what happens to this fledgling enthusiasm when there are casualties as a result of a crash? For flying cars and air taxis, large-scale application will require explicit attention to safety in order to gain and maintain passenger confidence. The second question is whether a provider of air taxi services will succeed in bundling demand and turning it into a successful sub-concept. Passengers will usually be at different locations and may not be willing to share a flight, especially in times of a pandemic (e.g. COVID-19). In essence, this is not different from current taxi services, and shared taxis only fill in a small part of the market (Ministerie van Infrastructuur en Waterstaat, 2017). Therefore, if we assume the initial price level for now, this means that a flight of 50 km, in 15 minutes, can in principle cost about $ 95 to $ 280. In the case of three paying passengers, this equates to a good $ 30 to $ 90 per person. Although faster than alternatives such as the car and public transport, this is also drastically more expensive. With an average Value of Time of €9 ($10.55) and €9.25 ($10.84) per hour per person for car and train respectively (Warffemius et al., 2013), which will be UAM's main competitors (Crown Consulting, 2018; Ministerie van Infrastructuur en Waterstaat, 2017), it is likely that UAM will be an overpriced option for most people to use as an everyday modality. Initially, therefore, people from the higher income groups, with a high travel time rating, will be most interested in UAM (Ministerie van Infrastructuur en Waterstaat, 2017). UAM will therefore be used more often for business purposes, for which the Value of Time is significantly higher at €26.25 ($30.76) and €19.75 ($23.14) per hour per person for car and train respectively. (Warffemius et al., 2013). The willingness to start using UAM at the stated price level is therefore generally considered to be relatively limited. From an economic point of view, a serious market will therefore only arise when a city meets two important and noteworthy aspects that we can relate to it: the GDP and the wealth concentration of a city. Cities with a high GDP and many high incomes will make up a larger market for UAM than cities with lower variables. Aspects that are also important in this respect are demographic characteristics such as a large population and high population density (see also 4.3.5) (KPMG, 2019; Roland Berger, 2018; Porsche Consulting, 2018).

Another disadvantage, or rather a shortcoming, of UAM has to do with the realization of time savings, the main driver of UAM. The disadvantage lies in the fact that UAM will mainly prove its value over longer distances. At shorter distances, (existing) ground transport will usually be only slightly slower or even faster. The exact boundary will differ per situation and per city and depend, among other things, on existing travel times, congestion levels, minimum time savings to accept transfer connection with ride-and-fly, vertiport coverage, transfers and first- and last-mile connections (Porsche Consulting, 2018; KPMG, 2019). Depending on the values of these variables, the minimum required distance for VTOL routes will be higher or lower, whereby Uber Elevate (2016), for example, assumes that the estimated duration of the VTOL route should be at least 40% faster relative to the estimated duration of the ground trip. However, on average the minimum required distance for VTOL routes is estimated to be somewhere between 15 and 25 km (Porsche Consulting, 2018; Roland Berger, 2018). Below that, (existing) ground transport will usually be faster, while the average ground-based vehicle journey is no longer than approximately 11 km (Porsche Consulting, 2018; Ministerie van Infrastructuur en Waterstaat, 2019; Centraal Bureau voor de Statistiek, 2017) to 17 km (Kasliwal et al., 2019). In terms of travel time savings, UAM is therefore not of added value for every journey, but only for medium to longer distance trips. This is illustrated by an example from the Munich Metropolitan Area (fig. 21). This region is also discussed later on in this thesis (chapter 7).

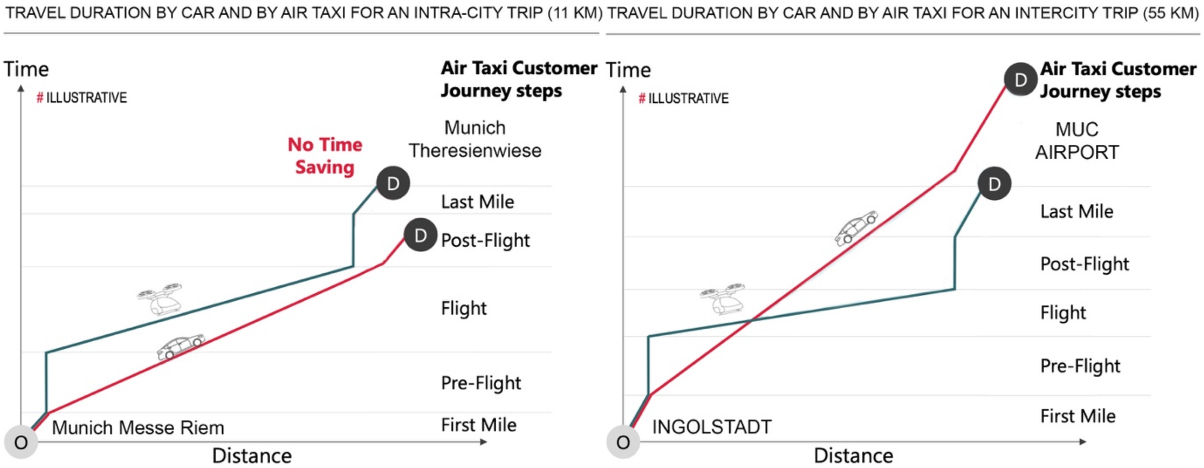

TRAVEL DURATION BY CAR AND BY AIR TAXI FOR AN INTRA-CITY TRIP (11 KM) TRAVEL DURATION BY CAR AND BY AIR TAXI FOR AN INTERCITY TRIP (55 KM)

Figure 21 | Travel duration by car and by air taxi for a short- (left) and long-distance trip (right) in the Munich Metropolitan Area. The passenger drone beats the car in terms of travel time on long-distance trips, but not (always) on short-distance trips. Obviously, the distance of the VTOL route is shorter than that of the car, thanks to the opportunity of straight-line traveling. The pre-flight phase comprises a ticket and security check, the boarding of the passengers, taxiing of the vehicle to the take-off and landing pad, clearance and finally the take-off. The post-flight phase comprises the descent, taxiing of the vehicle to the parking bay and deboarding of the passengers. These phases are also briefly discussed later on in this thesis (chapter 7). Sources: Porsche Consulting (2018), eMove360 (2019).

UAM is also considerably less energy efficient than its alternatives. Internal combustion engine cars (ICEVs) perform better than passenger drones on distances up to ~35km VKT. This is caused by the dominance of the energy-intensive hover mode of aircraft on these shorter distances. For long-distance trips, VTOLs can leverage efficient cruise performance to outperform ICEVs. Besides, the VTOL emissions approach, but do not match, those of battery-electric cars (BEVs) for distances > ~120 km. Only when VTOLs operate at or near-full capacity with at least three passengers (pilot excluded), they will be relatively efficient and able to outperform average-occupancy BEVs (with 1.54 passengers) (Kasliwal et al., 2019).

Another disadvantage concerns the number of people that can be transported with passenger drones. Most vehicle concepts are based on one to five passengers per drone (Appendix D.1), relatively few compared to alternative transporation modes. Depending on the development of the battery technology (6.1.2.1), larger vehicles may be possible in the future, but whether this will improve energy efficiency is a big question. With the current vehicle concepts, it will only be possible to transport large numbers of people with a large fleet of passenger drones, which would be desirable from the point of view of the congestion problem. Only then could there be a significant effect on urban congestion levels. However, this requires significant amounts of ground infrastructure (and low price levels), which does not seem realistic (7.3.3) (Powell, 2020).

Furthermore, UAM will cause social impacts when larger fleets of passenger drones emerge in cities (see also 7.3.3). This includes noise pollution. With approximately 72-75 dB(A), the noise production of passenger drones is comparable to levels adjacent to highways (Crown Consulting, 2018; Volocopter, 2019). In addition, passenger drones will leverage the now almost empty airspace above cities. The consequence of this is horizon pollution. The privacy of citizens may also be at risk when passenger drones fly over their heads and houses. There is also a risk that autonomously flying passenger drones will cause jobs to disappear. On the other hand, certain sectors will also see new jobs appear (Williams, n.d.). Finally, there is the risk of growing social inequality and tensions arising from the situation in which upper class higher income individuals are avoiding traffic by flying in drones, and middle class and lower class are being stuck in traffic.

Table 17 | List of potential disadvantages that UAM could bring.

Potential disadvantages of Urban Air Mobility
- UAM will not be suitable for cities that lack the right economic and demographic circumstances (KPMG, 2019) - Passenger drones will often be and remain less time efficient than alternative transportation modes at shorter distances (< ~20 km), depending on the specific circumstances in place (Porsche Consulting, 2018; Roland Berger, 2018) - Passenger drones will be less energy efficient than ICEVs at shorter distances, approximately up to 35 km VKT - Passenger drones will be less energy efficient than BEVs, unless they fly longer distances at or near-full capacity (Kasliwal et al., 2019; Uber Elevate, 2016) - High costs for a flight might cause low willingness to pay for speed (instant delivery, trip time) (Crown Consulting, 2018) - The number of people transported in each drone is limited compared to many ground-based transportation modes - Societal impact might be significant when larger fleets of passenger drones emerge in cities (Crown Consulting, 2018; Williams, n.d.) - Low market potential makes it not the ultimate sustainable mobility solution (Porsche Consulting, 2018)

To conclude, all of these factors, which can basically be seen as disadvantages of UAM, affect the market potential of UAM. Together, they make that this market potential will be relatively limited. UAM will most likely have a niche role in sustainable mobility and become one of the subaltern mobility regimes, in terms of market share still below existing subaltern regimes like public and active transport. UAM will be a suitable mode of transportation in specific places, for specific people and under specific circumstances. These specific places will mostly be larger and denser urban areas, with a high GDP. The main target group, at least at the start and in the near-term, consists of high-income people. Furthermore, UAM will mainly flourish on longer distances, under circumstances in which much travel time can be saved by bypassing congested or lacking ground connections. Although vertical mobility still holds the promise to relieve some pressure from particularly congested urban hot spots, this will only be some. This means that UAM will, generally spoken, not be the ultimate solution for sustainable urban mobility, which specifically means that it will not solve the congestion problem and will not have a major effect on reducing pollutant emissions. However, this does not mean that UAM will in no case be of added value. It is important to note that it can become a crucial part of an integrated solution to mitigate our growing transportation woes, by improving the connectivity and accessibility of urban areas that adopt this new mobility mode, among others. The next section will further discuss where, when and how many passenger drones there will fly.

4.3.5 Where, when, and how many passenger drones will there fly?

The question is not whether UAM will emerge as a feasible ride-sharing option. Rather, the question for relevant stakeholders who plan to participate in UAM is where, when and in which numbers (KPMG, 2019). The technology and product development of passenger drones and flying cars seem to be swiftly progressing. These vehicle concepts have been under development since the 1980s, and various prototypes already exist. The majority of these are electrically propelled and capable of vertical take-off and landing (Appendix D.1) (Deloitte, 2018). However, only recently these developments have rapidly increased (fig. 22).

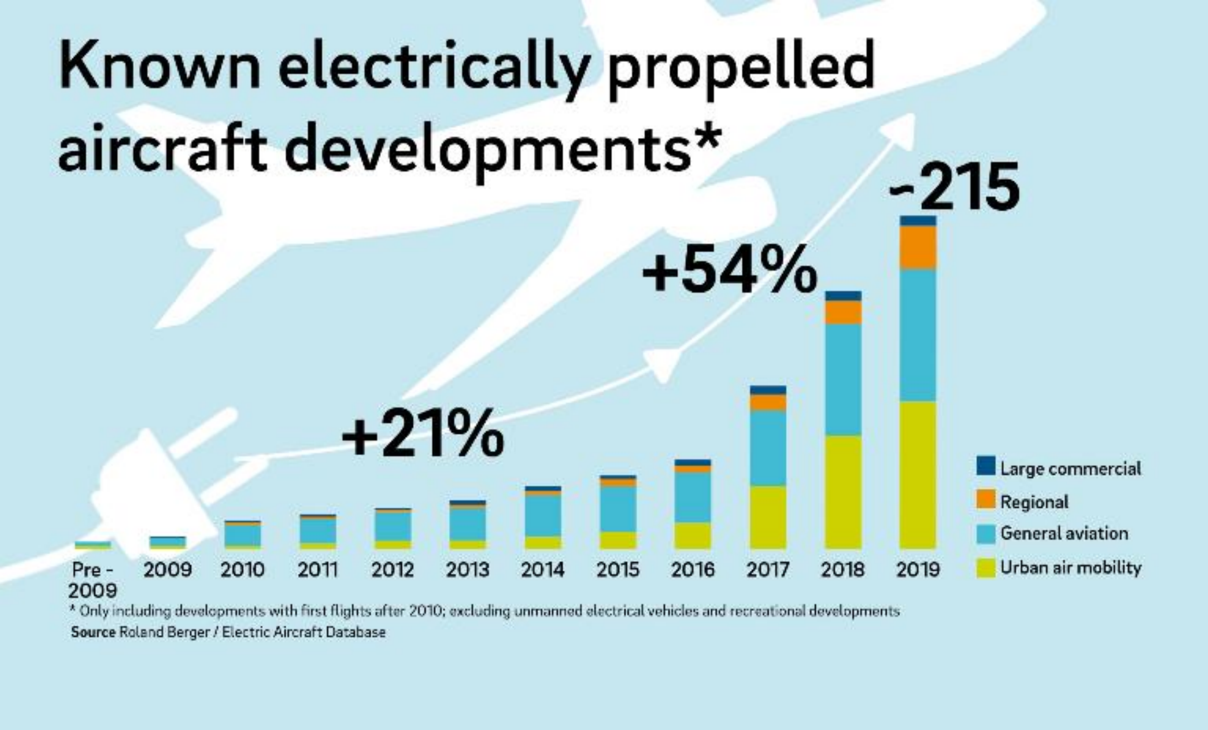
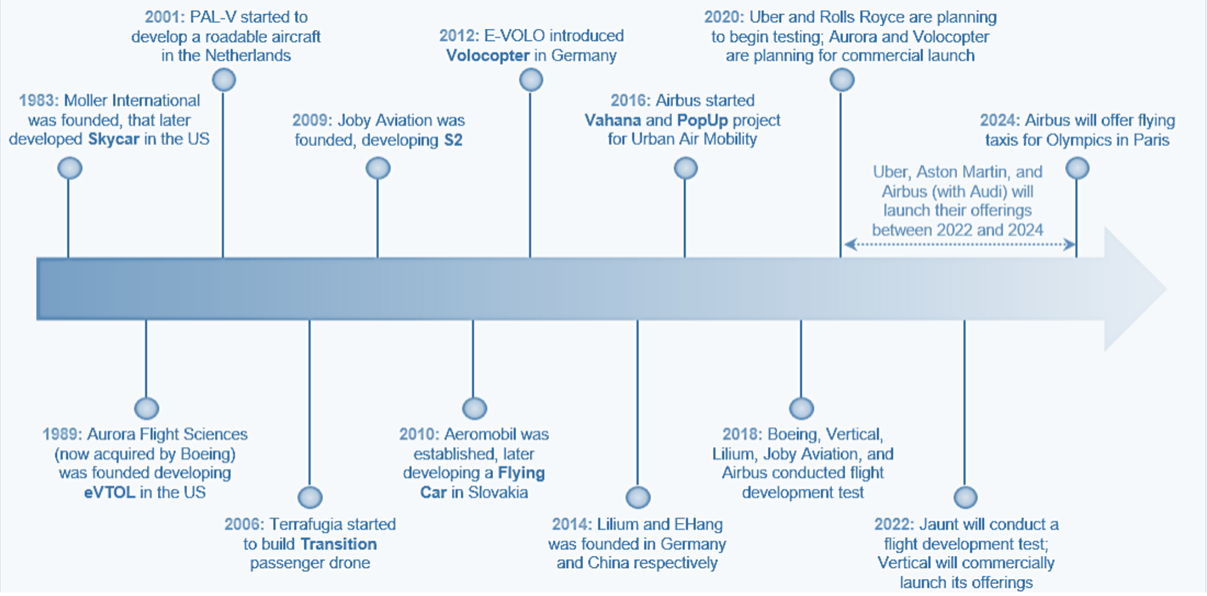


Figure 22 | Known electrically propelled aircraft developments (Thomson, 2020).

In the 21st century, major milestones have been and are to be achieved (fig. 23). As a testament to the maturity of the technology and the market, some big, traditional companies have joined fast-growing start-ups that are making major investments and commitments to UAM development and deployment. Promising vehicle concepts have already been introduced, and UAM demonstration projects have already been conducted, while others are underway, in places like Guangzhou, Singapore, Sao Paulo, Dubai, and New Zealand (NATA, n.d.).



1983: Moller International was founded, that later developed **Skycar** in the US

1989: Aurora Flight Sciences (now acquired by Boeing) was founded developing **eVTOL** in the US

2001: PAL-V started to develop a roadable aircraft in the Netherlands

2006: Terrafugia started to build **Transition** passenger drone

2009: Joby Aviation was founded, developing **S2**

2010: Aeromobil was established, later developing a **Flying Car** in Slovakia

2012: E-VOLO introduced **Volocopter** in Germany

2014: Lilium and EHang was founded in Germany and China respectively

2016: Airbus started **Vahana** and **PopUp** project for Urban Air Mobility

2018: Boeing, Vertical, Lilium, Joby Aviation, and Airbus conducted flight development test

2020: Uber and Rolls Royce are planning to begin testing; Aurora and Volocopter are planning for commercial launch

Uber, Aston Martin, and Airbus (with Audi) will launch their offerings between 2022 and 2024

2022: Jaunt will conduct a flight development test; Vertical will commercially launch its offerings

2024: Airbus will offer flying taxis for Olympics in Paris

Figure 23 | Key milestones during the development and commercialization of passenger drones (Deloitte, 2018; FutureBridge, n.d.).

It is generally assumed that it will take a while for the market to develop towards scaled commercial UAM passenger operations. Currently, the first vehicles are tested and it will not take long until small scale (private) operations will start in the early 2020's (fig. 24), e.g. by Quantum Air (Hampel, 2020) and PAL-V in 2021 (PAL-V, 2018).

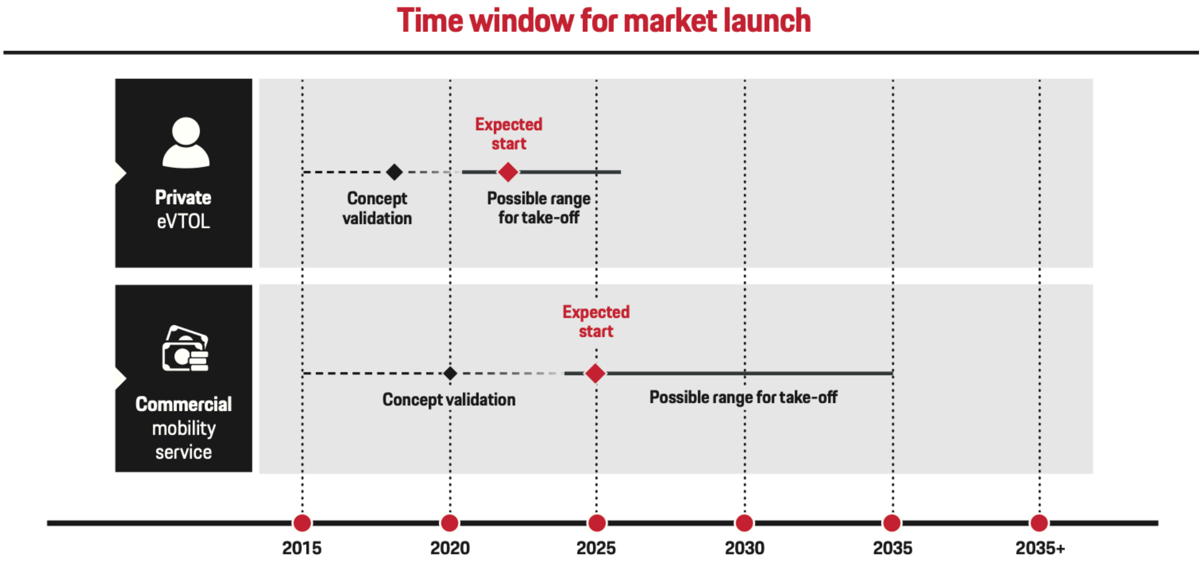


Figure 24 | Designing for the coming volume market: development timeline for private and commercial markets until 2035 (Porsche Consulting, 2018).

From 2023, we may start to see initial commercial operations (NASA, 2020c). In this year, Uber aims to start its services, beginning in Los Angeles, Dallas and Melbourne (Uber Elevate, n.d.). However, there is a significant degree of uncertainty as to whether the start of these types of commercial services is feasible before 2025. The technology is currently several years ahead of policymakers, meaning that community integration of UAM is falling behind. Cities will still need quite some time prepare, and it will be necessary to catch up to enable a market launch before 2025 (Alexander, 2020). It is therefore assumed that the first commercial services can be expected in the second half the 2020's (fig. 25 and 26). Innovative cities such as Singapore, Dubai, São Paulo, or Dallas/Fort Worth will be the main early adopters (NASA, 2020c; Porsche Consulting, 2018; Crown Consulting, 2018; Roland Berger, 2018b).

From 2025, the market will start to develop significantly. A few market studies (Booz Allen Hamilton, 2018; Crown Consulting, 2018; FutureBridge, n.d.; KPMG, 2019; Porsche Consulting; 2018; Roland Berger, 2018) have made forecasts regarding the expected numbers of passenger drones over time and it turns out that most of them are more or less in line with each other (fig. 26). The main exception to this is the study by Crown Consulting (2018). They expect 23 thousand passenger drones in the US alone by 2030, while all other known studies make a significantly lower estimate for the global market in 2030. The study by Booz Allen Hamilton (2018) also focuses only on the US market and, moreover, only makes statements about the 'near-term' market. While not very clear, the moment of this "near-term" market is assumed at 2030, in which they expect 4,100 passenger drones in the US. This makes this study more consistent with other studies. However, it does not contain any clear statements about specific years, the market development over time and the global market and so we have to rely on this single point for the US market. Furthermore, KPMG (2019) has based the market potential for UAM on the expected number of passenger enplanements. Although other studies have made assumptions regarding various indicators (e.g. average trip duration, average vehicle occupancy, operational hours, etc.) that can be used to calculate the number of passenger drones based on the number of passenger enplanements, it is not clear what assumptions KPMG (2019) has made in this. It is therefore difficult - and possibly risky - to make a firm statement about this. Therefore, the studies by Crown Consulting (2018), Booz Allen Hamilton (2018) and KPMG (2019) are considered less suitable for a further look at the market development of UAM and are disregarded when making further statements about this expected market development.

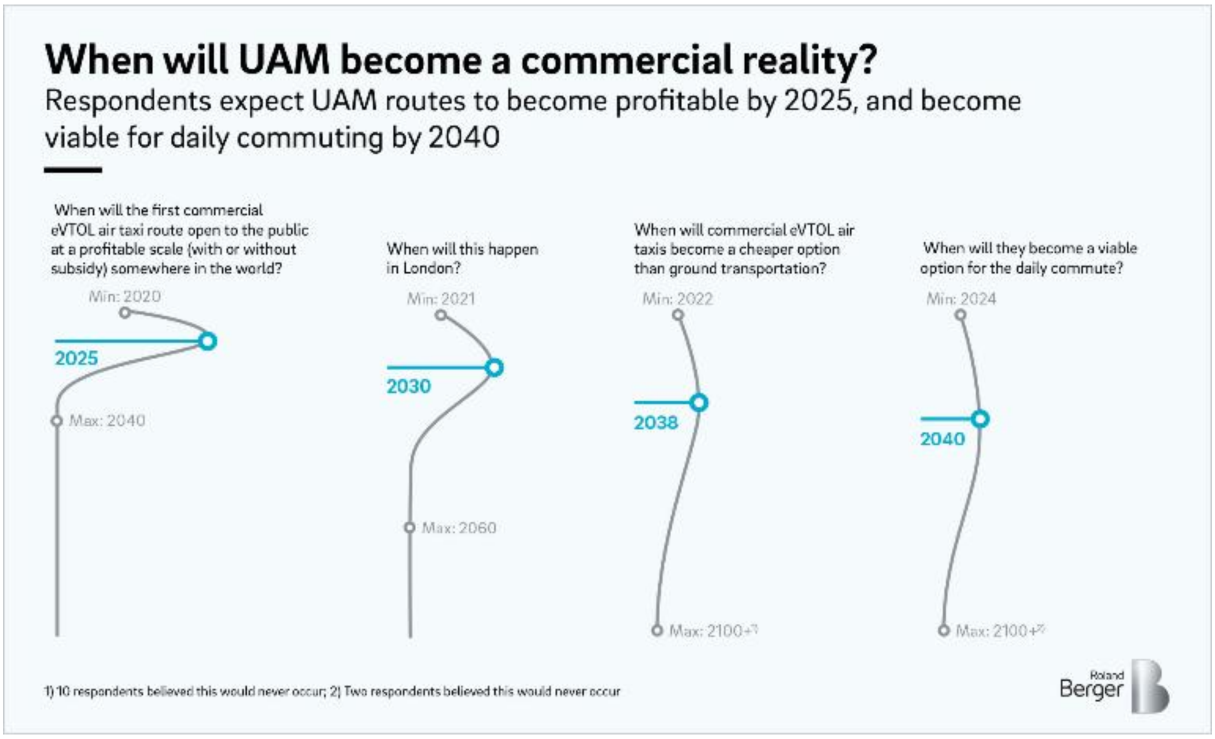


Figure 25 | 60 respondents in the burgeoning Urban Air Mobility (UAM) sector about the economic viability of UAM routes. They expect the first routes to become profitable by 2025, and become viable for daily commuting by 2040 (Roland Berger, 2018b).

The other market studies known to the author (FutureBridge, n.d.; Porsche Consulting; 2018; Roland Berger, 2018) provide a more complete picture of the expected market development of UAM. Between 2025 and 2035 we might see a large and almost exponential growth in UAM operations. At the start of this period, the expected numbers of passenger drones still vary considerably, probably due to the uncertainty surrounding the eventual market launch. When the market is in its accelerating phase, minimal variations in starting points can cause large differences in the numbers of vehicles. At the end of this period, the figures are approaching each other, with 18,000 to 28,000 passenger drones in 2035. There is thus some degree of consensus regarding the expected UAM market in 2035.

There is again much and more uncertainty about the period after 2035. Most market studies do not look beyond 2035 (FutureBridge, n.d.; Porsche Consulting, 2018), while Roland Berger (2018) already does and has looked until 2050. However, based on the development of all curves up to 2035, it can be expected that the growth will continue in the period to come, since no flattening curves can be observed until then. Rather, an increasing growth can be seen. Moreover, Roland Berger (2018), whose study is the only one to make a firm statement about the period after 2035, expects a growth to 53 thousand and 98 thousand passenger drones in 2040 and 2050, respectively. However, only recently they have spoken out in an interview to expect 160 thousand passenger drones in 2050 (Sarsfield, 2020). Such a (concrete) expectation cannot be read in other market studies, although Porsche Consulting does make predictions with regard to the total addressable market. According to them, there is room for a total of 200,000 passenger drones, but it is unclear when this number could be reached. Besides, they state that it is uncertain if this volume can even be attained. In order to achieve 200,000 units operating at a price point similar to today's taxis, passenger drones would have to be deployed in all types of cities around the world – not just in a few dozen large and megacities, but in medium and small population centres as well. These cities would have to offer a fully built-out network of ground infrastructure, which they think is not very likely. In megacities and large cities, Porsche Consulting (2018) expects the total addressable market will not exceed 75,000 active units, and without major infrastructure build-out the number will be limited to 40,000 active units.

At the same time, it is likely that further growth will also take place after 2050. This has been visualized by means of extrapolations (fig. 26). Until then, most scenarios barely show any flattening of the curve, indicating that no market saturation has occurred in 2050 and the full market potential has not yet been achieved. How the curve will develop after 2050 is far from clear, due to the lack of studies. It could be that it will level off from that moment on, which would fit the 'basic scenarios' of Roland Berger (2018) and Porsche Consulting (2018), assuming 98 thousand and 75 thousand passenger drones in 2050 respectively. In these scenarios, a more or less linear growth can be observed between 2035 and 2050, whereas in the preceding period there was still an increasing growth. Extrapolating the curves for this scenario, the market could reach a maximum of approximately 125,000 passenger drones in 2065. However, there is no hard substantiation for this. Other scenarios indicate that the curve could also experience further increasing or decreasing growth after 2050.

These insights show that the market of UAM could go different ways, either remaining relatively small or exploding. Many factors will eventually determine in which way the market will develop. However, the moderate way in which the market might develop seems most likely and fits the S-curve in which technological innovations often develop. In that case, the UAM market will mainly develop in larger cities or urban areas around the world (see also below). If they succeed in building out the necessary infrastructure, a market of around 100 thousand passenger drones should be achievable. It is therefore decided to take the number of 100 thousand passenger drones as a basis for 2050.

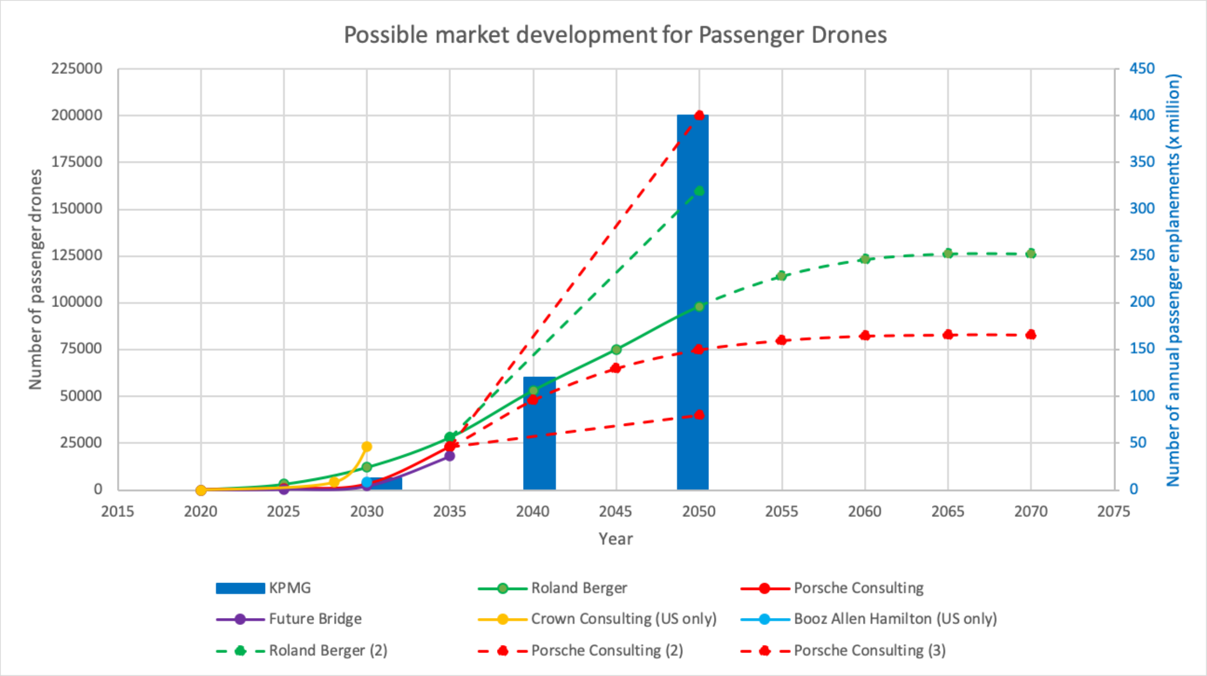


Figure 26 | Possible market development for passenger drones. Sources: KPMG (2019), Roland Berger (2018), Porsche Consulting (2018), FutureBridge (n.d.), Crown Consulting (2018), Booz Allen Hamilton (2018).

Some places in the world will be more suitable for UAM than others. The pros and cons of the transportation mode and several other factors play a role in this. To give an insight in which places UAM can most likely be expected, it is useful to make use of so-called 'urban archetypes'. For the purpose of this research, six urban archetypes are distinguished (fig. 28) based on three commonly considered important indicators: population, GDP and density (Porsche Consulting, 2018; Roland Berger, 2018; Shell, n.d.). The state of the mobility system also plays a role (KPMG, 2019; Porsche Consulting, 2018) (fig. 27).

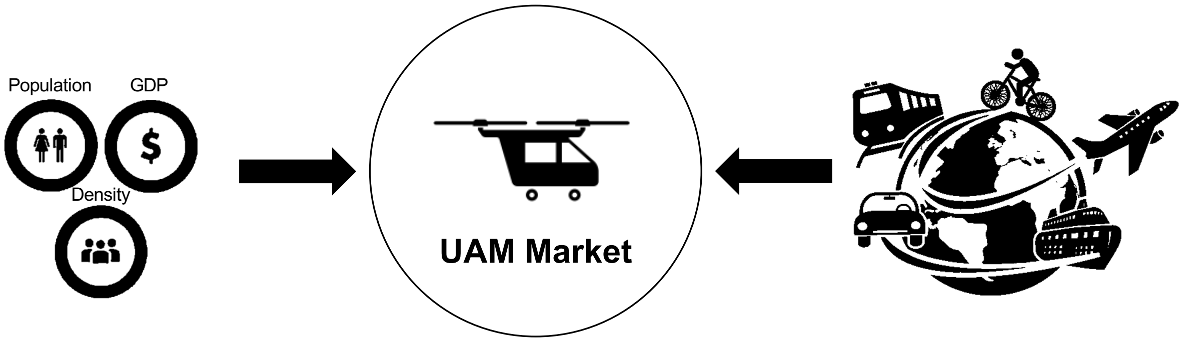


Figure 27 | Key factors that determine whether and to what extent a UAM market will develop in a particular area: demographic factors like population size, density and GDP and the state of the existing mobility system. The latter comprises, among others, factors like congestion levels, travel times and available transportation choices.

Based on the earlier mentioned market studies (Porsche Consulting, 2018; Roland Berger, 2018; KPMG, 2019), it is argued that UAM will especially fit in those cities that score high on the first two indicators: population and GDP. This means that 'Urban Powerhouses' and 'Sprawling Metropolises' are particularly suitable for UAM. Urban Powerhouses are both densely populated and wealthy, a relatively rare combination by today's standards. They enjoy an influential position as major commercial hubs in their region, thanks to successful and controlled urban development in recent decades. Many urban powerhouses such as Hong Kong have developed on isolated locations, and as a result they tend to avoid the negative impact of wider political, economic and social tension in the region. Public transport systems in those cities are usually modern and well-developed. Complex networks of trams, trains and buses serve millions of people on a daily basis. However, high levels of car ownership amongst the population often causes congested roads filled with heavy traffic. Sprawling Metropolises take up a large land mass and can be found in many developed countries around the world. Their populations are typically between 3 and 5 million people, of which the majority lives in large low-density suburbs. The citizens enjoy high incomes and large homes. Some sprawling metropolises - like Los Angeles and Houston - are typical US cities. They feature prosperous suburbs that are spread out over a large area. However, in reality there are many of these worldwide, especially in developed countries with modern industrial economies. In those cities, most people use their car to get from A to B, although modern public transport systems are in place. Driving is made easier by the extensive and well-maintained road networks and by the fact that for most citizens, car ownership is easily affordable (Shell, n.d.). The high populations and GDP of both urban archetypes make those cities very interesting for a UAM market, since they house relatively many people that could afford a service like this. In terms of market potential, Sprawling Metropolises may even be a bit ahead of Urban Powerhouses. Because the former cities are more sprawled, the distances people have to travel tend to be longer, which is perfect for UAM services (4.3.3 and 4.3.4). Besides, there is a greater role for the car and alternatives are less widely available. Therefore, Sprawling Metropolises are generally considered as most suitable cities for UAM, although the difference with Urban Powerhouses is considered minimal.

It should be noted that, although perhaps less suitable at the moment, the other urban archetypes can develop over time into new Urban Powerhouses and Sprawling Metropolises. Economic development in particular plays an important role in this. Economic growth in 'Crowded Cities' and 'Developing Mega-Hubs' enables a high score on the first two indicators for both. That is why especially these two urban archetypes are seen as potential candidates for UAM developments in the long-term future. As the name suggests, Crowded Cities have large populations, with densely packed housing and often extensive slums. Although their citizens are underprivileged compared to the above-mentioned archetypes from the developed world, these cities are growing fast. With the right planning and management, these cities could become future Urban Powerhouses. Crowded Cities are primarily found in the developing world on the continents of Asia and Africa. Many Crowded Cities have expanded quickly without careful planning. As a result, roads and public transport tend to be insufficient and congested due to the large number of people. Developing Mega-Hubs are fast-growing and densely populated cities that could become the Urban Powerhouses or Sprawling Metropolises of the future. However, their rapid rise – often a result of recent and aggressive industrialisation – causes important challenges in the coming decades. These mega-hubs can be found in the developing world. Many are based in China, one of the fastest-growing economies in the world. In many Mega-Hubs, inadequate planning and development has resulted in poor public transport, meaning that most people will need to use their car to get around (Shell, n.d.). In view of the large populations, combined with the inadequate mobility systems of both urban archetypes, UAM could be an interesting addition within these cities. It can open up a way to improve the poorly developed connections in these cities, at relatively low (infrastructure) costs. However, they will first need to be able to actually realize further economic development (Participant J, 2020).

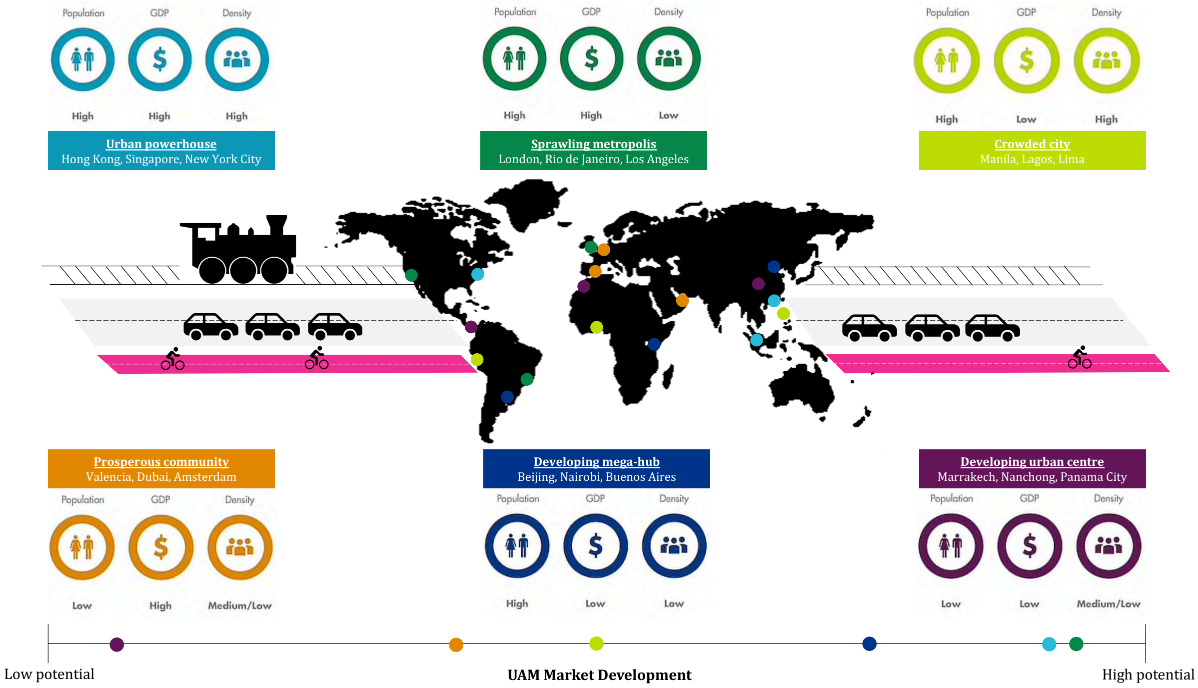


Figure 28 | Six different urban archetypes (Shell, n.d.).

Where no or only small(er) UAM markets are expected, is in ‘Prosperous Communities’, but especially in ‘Developing Urban Centres’. Like Sprawling Metropolises, the people who live in Prosperous Communities have high incomes and lots of space to live and work in. However, these cities have considerably smaller populations, typically between 750,000 and 3 million. Prosperous Communities are not only found in the ‘West’ - many exist in developed countries around the world as well, like South Korea and Japan. Even though most prosperous cities have a well-established public transport system, most people prefer (and can afford) to drive cars. This is also enabled by an extensive network of well-maintained roads and low-density housing. Developing Urban Centres are less populated, relatively spread out urban centres. No other urban archetype is more numerous than this one. Many of them are ripe for development and rapid urbanisation in the coming decades, but they often face important ongoing challenges. These smaller urban centres are mainly situated in many developing countries worldwide. They have poor public transport and road systems, which are in some cases even practically non-existent. As a result, most people walk or take their bikes and scooters to get around (Shell, n.d.). Due to a low score on all three indicators, UAM is not expected to land in Developing Urban Centers anytime soon. We will see UAM to some extent in the larger Prosperous Communities. However, because of the relatively small populations, low population densities and well-developed mobility systems, it will take quite a while before UAM will have an added value in those cities.

To conclude, we will mainly see UAM in large and economically developed (mega)cities, and possibly in smaller and less-developed cities in the longer term. Around 70 to 100 larger metropolitan areas in the world will especially be suitable for this by 2050 (Roland Berger, 2018 and KPMG, 2019). In line with the prospects of United Nations (2019), most of them will be found in the Asian-Pacific region, followed by North-America. South-America, Europe and the rest of the world fill the rest of the market (fig. 29).

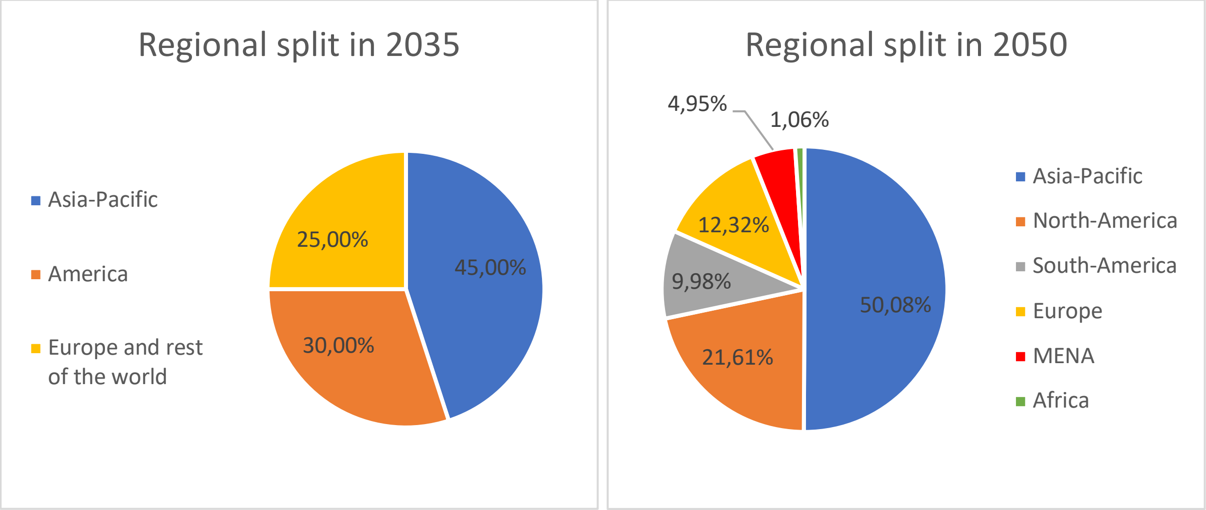


Figure 29 | Regional split of global passenger drone market in (l) 2035 (Porsche Consulting, 2018; Future Bridge, n.d.), and (r) 2050 (KPMG, 2019).

4.3.6 UAM framework

As mentioned in 2.2, the UAM framework exists of five pillars divided over three major bricks: aircraft and aircrew, airspace and community integration (fig. 2) (NASA, 2020). The barriers that will be faced, and the actions that we will need to take to react upon them, can be related to these bricks.

The first two bricks are very much about the UAM technology itself, while the latter one is more about bringing this technology into the community. Fig. 30 shows the related topics of each of these bricks. The Aircraft & Aircrew brick consists of the design, manufacturing and system readiness of the UAM vehicles. It also contains the operations, management and maintenance of these vehicles, as well as piloting type of considerations. The Airspace brick consists of the design, development and implementation of (digital) infrastructure to enable safe and efficient multi-vehicle UAM operations, like U-space and Unmanned Traffic Management (UTM) systems. Besides, it is about the operations and management of multiple vehicles within a UAM system that enables safe and efficient sharing of airspace and other system resources (NASA, 2020b).

The Community Integration brick is more about bringing this technology and their services into the community. This encompasses a variety of physical and social topics, like infrastructure integration, sectoral policy and social acceptance of UAM operations (NASA, 2020b).

The transition and realization of UAM is an ongoing process. There have been various conducted and ongoing studies within these fields. Most of the attention within the UAM framework has been focused on the technology, mainly comprising the first two building blocks: Aircraft & Aircrew and Airspace. As mentioned earlier, the development in these two areas is therefore ahead of the Community Integration. This makes it necessary to catch up within the latter field by conducting research into the necessary actions within the communities (Powell, 2020; Alexander, 2020; Community Air Mobility Initiative, n.d.). While the focus of this research is therefore on the Community Integration of UAM, the barriers and necessary actions in this field are elaborately discussed later on in this thesis (chapter 7).

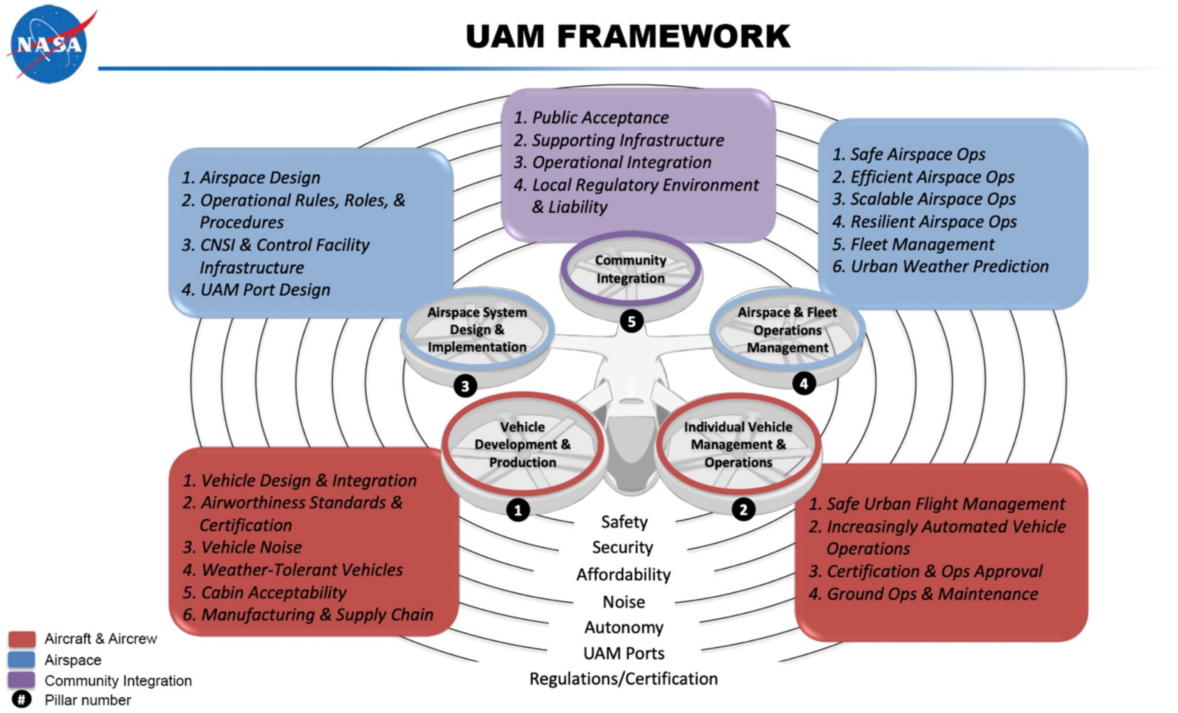


Figure 30 | UAM framework and its related topics. Source: NASA (2020d).

4.4 Reflection on theory

The previous chapters gave an insight in the concepts of the future mobility options, transitions theory and Urban Air Mobility, which are all somehow related to each other. It was found out that a variety of transitions will get their place in future cities. To deal with the variety of mobility issues, a mobility transition must help cities to achieve more sustainable urban mobility (see also fig. 31). How the 'Mobility of the Future' will look like is uncertain, but literature shows that some key trends, developments or goals can be identified that will play a large role in this change. Examples have to do with shared mobility, decarbonisation, automation, connectivity, proximity or the discouragement of mobility and large distances, densification around public transport hubs, encouragement of public transport and (slow) active transport modes, adapting working hours, etcetera. But also new, innovative transportation modes are finding their way into the future of mobility. All these changes, as part of the mobility transition, must to a smaller or bigger extent get their place in our future cities. However, this chapter also made the argument that cities are facing a variety of problems to make the transition to more sustainable urban mobility. As a result, mobility problems might continue to exist for at least some amount of time.

In the context of these developments, this chapter introduced Urban Air Mobility, and how it can add value to the future mobility system in specific areas and situations. In short, there will always be main arteries for mass transit and the fast conveyance of people and goods, complemented by secondary arteries and even smaller routes, similar to the finely tiered circulatory systems of a biological organism. Vertical mobility is an innovative option to provide fast service for second- and third-tier connections with lower transportation capacity. It is important to note, however, that while vertical mobility will not be a panacea to solve congestion, it can become a crucial part of an integrated solution to mitigate our growing transportation woes. UAM is able to improve connectivity on congested or lacking connections in urban areas. Before this is the case, a long way is still to go. A transition is needed to make Urban Air Mobility a reality and that will not be an easy process. Several barriers will be faced, upon which a variety of actions needs to be taken. Whereas the industry is already quite on the way to address the aircraft and airspace challenges and actions, the field of community integration has gotten behind. This research aims to further identify the challenges and necessary actions towards the community integration of UAM.

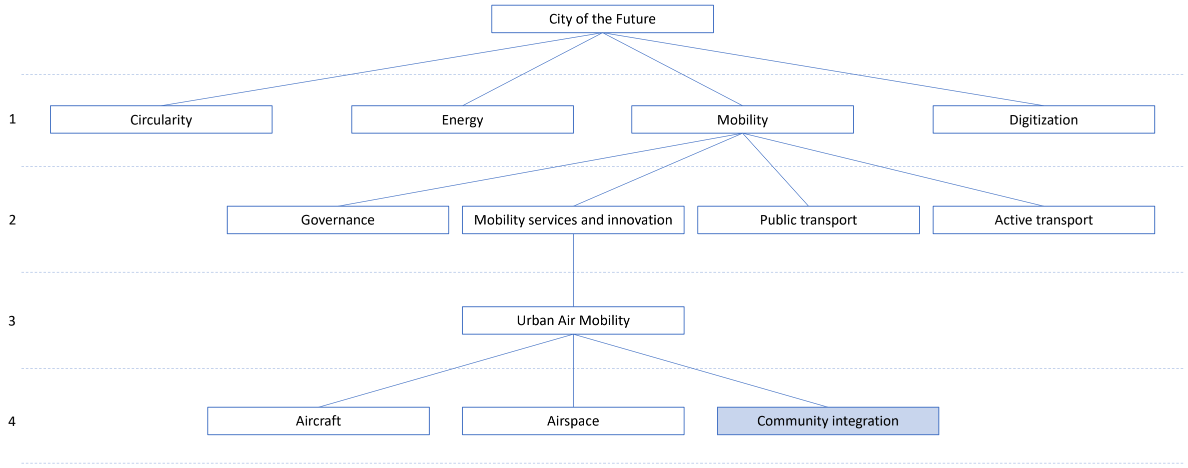


Figure 31 | Urban Air Mobility as a potential part of the mobility transition. 1 – Transitions; 2 – Key factors mobility transition; 3 – Niche innovation 'Urban Air Mobility'; 4 – Corestones Urban Air Mobility.

The literature review has elaborated on transitions theory and the MLP in particular. It turns out these can be very useful in analysing and understanding transitions. Transitions deviate in one or more dimensions (e.g. technical, cultural, behavioural, policy, infrastructure) from the established regime(s). The framework shows that for a sustainability transition to happen, a certain path of development must take place from niche to regime. Therefore, in this research the theory will serve as a framework and be applied to the sustainability transition of Urban Air Mobility.

This new way of urban transportation is quickly developing at the niche level, though still in an early stage, while a window of opportunity is opened by landscape developments like climate change, urbanisation and traffic congestion. While the industry has focussed to make progress on the vehicles and airspace integration, the community integration of UAM is still underexposed. Nevertheless, this is an important aspect to enable the transition. Therefore, cities should start to think about this new transportation mode. This thesis can serve as a starting point to do so by exploring what actions they should take on the path from niche to the desired situation at the regime level. To do so, the research will assess the changes that (must) be implemented in the socio-technical regime dimensions, which were discussed above. Based on this, challenges of UAM Community Integration are identified that can be associated with these changes, after which actions can be recommended to get started. Literature already gave some insight in where challenges could exist. This research will explore this further. How this is conceptually made up, is presented in the conceptual model (fig. 32) and in figure 34. A simplified version of figure 32 is given in figure 33. Based on the available information of UAM, the hypothesis is that the community integration of UAM will largely depend on the extent to which the challenges in figure 32 will be filled up. The research must further clarify this. From here, a variety of recommendations for the pathway of UAM will be given.

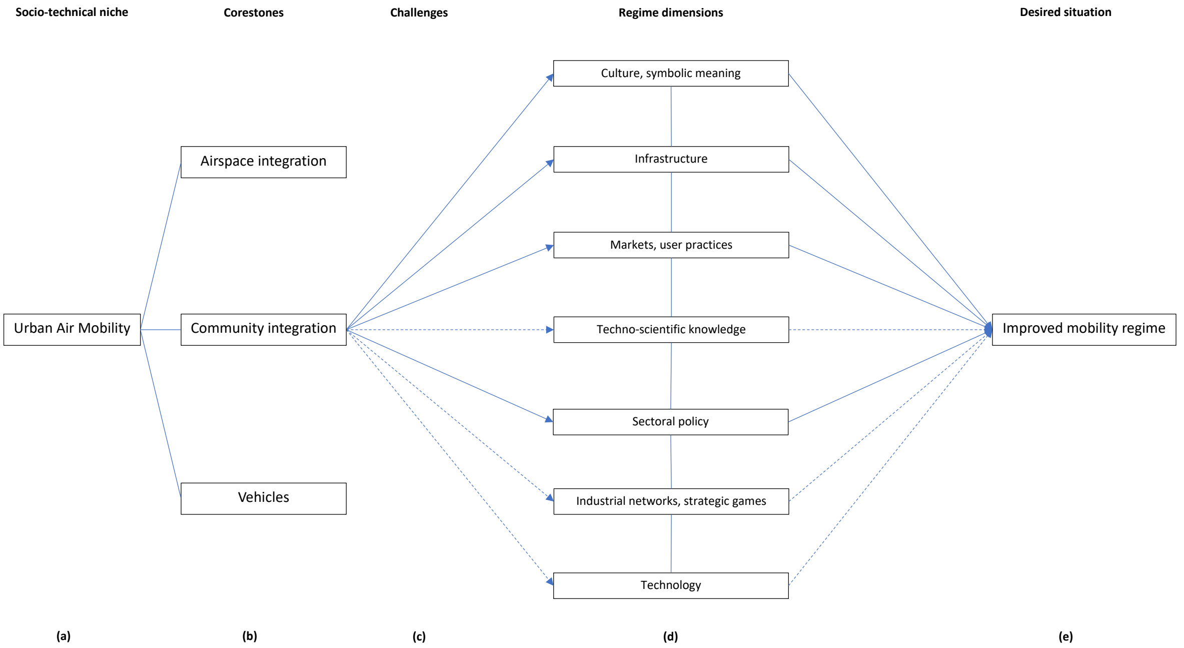


Figure 32 | Conceptual model. The (a) socio-technical niche of Urban Air Mobility exists of (b) three corestones: Vehicles, Airspace Integration and Community Integration. This research focuses on the Community Integration, which requires changes and (re)alignments of the (d) regime dimensions, in order to achieve the (e) desired situation of an improved mobility regime with UAM fully integrated. Before these changes to the regime can be applied, several (c) (unknown) challenges or barriers might be faced, which must be overcome. This research aims to identify these barriers, and recommend a variety of actions to deal with them.

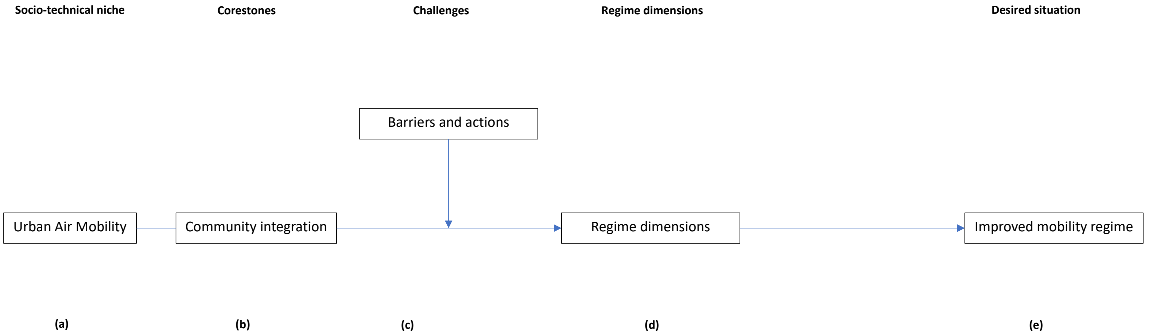


Figure 33 | Simplified conceptual model. The (b) Community Integration of the (a) socio-technical niche development Urban Air Mobility requires changes in the (d) regime dimensions. These changes are accompanied or hindered by (c) (unknown) barriers that ask for actions, after which the (e) desired situation of an improved mobility regime should be achieved. This research aims to identify these barriers, and recommend a variety of actions to deal with them.

To better understand the community integration of UAM, the broader and guiding question of this research is defined as,

How can the transition of Urban Air Mobility be realised in communities?

As mentioned above, different aspects can be related to the community integration of UAM. Following on transitions theory and the practical relevance for, among others, APPM, the choice was made to narrow the main research question down to four sub questions.

UAM is a transportation mode that will likely have an added value in specific cases. It is useful to globally explore if, how and when UAM adds value to a city and its goal towards sustainable mobility.

How does UAM contribute to the realization of more sustainable urban mobility?

During and at the theoretical 'end' of the (stepwise) community integration, it is likely that UAM will increasingly interfere in the city as we know it today. Depending on the adoption rate of UAM, it will have some impact on different aspects in the city. This can be related to the dimensions in the MLP and the conceptual model. How, where and to what extent UAM will have an impact, is not clear yet. Therefore, the sub-question is defined as,

How does UAM interfere in the current city?

Related to the interference of UAM in the current city, different challenges and barriers will arise to cope with and which are currently blocking the path of UAM towards the regime level. Therefore, a second sub-question that needs to be answered is,

What challenges or barriers can be identified that must be overcome for UAM to reach the urban mobility regime level?

Finally, the necessary steps to establish in the regime level and integrate this new transportation mode in a city should be concluded. Finding a possible pathway provides a temporal and stepwise implementation plan for the community integration of UAM. The sub-*question is defined as,*

Which actions can communities take to prepare themselves for UAM?

Urban Air Mobility is a new, emerging form of mobility that can also play a (positive) role in the City of the Future. However, a clear insight in what it takes to integrate it in a city is lacking. That is why this research aims to unveil a pathway in the following chapters.

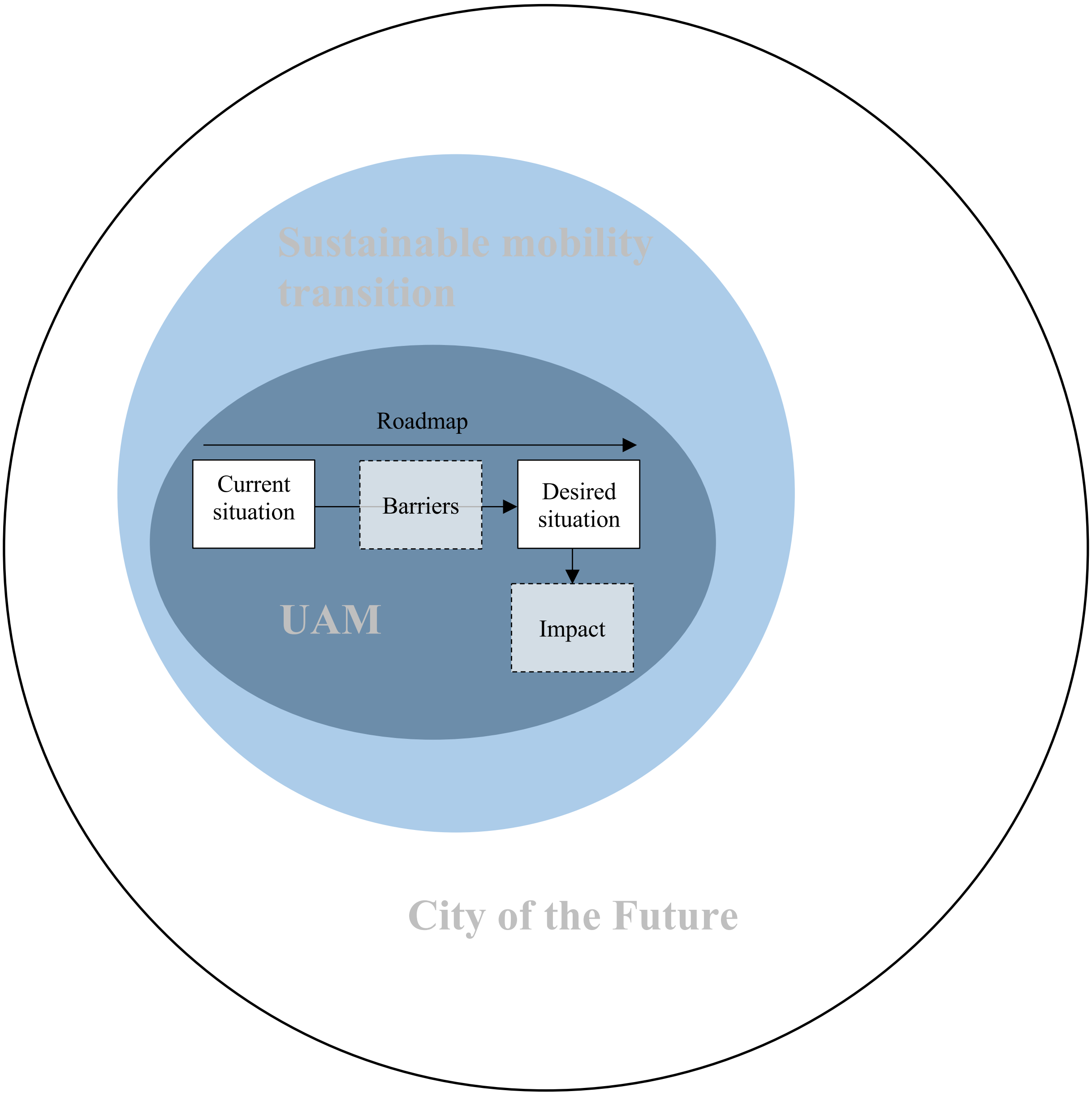


Figure 34 | The context within which UAM must be realized.

RESULTS

Part III – Results

In this part of the research, the research methodology that was used to get to the final results is extensively outlined in chapter 5. In chapter 6 and 7, the final results are provided. Conclusions, including the final roadmap, are given in chapter 8.

5. Methodology

This chapter will explain in detail how the research for this thesis was conducted in order to answer the sub-questions and the main research question. As already mentioned in the research design, a qualitative expert interview design was used besides an extensive literature study. The first section of this chapter will introduce the general research method for this qualitative research. The sections that follow will explain how data has been collected and analysed, and attention will be given to the validation of the acquired data.

5.1 General research design

The first step in identifying the barriers to future large-scale application of UAM is to describe the current state of affairs of UAM using the seven dimensions of a sociotechnical regime (see table 1 in 3.2.1). It was then analysed which forces are putting pressure on the current mobility regime from above and below.

Based on the regime dimensions, a future situation, a 'final picture', will also be outlined, in which UAM is a serious, yet modest part of the mobility system (Appendix D). This future situation will then be compared with the current situation (Appendix C), after which it will be indicated at which dimensions (major) changes will (must) take place and at which dimensions nothing or less will change. Based on this, insight can be obtained into which barriers may arise in the various dimensions.

The comparison of the final picture with the current regime provides insight into the changes that are needed in the long term. These developments will already have to be initiated very early on. Subsequently, attention will be paid to the continuation of the transition path (until 2050). Actions will be recommended based on the conclusions of this analysis as a whole, which communities can take in order to prepare themselves for UAM.

5.2 Data collection and recording

A qualitative research methodology was applied to identify the dynamics of the transition towards urban air mobility. The research aims at finding the most important transition actions by examining and analysing transition barriers through collecting literature evidence and empirical data.

Given the aims of this research and the available knowledge, there is a need to identify the factors that affect each dimension of current mobility regimes. Those factors are identified through the collection of qualitative data, recommended to be used when the investigated phenomenon is new and when the investigator seeks to answer “why” and “how” questions (Yin, 2014). Thus, a combination of different qualitative data gathering methods was adopted: literature reviews and semi-structured interviews, as described further in this section.

With an extensive literature study data was collected to uncover the dynamics that are at play when considering a transition and what concepts are important to consider in that context. The basis was mainly formed by academic articles from journals such as Research Policy, Transport Geography, Transportation Research Interdisciplinary Perspectives and Technological Forecasting and Social Change, among others. A snowballing method was applied to find more relevant literature, by looking at which literature was cited by the authors. Literature on transitions theory in general and on the MLP framework in particular formed the most substantial and scientific part of the literature. These concepts were placed in the context of the 'Mobility of the Future' and linked to the subject of interest which is the transition of Urban Air Mobility. This was done by analysing literature on these topics, which was complemented by other informative documents. Eventually, these concepts were translated into a main question and sub questions which guide the research.

In order to answer the research questions, in addition to literature, the knowledge of experts and insights from governments was consulted through interviews. Based on the insights on what a future situation, in which UAM is part of the mobility system, will look like, a final picture was retrieved. The basis for these interviews, which are conducted orally, is a semi-structured questionnaire, which made sure that all relevant information would be discussed, while at the same time providing room for the interviewee to bring up other information (see Appendix A). The questions that were asked were based on the four sub-questions, which encompass the added value to overall mobility, interference in a city, the challenges that are faced and the necessary actions to take. The first questions provide an introduction and gave the respondent the opportunity to paint a general picture of both the current and a future situation in which UAM achieves its full potential. For other questions, experts from industry as well as governments were used as a starting point. Respondents were asked all questions and depending on the area of expertise of the respondent, some questions were emphasized during the interview or questions were asked about specific matters. In addition to interviews, existing written sources were also used, either as a starting point prior to the interviews or to clarify the interview data afterwards. As such, both data collection methods complemented each other and had more or less an equal role in the research.

The pictures of the current and future situation gave direction to the data collection. On the basis of this, with the help of the interviewees and literature, an image could be obtained of the gap between the current situation and the future, and which changes (must) take place when UAM is integrated into a city. These kinds of changes are accompanied by challenges, which could be identified with the collected data. Based on this, a roadmap for the further development of UAM could be constructed.

This method of data collection was chosen because experts, based on their knowledge, can give a good estimate of what it takes to successfully integrate UAM in a city. Governments that are actively involved in UAM projects also see from their own experience which challenges arise in the roll-out of these projects. By using a basic questionnaire, an attempt was made to map out the respondents' visions as structured as possible in order to be able to compare them with each other as closely as possible. The questionnaire was sent to respondents in advance. The interview format provides the opportunity to clarify questions and ask additional questions that relate to the respondent's area of knowledge. An oral interview also offers the respondent the opportunity to present his/her opinion in detail, possibly also on aspects that are not explicitly included in the questionnaire, but which he/she considers to be important. Parallel to the interviews, more information on UAM was gathered, consisting of informative documents and policy reports, among others. Besides gathering the data via interviews and documents, a visit was made to UAM events, like the ones hosted by RAI Amsterdam and NASA. The latter one took place in a digital way due to the outbreak of Covid-19, which was not always optimal and made it difficult to meet experts in person and invite them for an interview. However, all the data still provided a solid foundation to move onto the analysis.

Of course, for a representation of the final picture as detailed as possible, it is desirable to interview a sufficient number of experts. Normally, qualitative research is characterized by a relatively small number of sites and participants to be involved in the study. But how many participants is sufficient, and should you have? According to Creswell (2014), there is no specific answer to this question. One viable approach to the sample size issue is the idea of saturation. This idea comes from grounded theory. Charmaz (2006) said that you stop collecting data when the categories (or themes) are saturated: when gathering fresh data no longer sparks new insights or reveals new properties. Although one cannot be completely sure that no new insights are gathered when the sample size is increased by one participant – since one cannot know the unknown – it was decided not to plan any more interviews once the collected information showed saturation. As a result, the number of respondents to whom the entire questionnaire was presented is limited to 20, divided over 16 interviews. A list of all interviewees and relevant details can be found in Appendix B. Contact with the interviewees was obtained through networking at the aforementioned UAM events, the network of APPM Management Consultants and snowballing was used in order to find out whether there were other potentially relevant interviewees. Attempts were made to cover the different elements of the final image as much as possible by multiple opinions and respondents from different 'worlds' (research, business, government and intermediary organization) and with various knowledge areas were chosen.

5.3 Data analysis and validation

Several steps were taken to analyse the collected data, taken from Creswell (2014) who elaborates on steps to be taken in qualitative data analysis. First of all, the interviews were transcribed, and they were analysed to a certain extent by retrieving relevant quotes from these transcripts. These quotes already gave an idea of the main concepts mentioned by the interviewees and helped in creating a pattern. Afterwards, these transcriptions were structured by giving them specific codes in Excel, in a process known as content analysis (Bengtsson, 2016). The codes were based on the four empirical sub-questions that were formulated, which encompass the added value to overall mobility, interference in a city, the challenges that are faced and the necessary actions to take. These codes formed rough guiding categories, after which the categories were adjusted based on the actual information that was retrieved from the interviews. Eventually, a variety of coding categories could be defined.

The findings derived from the interviews were complemented with data retrieved from informative documents and policy reports, after which it was written down in a qualitative narrative. The research process was iterative, going back and forth between the theoretical insights gathered by the literature study and the empirical data, and vice versa. This messy process is one of the main characteristics of qualitative research, which includes processes and contexts as part of the investigation.

In order to validate the research findings, two major strategies were used. *Member checking* was applied through taking the final report or specific descriptions or themes back to participants and determining whether these participants feel that their answers had been reported sufficiently and whether the information had been interpreted correctly, ensuring the accuracy of the results. Furthermore, the use of opinions from different perspectives – from both experts and governments – and the use of other data besides the interviews ensured *triangulation* of the collected information.

6. The current regime and future vision

The current regime of urban passenger transport is dominated by ground transportation and especially automobility. This regime has been described on the basis of the seven regime dimensions, as discussed in table 1 in 3.2.1. This description can be found in Appendix C.

This chapter first analyses which macro and micro factors exert pressure on the current regime (6.1). Then a comparison between the existing regime and final image, in which passenger drones are part of the urban mobility system of 2050, is outlined (6.2).

Based on a comparison of the current regime and the final image, which have been described on the basis of the regime dimensions, the changes required to achieve the final image can be identified. This provides a first insight into where transition characteristics can be found in the process of community integration (6.3) and which barriers can arise (chapter 7). Then a roadmap with recommended actions towards community integration of UAM is constructed to map important steps to make this possible (chapter 7 and 8). This is shown visually in figure 35.

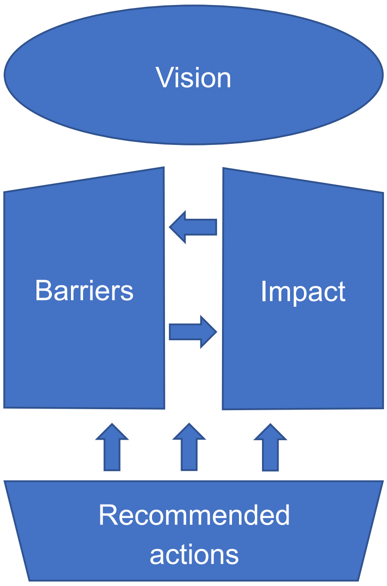


Figure 35 | The structure of the results visualised.

6.1 Pressure on the current regime

Over time, the rules that make up the current mobility regime have become increasingly anchored and aligned in a material and social way, creating a dynamic balance. However, according to the idea of the MLP (3.2.1), the current regime is being pressured from above and below by landscape developments and niche innovations respectively. Eventually, these pressures could lead to a reconfiguration of the mobility regime, in which UAM will be embedded.

6.1.1 Landscape developments

At the landscape level (from above), there is a variety of landscape developments that may gradually put a pressure on the incumbent regime, as discussed in 3.2.1. This thesis revolves around the mobility regime, with a strong focus on urban mobility. In this field, several landscape developments putting a destabilizing pressure on the existing mobility regime – and supporting more sustainable urban mobility – can be distinguished (table 18).

Table 18 | Destabilizing landscape pressures supporting more sustainable urban mobility.

Destabilizing landscape pressures supporting more sustainable urban mobility
- Climate change (debates) (Geels, 2012; Geels et al., 2011; Hillman and Sanden, 2008; Hodson et al., 2015; Rip and Kemp, 1998; PWC, n.d.; Alonso Raposo et al., 2019; KPMG, 2019b)
- Macro-political developments (Ngar-yin Mah et al., 2012; Rock et al., 2009)
- Energy and fuel prices and market change (Foxon et al., 2010; Geels, 2012; Geels et al., 2011; Hillman and Sanden, 2008; Hodson et al., 2015; Rip and Kemp, 1998; Turnheim et al., 2015a)
- Changes in international economic financial situation (Foxon et al., 2010)
- Government–industry links (Geels et al., 2011)
- Commitment to international low carbon targets (Foxon et al., 2010)
- Carbon trading policies and debates (Hillman and Sanden, 2008)
- Economic crisis (Hodson et al., 2015)
- Greening production processes (Chiarini, 2014a)
- Public awareness and willingness to changes (Turnheim et al., 2015a; Moradi and Vagnoni, 2017)
- Smart city strategies
- Changes in values and ideologies of younger generations
- EU policies and upstream documents
- Government viewpoints, supports and policies for low carbon mobility
- High competition in the industry and the need for introducing new innovations (Moradi and Vagnoni, 2017)
- Population growth (PWC, 2017
- Rapid urbanisation (Alonso Raposo et al., 2019; Vandecasteele et al., 2019; European Commission, 2019; PWC, 2017; PWC, n.d.; KPMG, 2019; EIP-SCC, 2016; Canitzed, 2019)
- Increasing mobility demand (Alonso Raposo et al., 2019)
- Ageing population (Alonso Raposo et al., 2019; Vandecasteele et al., 2019; PWC, 2017; PWC, n.d.)
- Shift to a service-oriented economy (European Commission, 2019b)

Some of these landscape developments are more relevant in the case of UAM than others. The main landscape development that is considered particularly important is rapid urbanisation. It is argued that urbanisation is the main source of the increasing urban mobility problems and the main reason for taking urban mobility into the sky. Urbanisation triggers a further rise in urban mobility demands, causing all kinds of earlier mentioned concerns (4.1) related to the increasingly unsustainable character of the urban mobility system. Greater demand for urban mobility means an increasing strain on our mobility infrastructure. As cities get ever larger, enabling efficient, effective and sustainable urban mobility will become a more pressing challenge. The pressure on the already limited space is also growing, air pollution and noise pollution are increasing, and traffic safety remains above the set target. In addition, global problems, including climate change, are also at issue. Mobility in general and urban mobility in particular is already making a substantial and ever-increasing (negative) contribution to this phenomenon. Together, these developments - triggered by rapid urbanization - are causing increasing, downward pressure on the (urban) mobility regime, which is causing existing (urban) mobility systems to become increasingly fractured and could eventually lead to a system breakdown. This asks for solutions that improve the efficiency and sustainability of the mobility system. Recently, there is an increasing awareness of this unsustainable nature of the current traffic and transport sector. This in itself can also be seen as landscape development.

6.1.2 Niche-innovations

At the micro level, alternative technologies for the traffic and transport sector are being developed. From below, some pressure is exerted by new transport systems, propulsion techniques and fuels, which are developed and applied in niches. Urban Air Mobility is – as a new transportation mode - one of the niche developments that puts a pressure on the current regime. The breakthrough of it is dependent on a variety of technological niche-innovations, most of them being part of the aircraft and airspace integration pillars instead of the community integration pillar, emphasizing the internal dependencies between the different sub-systems of the concept. In this section, the key technologies[1] to enable UAM are discussed. These have to do with propulsion technique, autonomous flight technology and communication networks, among others. Recent technological advancements in these areas have been made, but if and when UAM will break through into the mobility regime will highly depend on the further development of these technological innovations.

6.1.2.1 Propulsion technique

The development of a suitable propulsion technique is one niche-innovation that will be important (Kellermann et al., 2020). This mainly concerns the right energy source for passenger drones, which should cover distances of approximately 20 kilometres up to a few hundred kilometres. Currently, fossil fuels would be the most suitable energy source for these operations, but these are not preferred from a sustainability point of view. Although the ultimate energy source for passenger drone has yet to be determined (Participant C, E, H, 2020), two other major and promising energy sources can be distinguished that do meet the sustainability requirement: electric batteries and hydrogen. In general, the focus is therefore on these two energy sources, with most vehicle concepts trending more toward fully electric propulsion (Dubois et al., 2016).

At the moment, electric batteries are primarily used to power small drone types (Class 1 multicopters, for instance, less than 150 kg). Currently, the state of the art in battery technology is the Lithium Polymers (LiPo) battery, with an energy density that is limited to 250 W h/kg. Powered by such batteries, drones can fly for around 30 minutes today, and, depending on the model, the batteries are removable. This is by far not enough to execute viable air taxi operations, certainly given the need of significant reserves for emergency situations, which today are budgeted at an additional 45 minutes of flight. Even if this safety buffer were lowered to just 15 minutes, due to a dense network of alternate landing spots, it would still require half of today’s battery capacity (Porsche Consulting, 2018). So, Lipos are not yet strong enough to power large drone types (Class 3, more than 600 kg) for the required distances, which is related to the energy density (Ministerie van Infrastructuur en Waterstaat, 2017; Porsche Consulting, 2018; Uber Elevate, 2016; Participant E, I, 2020). Today’s available battery technology only allows short flight times for eVTOL applications (Roland Berger, 2018; Colucci, 2016). Kerosene and gasoline contain respectively 60 and 40 times more energy than a battery (Melkert, 2017; Roosien and Bussink, 2018). A Class 3 drone would therefore require many batteries, thereby adding extra weight and costing more energy (Ministerie van Infrastructuur en Waterstaat, 2017). Besides, LiPo batteries can be unstable and decompose, leading to fires (Participant C, 2020) as was seen with the introduction of the B787. Another challenge with respect to batteries is the charge rate and longevity, which do not yet support the intense high frequency demand of ridesharing operations

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[1] Be aware that only the technological niche-innovations that the development of UAM will depend on, i.e. the key enabling technologies, are discussed here. Other, community integration actions that are required, play out more on the regime level and are discussed later in this report.

(Participant E, I, M, 2020). Additional research into pulse chargers (capable of recharging in as little as 10 minutes) is already showing improved cycle life and maintaining improved maximum charge capacity over time. Achieving rapid charging for large battery packs is as important, if not more important than achieving high specific energy batteries (Uber Elevate, 2018). Nevertheless, as energy and power densities can be improved, however, flights speeds and distances will increase accordingly (Roland Berger, 2018). Research is ongoing on lithium-metal batteries (Roosien and Bussink, 2018) and several initiatives aim to power larger aircraft by electricity, including those by start-ups in the USA, such as Zunum Aero and Wright Electric, as well as those by established firms like Airbus (Melkert, 2017; Dorrestijn, 2017). Electric propulsion will eventually make eVTOL cheaper than current models. Once the production of electric aircraft reaches maturity, the upfront cost of buying or leasing an eVTOL will be lower because electric powertrains are simpler than gas turbines. Battery costs too are dropping thanks to the scale afforded by automotive manufacturing (Ministerie van Infrastructuur en Waterstaat, 2017) and running an urban air taxi on electricity is more cost-efficient than running a conventional helicopter on kerosene. Electric powertrains also have lower maintenance costs due to their simplicity, although technical services have to be able to deal with high voltage. The total cost of ownership of eVTOL is therefore expected to be lower overall (Roland Berger, 2018). To sum up, there are still major improvements required in battery technology to enable fully electric passenger drones to fly longer distances. It is expected that it might take until 2025 to achieve a density of up to 300 W h/kg, and thus a flight time of around 36 minutes. By then, batteries can be charged to 80 percent capacity in 15 to 30 minutes assuming an available charging rate of 2C to 4C, thereby only achieving a short lifespan of 500 to 700 cycles. It might take until 2035 to achieve an energy density of 400 to 500 W h/kg or more, when more advanced battery technologies such as lithium-silicon, lithium-sulfur, or all-solid-state can be expected. This is roughly double from today's energy density and resulting in around 60 minutes flight time. This should be enough for (fast) intercity drones to fly distances of over 100 kilometers and still guarantee additional safety time, as a buffer (alternate time) for emergency landing. New technologies will extend a battery's lifespan to between 700 and 1,000 cycles and increase the charging rate, meaning it will take only 15 minutes to reach 80 percent capacity (Porsche Consulting, 2018).

The other energy source that is often mentioned is hydrogen. It is produced by splitting water into hydrogen and oxygen and contains much energy. Today, various car models are hydrogen-powered, which requires compressing hydrogen into sturdy tanks; however, such tanks are heavy and hence largely unsuitable for aviation. Cooling the hydrogen until it becomes liquid is one alternative, but this technology is still in the developmental stage. Consequently, using hydrogen in aviation is not yet viable (Hermans, 2017).

Instead, we could also look at hybrid solutions. Hydrogen fuel cells could potentially provide ranges up to 1600km. However, this technology is still in its infancy, complex and therefore costly (Wright, 2018). Hybrid-electric propulsion technology—hybridization of electric and internal combustion engines—may offer an interim solution (NASA, n.d.; Crown Consulting, 2018; Safran, 2018).

Other energy sources that may be used for unmanned aerial aviation are solar energy and laser beams. However, as far as to the author's knowledge they are not included in any passenger drone concept and seem to be more suited to smaller drones (Ministerie van Infrastructuur en Waterstaat, 2017).

6.1.2.2 Autonomous flight technology

Monitoring and control of the vehicle can be handled by a human pilot on board the aircraft, a human pilot at a remote location, automation on board the vehicle or a centralised automated system on the ground (Roosien and Bussink, 2019). Although passenger drones will carry out piloted operations in the early years of the emerging UAM market, autonomous flight is the drone designers' ultimate goal (Ministerie van Infrastructuur en Waterstaat, 2017) and will gradually be introduced. Autonomous flight technology is seen as another niche-innovation that is required for

UAM operations (Kellermann et al., 2020). There are generally two main reasons for striving to fly autonomously:

- Efficiency: flying without a pilot brings costs down (Scherer, 2014), and an extra free seat in each craft will also boost potential by facilitating a significant increase in the payload (Roland Berger, 2018; Crown Consulting, 2018);
- Safety: many accidents are caused by human error (Scherer, 2014; Crown Consulting, 2018).

For both efficiency and safety, fully autonomous eVTOLs should contain robust situational awareness systems, to be able to perceive surroundings, navigate using pre-existing maps, and track objects—both static and mobile. This requires advanced capabilities in cognitive systems and AI, such as deep learning neural networks able to identify objects such as buildings, power lines, and telephone towers and chart an optimal flight path while airborne. Advanced AI capabilities can also help eVTOLs identify riders and—even more important—designated landing sites. Advanced sensing capabilities are required to empower eVTOLs to autonomously operate in safe and reliable ways. Specifically, for effective tracking capabilities, aircraft would need micro and millimeter wave in radar sensors and advanced technologies such as LiDAR (light detection and ranging), time-of-flight sensors, and ultrasonic sensors (Lineberger et al., 2019b; Crown Consulting, 2018).

Besides, they need an advanced detection and collision avoidance system. The established infrastructure for aircraft to communicate is expanding, with systems such as ADS–B (automatic dependent surveillance–broadcast) that show other aircraft currently aloft (Federal Aviation Administration, 2020). But to make on-the-fly decisions and ensure passenger and cargo safety, autonomous eVTOL aircraft would need to be able to see even farther ahead. Enhanced detect-and-avoid technology that uses micro or millimeter wave technology is needed to (a) accurately identify and measure other aircraft and objects over longer distances, especially in difficult terrain and unsafe operating environments and (b) assist in real-time decision-making to establish safe navigation during bad weather conditions and other hazards (Ministerie van Infrastructuur en Waterstaat, 2017; Lineberger et al., 2019b; Crown Consulting, 2018).

Drones with these systems in place can fly everywhere, except for in closed air spaces. However, at present, no fully functioning autonomous systems like sense-and-avoid are available (Airbus, 2016; Participant D, 2020). These systems, e.g. LiDar, are in a moderate state of development and planned to become commercially available for small drone types within 1 to 3 years, and 5 to 10 years for larger drone types (Ministerie van Infrastructuur en Waterstaat, 2017; Crown Consulting, 2018; Participant C, H, K, 2020). Camera technology and other sensor systems likely need to be developed further to improve accuracy (Crown Consulting, 2018).

6.1.2.3 U-space and Unmanned Traffic Management

Airspace integration of passenger drones is a third key topic and to enable this, innovation in the field of air traffic management is needed (Kellermann et al., 2020; Participant B, C, K, L, Q, S, T, 2020). The airspace currently consists of controlled and uncontrolled areas, meaning that air traffic control does or does not coordinate the air traffic. The controlled areas are primarily the higher altitudes and airspaces over airports. Consequently, not all airspace users engage with air traffic control. Recreational aircraft for example make much less use of controlled airspaces. Also, the existing Air Traffic Management system is not suited for high density operations (Ministerie van Infrastructuur en Waterstaat, 2017; Booz Allen Hamilton, 2018; Participant K, 2020).

Drones are expected to primarily access the lower altitudes, and hence the uncontrolled airspace. A system that can facilitate large numbers of aircraft is required to ensure that drones have reliable, efficient and safe access to airspace. SESAR (2017) has therefore developed U-space5, a concept in which airspace coordination (largely) occurs digitally and automatically. U-space is a European concept for “a set of new services relying on a high level of digitalisation and automation of functions and specific procedures designed to support safe, efficient and secure access to airspace for large numbers of drones. As such, U-Space is an enabling framework designed to facilitate any kind of routine mission, in all classes of airspace and all types of environment - even the most congested – while addressing an appropriate interface with manned aviation and air traffic control" (SESAR JU, 2018). Operators submit flight plans, so that their drones are identifiable. The system then coordinates all flights. Areas that are (temporarily) unavailable are also communicated within this system (Ministerie van Infrastructuur en Waterstaat, 2017).

Large, passenger drone types may however want to fly in both uncontrolled and controlled airspaces (Ministerie van Infrastructuur en Waterstaat, 2017). Seamless inter-aircraft communication demands effective integration of the existing airspace management systems with unmanned aircraft system traffic management, allowing operators to interact with multiple vehicles flying simultaneously (Lineberger et al., 2019b). Air traffic control and drone users must jointly develop a method for facilitating this dual airspace use. Achieving a scaled commercial deployment of VTOLs requires a traffic management system to oversee airspace design, dynamic geofencing, guidance for severe weather and wind avoidance, congestion management, route planning and re-routing, sequencing and spacing, and contingency management (Metts et al., 2018). In the US, NASA, FAA and the industry are working on prototype technologies for an Unmanned Traffic Management system that could develop airspace integration requirements for safe and efficient low-altitude operations (NextGen, 2018). They envision UTM as an air traffic management ecosystem for eventually fully automated drone operations that is separate but complementary to the FAA's Air Traffic Management (ATM) system (International Transport Forum, 2018b). However, the developments of both U-space and UTM will play out over many years, while the timeline is unknown. Their pace may ultimately bottleneck growth. Clearly, such technological progress is still needed before drones can be integrated in the airspace, regardless of their size (Ministerie van Infrastructuur en Waterstaat, 2017; Roosien and Bussink, 2018; Crown Consulting, 2018; Particpant B, C, K, L, Q, S, T, 2020).

6.1.2.4 Communication and location technologies

GPS-denied environments are ample in urban areas, especially at high altitudes and areas dense with buildings. This challenge poses the risk of either inability to continue to rely on GPS, or a lag time in response from GPS systems. Considering the potential for use of UAS in these areas there may need to be a redundant system that allows for vehicles to communicate with each other and continuously navigate despite loss of communication (Crown Consulting, 2018). Drones must also be able to identify locations even in areas where GPS signals are limited or degraded (Cohn et al., 2017). Therefore, advanced communication and location technologies are a further technological enabler for the realization of air taxis (Roland Berger, 2018; Participant B, I, K, 2020). This might ask for GPS alternatives, such as 5G communication networks. Whereas GPS-based satellite reception can be poorer because of highrise buildings, 5G will allow the ultra-precise navigation that is needed for urban air mobility (Roland Berger, 2018). It targets high data rate, higher system capacity, and massive device connectivity that would be essential for seamless communication between multiple eVTOLs flying in the air (Lineberger et al., 2019b). The current state of development of these systems is estimated low to moderate. Use of beacons and offline technologies (i.e. software to calculate based on trajectory and last point of online contact) is fairly developed (Crown Consulting, 2018), but like air traffic management integration, the widespread rollout of a GPS alternative is more than ten years in the future (Cohn et al., 2017).

6.1.2.5 Drone design

Another niche-innovation concerns the overall drone design. Today, many of the existing vehicle concepts can only 'hop', but cannot really fly yet (Participant T, 2020). Drone designs therefore have still a way to go before they could actually go into service (Participant Q, 2020). Choosing the right technology for each use case is central to the nascent industry. It is yet to be determined what the first drone for urban air traffic will actually look like. The most promising architectures include multi- and quadrocopters, tilt-wingers, electrical vertical take-off and landing (eVTOL) aircrafts as well as hybrid constructions (Appendix D.1). While the former types are particularly suitable for inner-city operations in confined spaces, the fast flying vertical starters are ideal for use between longer distances (Roland Berger, 2018b). However, it can take a while before vehicle designs for 240-320 km/h cruise speeds are fully developed and certified (Uber Elevate, 2016; Porsche Consulting, 2018; Participant I, 2020).

Another important part of the aircraft design will be noise control acoustics. Noise levels in today's eVTOL aircraft may necessitate pulling on helicopter-style earmuffs —which can't help but impede public acceptance (Christian and Cabell, 2017). Reducing vehicles' noise profile is a priority the industry should continue to address now, at the development stage. eVTOL aircraft manufacturers should work on the ducted rotors' acoustics, primarily cutting the rotor tip speeds to reduce noise levels relative to helicopters (Lineberger et al., 2019b; Community Air Mobility Initiative, 2020b).

Besides, vehicles must prove a sufficient safety level for public acceptance and robustness in varied weather conditions. In case this is not achieved, the areas and operational windows in which the vehicles will be able to fly would be highly limited (Uber Elevate, 2016; Booz Allen Hamilton, 2018; Participant H, 2020).

6.1.2.6 Decentralised smart grid

A niche-innovation that is more part of the community integration pillar and considered as important for a regime breakthrough of UAM, is the development of a decentralised smart grid. Load increase (Participant A, 2020), aging infrastructures and equipment, as well as increasing distributed energy generation lead to highly utilized networks during peak load conditions. In addition to the high power system loading, other technical challenges for ensuring reliable energy supply include the increasing distance between the central generation and load, increasing variability of supply, as well as the emerging new loads (e.g. from hybrid/electric vehicles). These trends coincide with a strong political and regulatory push for enhanced competition and thus lower energy prices, and increased energy efficiency (European Commission, 2013c).

Addressing these challenges in electricity networks in a traditional way by increasing and upgrading network capacity entails costly and time-intensive interventions. However increased use of ICT technologies enables new ways of operating power systems, combined in the Smart Grid concept. This includes increased interaction and integration of formerly separated systems to improve their observability and/or the controllability. Thereby, Smart Grid technologies help to convert the power grid from static infrastructure being operated as designed, to a flexible, "living" infrastructure operated proactively based on the actual condition of the electricity system (European Commission, 2013c).

The main drivers for Smart Grids deployment are the European environmental policy goals aiming at CO2 reduction, deployment of renewable energy sources, energy efficiency and the resulting requirements and needs of grid users. Moreover, an increased demand for flexibility emerges both in the transmission and in the distribution grids due to the massive deployment of variable generation (European Commission, 2013c).

Smart Grids employ innovative products and services together with intelligent monitoring, control, communication, and self-healing technologies. Inter alia, Smart Grids provide improved reliability and security of supply by allowing consumers to play a part in optimizing the operation of the system via a provision of information and choice of supply. The Smart Grid enables for adaptation of electricity demand to grid and market conditions, automatic grid reconfiguration to prevent or restore outages, and the safe integration of distributed generators, electric vehicles and large scale renewables (European Commission, 2013c).

Two main advantages of a Smart Grid are summarised as follows:

- The Smart Grid requires an increased use of ICT to improve reliability, security, and efficiency of the electric grid through a dynamic optimization of grid operations and resources, (with full cyber security). Communication as a whole is the backbone of Smart Grid. Deployment and integration of distributed resources and generation, including renewable resources;

- Deployment and integration of advanced electricity storage and peak-shaving technologies, including plug-in electric and hybrid electric vehicles, and thermal- storage air conditioning (European Commission, 2013c; Participant J, 2020);

6.1.3 Conclusion

In 6.1 the major landscape developments and technological niche-innovations were discussed. These developments are putting pressure on the current transport regime. At the landscape level, rapid urbanisation is in this case the major driver for a reconfiguration of the transport regime. It causes urban mobility growth, congestion, pollution, urban land consumption, increased contribution to climate change by cities, etcetera. All these developments ask for changes in the transport regime, which are possibly enabled by technological niche-innovations.

Drones rely on a number of sophisticated technological niche-innovations, but many of these are still under development. Until we see improvement in the following areas, many of the most innovative UAS applications will remain at the concept or pilot stage, including those related to drone delivery and transport.

- Improvements are still needed in terms of energy, because the drones 'payload-range-combination is currently limited. Lipo-batteries are not yet powerful enough for heavier loads and/or longer flights. However, improvements are likely. Apart from the use of fossil fuels, alternative energy sources are not yet sufficiently developed for large-scale applications (Ministerie van Infrastructuur en Waterstaat, 2017).
- In terms of control, autonomously flying drones are the ultimate goal. Although autonomous control is not necessary for all applications, it does offer numerous benefits; for example, human intervention is no longer needed, which saves on costs and improves safety levels. However, to achieve autonomous control, sense-and-avoid technology must be developed, and that is still several years away (Ministerie van Infrastructuur en Waterstaat, 2017).
- If drones find wide applications, the airspace will become more crowded. At lower altitudes, operators or autonomously flying drones must know where other drones are situated in their area, and they must be able to detect objects on their flight paths. At higher altitudes, drones must be integrated into the air traffic management system for manned aviation (Ministerie van Infrastructuur en Waterstaat, 2017).
- Autonomously flying drones need to be able to make fast communications with other aircraft and very precisely determine locations to fly and land. Existing GPS technologies do not always comply to this. Alternatives need to be developed, which can take several years.
- There are many different passenger drone concepts currently in development. None of the concepts meets all of the requirements for commercial flights yet.
- To meet the requirement of very fast charging of the big batteries that passenger drones will have, they require high levels of power. The current power grid might not be able to facilitate this at multiple, distributed and concentrated areas throughout a city. Therefore, digitisation and decentralisation of power generation and the power grid are required, resulting in the realisation of a decentralised Smart Grid.

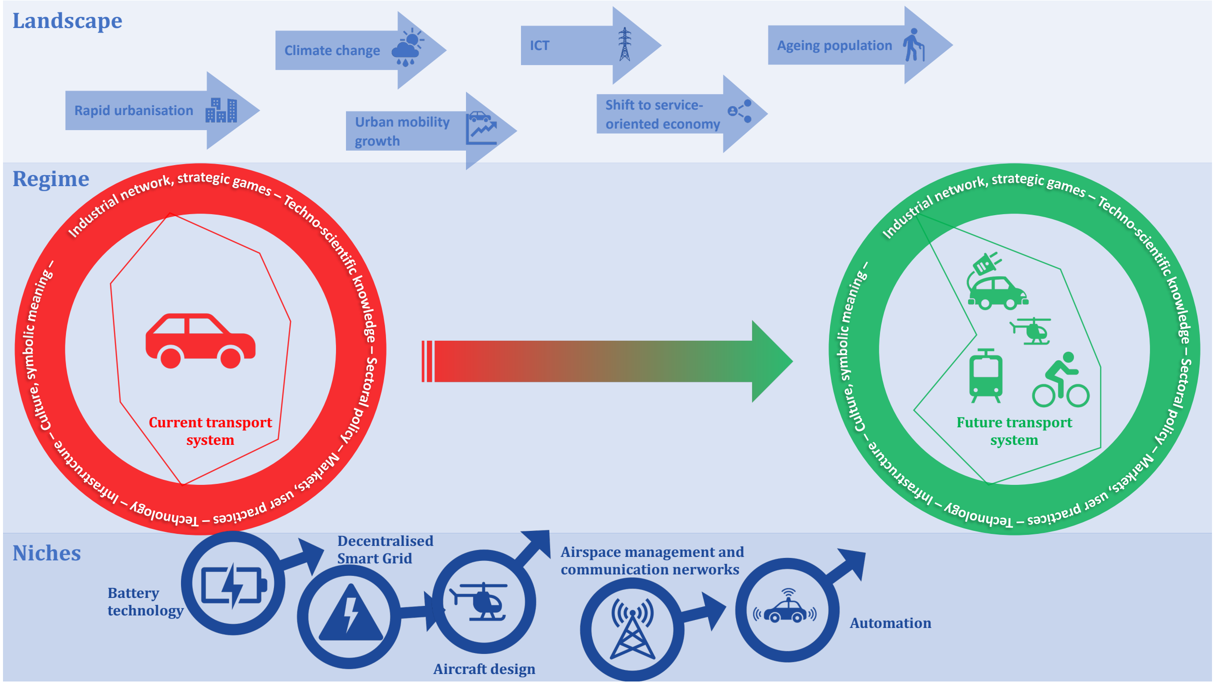


Figure 36 | Illustration of the main factors that put a pressure on the existing mobility regime from above (landscape) and from below (niche). The landscape factors are more general factors, while the niche innovations are mainly related to the concept of UAM.

Although these factors make now the time to press ahead with urban air mobility, this disruptive development will not be implemented overnight. The speed at which the above technologies progress limits the pace at which the UAM market can evolve. Moreover, working services and an attractive customer experience have yet to be created (Roland Berger, 2018).

When these alternative, complementing technologies have consecutively passed through different niches, and merged with each other (3.2.1), they acquire a growing market share and can thus put pressure on the existing regime and sometimes even initiate a regime transformation.

Currently, the alignment of the developments at the different levels of the Mulit Level Perspective makes that a 'window of opportunity' is open for the breakthrough of Urban Air Mobility to the regime level. It must be noted here, that the niche-innovation of UAM will eventually only break through if the developments at both the regime and landscape level remain aligned with the niche level. In other words: only if the landscape keeps pressuring the regime level, and the cracks within the regime level keep existing, the niche-innovation will break through.

The next section will outline the regime changes that will take place when UAM is introduced, by comparing the current and future mobility regime.

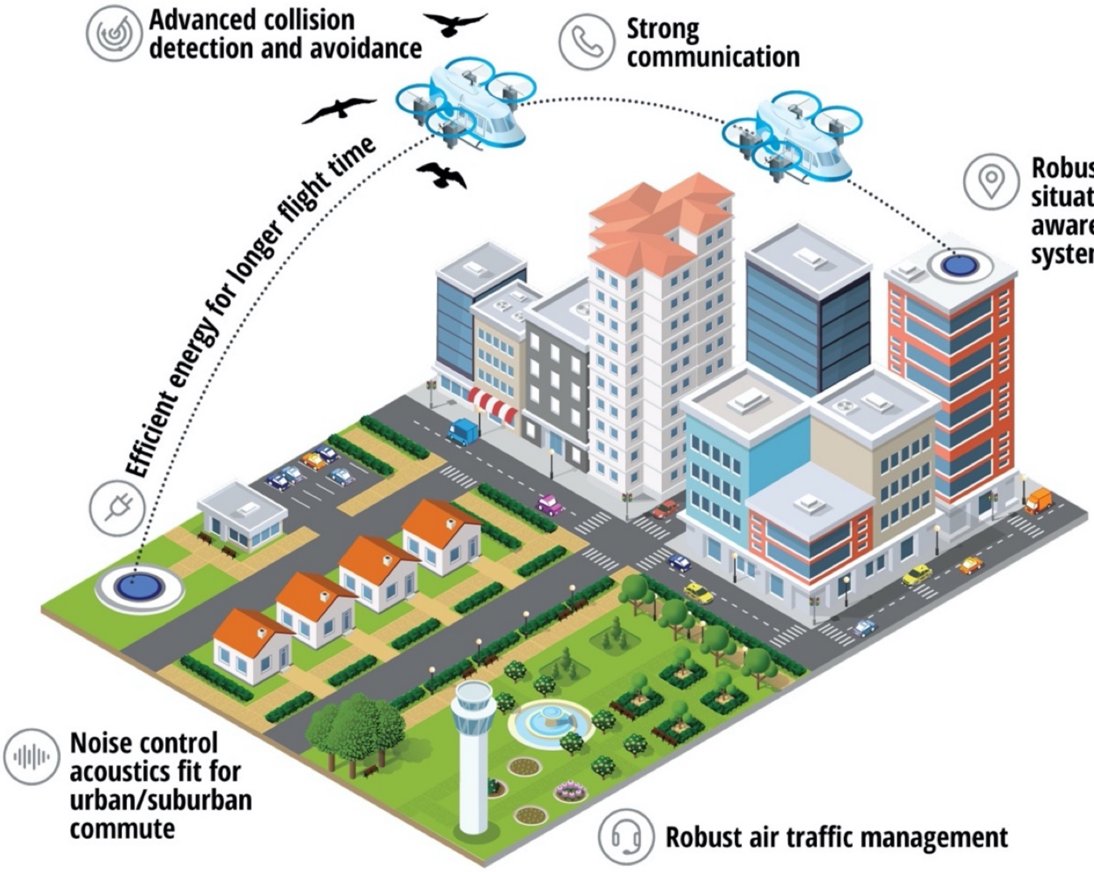


Figure 37 | What eVTOL operations require to carry people and products within cities (Lineberger et al., 2019b).

6.2 Comparison of the current regime and the final picture

In this section, the final picture is compared with the current regime and the main changes are identified. The description of the final image on the basis of the seven regime dimensions (table 1, 3.2.1) can be found in Appendix D.

6.2.1 Vehicles

In the field of technology, developments are mainly required with regard to vehicles and infrastructure. A new type of vehicle must be developed that can fly autonomously and on sustainable energy (for the time being mainly electric). This calls for optimizations of current vehicle designs and in particular progress in autonomy and battery technologies. Other technologies that are needed are in the areas of sensing, cybersecurity, emissions, structures, safety, pilot training, certification, communications, controls, operations and traffic management. See also the infrastructure dimension for the required changes in that area.

6.2.2 Infrastructure

Currently, the urban mobility system is mainly designed for ground transportation purposes, which is why there is not much infrastructure in place for urban air mobility in most cities. In some cases, a small number of suitable existing infrastructure pieces, like helipads, can be found, which may be sufficient for small scale operations in the first years. However, in general cities lack the necessary infrastructure for UAM operations, especially in city centres and for scaled operations. This asks for the installation and expansion of the critical infrastructure elements over time, which are proper take-off and landing zones, battery charging stations and a fit-for-purpose energy network. In some of the biggest cities around the world, this may eventually involve more than hundred vertiports.

6.2.3 Markets, user practices

The use for which UAM is intended does not necessarily differ drastically from current practice in the field of transport and mobility. UAM potentially has a wide range of applications, including inspection, freight transport and passenger transport. For this thesis, the focus is on passenger transport. In practice, the uses of UAM will be consistent with the use for which the current transport modalities, especially the car and to a lesser extent the train, are intended. The most potential passenger markets are the airport shuttle, intra-city air taxi and intercity air taxi. Typically, these use cases will focus on quick point-to-point movements of one to five passengers, with distances of more than 15 to 25 kilometers being most appropriate (4.3.3-4.3.5). In that respect, the use of passenger drones will be most competitive with longer-distance modes, especially the car and to a lesser extent the train (Ministerie van Infrastructuur en Waterstaat, 2017). UAM is seen as an improvement and addition to the current mobility system and Mobility as a Service. In the future vision it can become a part of the multi-modal journey of passengers. For example, they take the tram from home to a nearby vertiport, fly from there to another vertiport, and then make the last-mile to work with a shared bicycle. However, due to the expected price level, UAM might become a niche market.

6.2.4 Culture, symbolic meaning

Compared to the current transport regime, UAM basically fits in well with the cultural values that people attach to automobility and it potentially symbolizes even more freedom, choice, progress, wealth, modernity, status, convenience and speed. Furthermore, it could encourage feelings like the 'joy of flying'.

On the other hand, however, there is a risk of gaining negative values, which arise from the possible nuisance of noise and visual pollution, invasion of privacy, safety risks and the idea that UAM will become a transport mode for the rich. It will largely depend on the framing of UAM which way it will go.

6.2.5 Industrial networks, strategic games

Compared to the current regime, many large and small players are joining the playing field of urban mobility. The biggest change from the current regime is that new stakeholder relationships will (should) arise that were not there before. These new relationships arise mainly between actors from the first four pillars and the last pillars: local authorities suddenly have to deal with actors from the aviation industry, and vice versa. For instance, actors like Airbus that are used to talk to the big players, national governments, national authorities, big aircraft operators, now suddenly have to dive into the complicated headache world of local politics and stakeholders where everything and everywhere is different. Whereas the city stakeholders were not really a priority before, with UAM now the stakeholders are much more different for traditional aircraft developers. They are very politically driven and very different from one place to another one. Dealing with this can be a complex process.

6.2.6 Sectoral policy

There are a number of important changes to be made to sectoral policy to enable commercially viable urban air mobility. These mainly have to do with regulation. Firstly, sectoral policies currently differ from country to country. Each country has its own regulations and has its own position with regard to drones, which makes for an unclear patchwork and does not benefit smooth developments of the drone industry. Standardization of sectoral policy, and in particular in the field of regulation, is therefore desirable. This also applies to vehicles and infrastructure. A standardized policy in these areas, and internationally agreed certification, will ensure that every vehicle is able to use every infrastructure component.

In addition to standardization, changes in the regulations themselves are also required. Currently, regulations in many countries hinder the development and application of drones, as current regulations rely heavily on public safety and security concerns. Although it is desirable that these aspects continue to be respected in future regulations, they now have the upper hand, as a result of which drones can barely operate in urban areas, while UAM should take place there. It is therefore important for the drone industry that a regulatory framework will be created that allows to take off, depart terminal areas, fly, interact with other aircraft, approach, and land. This implies that regulations with regard to VLOS, flying over populated areas, maximum altitudes and the like will need to change in order to make (autonomous) commercial drone services in urban areas possible.

6.2.7 Techno-scientific knowledge

The existing knowledge of the socio-technical transport system is also very useful when it comes to adding a new modality to this system. However, new knowledge is also required, which is akin to the five pillars formulated by NASA: (1) Vehicle Development and Production, (2) Individual Vehicle Management and Operations, (3) Airspace System Design and Implementation, (4) Airspace and Fleet Operations Management and (5) Community Integration. Specifically, the Community Integration, which this thesis focuses on, requires knowledge with regard to public acceptance, infrastructure, integration with ground transportation and sectoral policy, among other things.

6.3 Conclusions regarding transition characteristics

The above comparison of the current regime with the final picture demonstrates that each socio-technical dimension shows transition aspects to some extent, which is a characteristic of a transition. In some of the dimensions, the changes will be bigger than in others. In the context of community integration of UAM, it seems that the biggest changes are required in the dimensions of infrastructure, sectoral policy and culture. This is in line with the expected challenges and barriers that are encountered on the way to the future (see chapter 7). For example, a completely new infrastructure must be built, and existing infrastructure must be upgraded. This mainly concerns the construction of vertiports, charging infrastructure and adjustments to the energy network. On the other hand, changes in the public opinion are required for drones, which is reflected in changing policy and a changing attitude.

7 Identification of transition barriers and actions towards scaled UAM operations: a case study

7.1 The Randstad

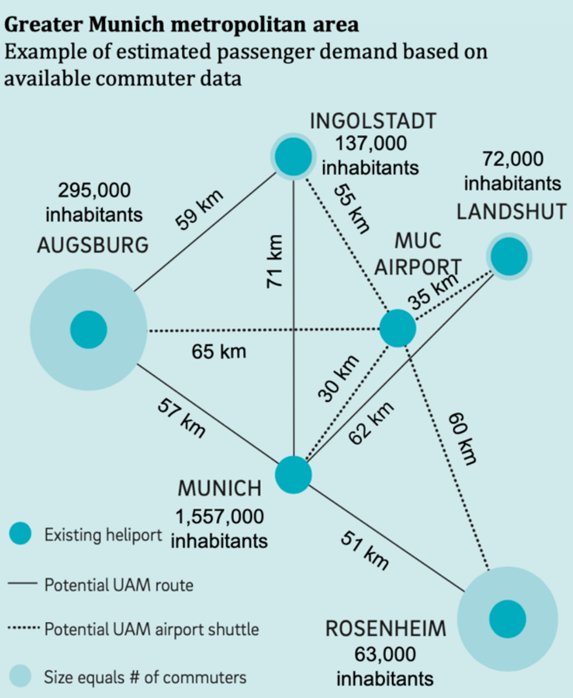
The necessary changes in the dimensions of the mobility regime must be given a place in the community in some way. This will cause challenges and barriers that will require action in the coming years. An area of 1 km^2 of an urban environment has been taken to illustrate this. Within the Netherlands, UAM has the highest potential in the Randstad. The Randstad is a 'polycentric' (multi-core) urban concentration or conurbation in the west of the Netherlands, a metropolitan area where various agglomerations with their own central cities have grown together or are growing. It includes the four largest cities in the Netherlands: Amsterdam, Rotterdam, The Hague and Utrecht, with the urbanized areas in their vicinity. With a population of 8.2 million people it is one of the biggest metropolitan regions in Europe, comparable in population size to the metropolitan area of Milan or the San Francisco Bay Area. It covers an area of approximately 8,287 km^2 and includes both the metropolitan areas of Amsterdam and Rotterdam–The Hague (Regio Randstad, 2019).

7.2 The Randstad compared to the Munich Metropolitan Area

As an area, the Randstad shows strong similarities with the Munich Metropolitan Area, located in the south of Germany. Because market studies have focused on this area, it can be used to estimate the market potential of the Randstad. This area is expected to have sufficient potential for a UAM market (KPMG, 2019; Porsche Consulting, 2018; Roland Berger, 2018). The extensive reasoning behind these similarities can be found in Appendix E. The focus is on aspects that are considered important for the market potential of UAM, including demographic factors, business climate and the state of the existing mobility system (KPMG, 2019; Roland Berger, 2018; Porsche Consulting, 2018). Both regions score better than the other on a number of aspects and almost the same on others, and can be categorized as large 'Prosperous Communities' (4.3.5). Based on these scores, it is assumed that the Munich Metropolitan Area has overall a slightly greater market potential for UAM than the Randstad. However, the conclusion is that a UAM market may also develop within the Randstad in the long term. Because the latter area is well known to the author, it is eminently an area in which to uncover the barriers and necessary actions for the realization of UAM.

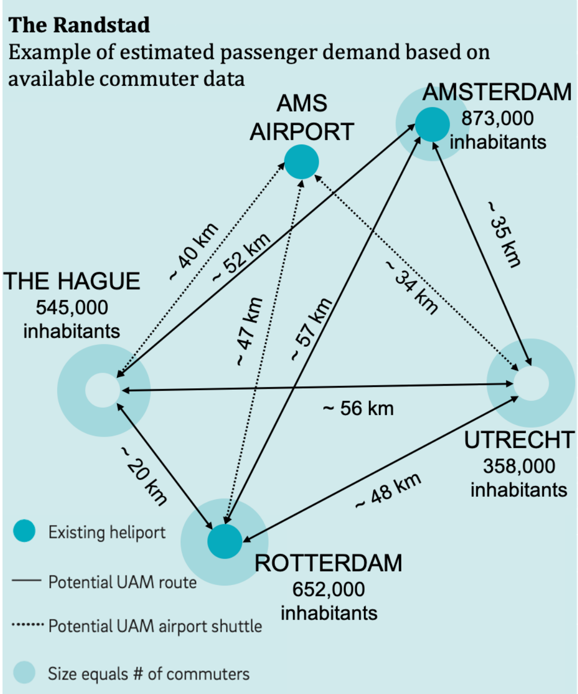
Based on the data, various potential routes for UAM can be identified, as Roland Berger (2018) did for the Munich Metropolitan Area (fig. 38). From this it can be assumed that commuters and air travelers considered as important categories of travelers for a UAM market. Routes where demand is limited, such as between a number of German cities, probably have too little potential for a UAM market and are therefore not included in the table.

A similar illustration can be made of the Randstad (fig 39). It is likely that the vast majority of flight movements will take place in and between the five nodes in this figure: the G4 and Amsterdam Schiphol Airport. It is therefore assumed that the first market developments of UAM in the Netherlands will arise here. Together, these cities account for almost 2.5 million inhabitants, almost 400 thousand more than the five cities in the Munich metropolitan area. Between all four cities within the Randstad, significant numbers of commutes take place. On the other hand, the distance between Amsterdam and Amsterdam Schiphol Airport is so small (<12 km) that a commercially viable market seems unlikely for this route. Therefore, this route is not included in the table as a potential UAM airport shuttle.



Potential UAM intercity routes	Total commuter demand [# of commuters]	Distance [km] [car / eVTOL]	Travel time [min] [car / eVTOL]
Munich - Augsburg	22,644	80 / 57	55-110 / 35
Munich - Ingolstadt	8,512	80 / 71	55-100 / 40
Munich - Landshut	5,672	73 / 62	50-85 / 37
Munich - Rosenheim	20,874	67 / 51	50-85 / 33
Augsburg - Ingolstadt	834	78 / 59	60-100 / 36
	58,536	**75 / 58**	
Potential UAM airport shuttle	**Potential demand per route per day [# of travelers]**		
MUC - Munich	34,000	40 / 30	30-55 / 26
MUC - Augsburg	6,600	85 / 65	50-85 / 38
MUC - Ingolstadt	3,300	71 / 55	45-80 / 34
MUC.- Landshut	1,600	41 / 35	30-50 / 28
MUC - Rosenheim	1,400	75 / 60	65-100 / 36
	46,900	**50 / 38**	
Potential UAM air taxi routes			
The study by Roland Berger (2018) has not specified potential routes for this use case.			

Figure 38 | Potential routes for UAM operations in the Munich Metropolitan Area. Sources: Roland Berger (2018), Bundesagentur für Arbeit (2019), Bayerische Landesamt für Statistik (2019), Stadt Augsburg (2019), Stadt Ingolstadt (2018), Landeshauptstadt München (2019), Google Maps.



Potential UAM intercity routes	Total commuter demand [# of commuters]	Distance [km] [car / eVTOL]	Travel time [min] [car / eVTOL]
Amsterdam - Rotterdam	21,400	78 / 57	55-80 / 35
Amsterdam - Den Haag	26,400	64 / 52	50-85 / 33
Amsterdam - Utrecht	67,800	50 / 35	40-60 / 28
Rotterdam - Den Haag	54,400	25 / 20	30-65 / 23
Rotterdam - Utrecht	18,200	66 / 48	45-75 / 32
Den Haag - Utrecht	30,200	73 / 56	55-85 / 35
	218,400	**53 / 40**	
Potential UAM airport shuttle	**Potential demand per route per day [# of travelers]**		
AMS - Rotterdam	9,400	60 / 47	40-60 / 32
AMS - Den Haag	7,900	47 / 40	35-70 / 29
AMS - Utrecht	5,200	53 / 34	40-65 / 27
	22,500	**54 / 42**	
Potential UAM air taxi routes			
Just like in the study by Roland Berger (2018), potential routes for this use case are not specified here yet.			

Figure 39 | Potential routes for UAM operations in the Randstad. Sources: AlleCijfers.nl, Planbureau voor de Leefomgeving (2019d), CBS (2020), Royal Schiphol Group (2020), Zijlstra (2020), Parkago (2015), Google Maps.

A commercially viable UAM market is expected for the Munich Metropolitan Area from the 2030s onwards. By 2050, up to 800 passenger drones could be in operation (Roland Berger, 2018). After the comparison with the Randstad, it therefore seems plausible that a similar market could emerge in the Randstad, also in view of a study by KPMG (2019), which expects the first flight movements in Amsterdam between 2030 and 2040. In 2050 they expect 40% more passenger enplanements in Munich than in the Randstad. Given these facts and expectations, the Randstad appears to be a moderately suitable region for UAM. Due to the similarities between the Munich metropolitan region and the Randstad, it is therefore assumed that the market potential of UAM in the Randstad is approximately slightly below that of the Munich metropolitan region. A rough estimate of 500 to 600 passenger drones in 2050 therefore appears to be realistic. Therefore, and because of the author's familiarity with the city, 1 km^2 of Rotterdam is used as part of the Randstad to further illustrate the challenges and necessary actions for facilitating UAM.

7.3 One square kilometer in the Randstad: Rotterdam – Central District

7.3.1 Task

With a potential of 500 to 600 vehicles in 2050, a number of up to 50 veriports would be realistic (Porsche Consulting, 2018). It is likely that the first and most of these will be realized in the four major cities, after which expansion will take place step-by-step (fig. 40 and 41). These must be integrated into the existing environment as well as possible and this is accompanied by challenges and necessary actions. For the purpose of this study, we zoom in on one of those cities, Rotterdam. In a city like Rotterdam, vertiports could eventually be realized at several locations, spread across the city, in order to create a network that offers sufficient coverage (Porsche Consulting, 2018) (fig. 42). These locations were selected because they score relatively well on a number of criteria that are considered to promote a well-functioning, commercial UAM market (table 19). These partly correspond with the factors that were used to compare the Randstad and the Munich Metropolitan Area, and can be attributed to the three previously distinguished categories: demographic factors, business climate and the state of the existing mobility system. By specifically zooming in on an urban area of 1 km^2, challenges and necessary actions for the realization of UAM can be made clear.

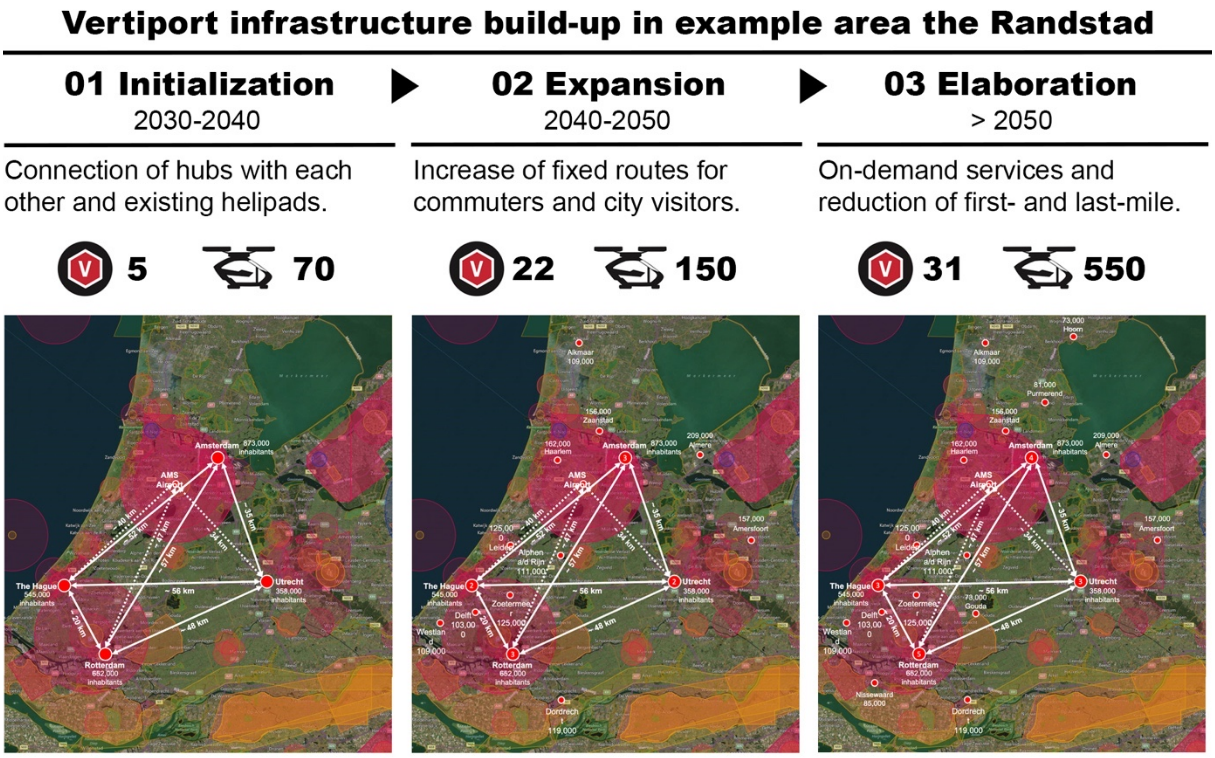


Figure 40 | Possible scenario of vertiport infrastructure build-up in example area the Randstad.

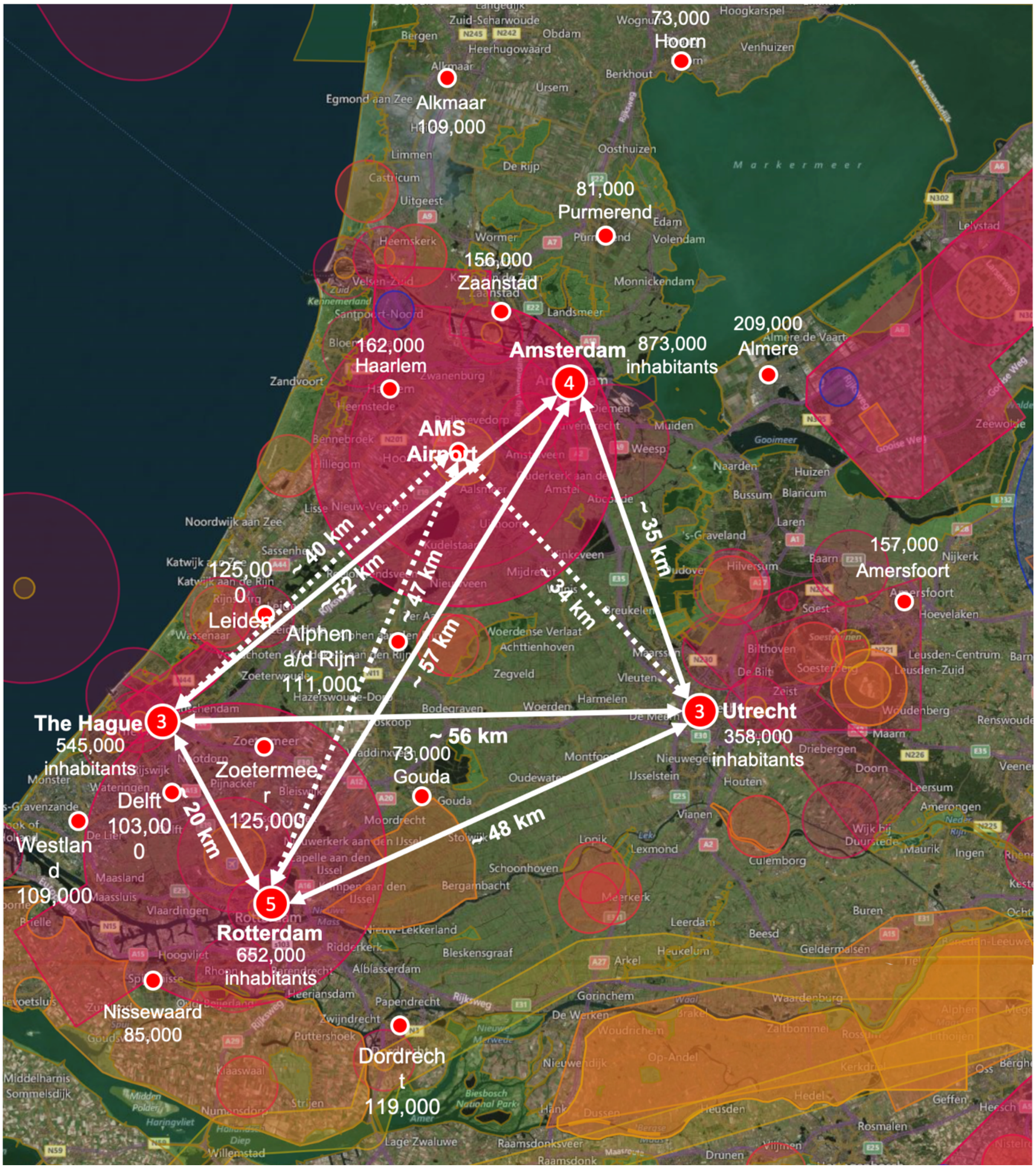


Figure 41 | Possible vertiport network in the Randstad from 2050, with the main UAM routes between the G4 and Amsterdam Schiphol Airport.

Figure 42 | Possible vertiport network in Rotterdam from 2050, with vertiports located at or near (major) transport nodes.

Table 19 | Factors Influencing UAM Ground Infrastructure Placement.

Demand side	Supply side
Population size and density	Existing helipads and potential spots
GDP per capita	
Office rent price	
Jobs density	
Major transport node	
Number of (extreme) commuters	
Point of Interest	

7.3.2 Situation

The square kilometer that is zoomed in on, is the area around Rotterdam Central Station (fig. 43). The area is located on the boundary between the districts of Rotterdam Center and Rotterdam-North and is enclosed to the west and east by the districts of Delfshaven and Kralingen-Crooswijk respectively. Further south is the Feijenoord district. As mentioned, it is important that UAM is integrated at locations that score well on the aforementioned factors (table 19). Realizing UAM ground infrastructure at those locations maximizes the chance of market success. The square kilometer around Rotterdam Central Station is such a location within the Netherlands, the Randstad and Rotterdam (table 20).

An estimated 11 thousand people live in the area (Gemeente Rotterdam, 2020b; Google Maps). This is fairly densely populated. By having a dense population living in a particular area, the possibility of UAM ground infrastructure to reach potential passengers becomes higher (Vuchic, 2005; German et al., 2018; Roland Berger, 2018; Porsche Consulting, 2018; KPMG, 2019). However, there are denser populated areas in the world. Manhattan is one of the most densely populated areas in the world with approximately 26,000 people per square kilometer (United States Census Bureau, 2019).

The standardized income - adjusted for the size of a household - is also relatively high. On average this is € 31,800. Furthermore, more than a quarter of the inhabitants belong to the top quintile of income groups, which means that a relatively large number of people with a high income live here (Gemeente Rotterdam, 2020c). Since the initial operations of UAM are predicted to be quite expensive – and more expensive than taxi services – previous studies mention income level of a population in a particular area as a demand indicator (Syed et al., 2017; Vascik and Hansman, 2017b; German et al., 2018; KPMG, 2019; Porsche Consulting, 2018; Roland Berger, 2018; Uber Elevate, 2016; Participant B, 2020). This thesis selects standardized income as one of the demand factors. It corrects for differences in household size and composition, thus presenting the actual purchasing power of a household (CBS, 2020b).

Office rents are also high. With prices rising to € 265 per m^2, the area is in the top of the Netherlands (Dynamis Research & Consultancy, 2020). The idea is that office rent price is a proxy for estimating business trip budget of a company. The higher the office rent price a company pays supposedly represents a higher budget for business trips done by its employees. As a result, more potential UAM demand exists at locations where office rent prices are high (Nexa Advisors, 2009; Uber Elevate, 2016). The location is also home to a large business district. There are many jobs to be found here: an estimated 21 thousand (Gemeente Rotterdam, 2020b; Google Maps). In the planning phase, a transportation infrastructure should be designed to create a supporting relationship with land use patterns (Vuchic, 2005). Taxi stands in New York city, for example, are predominantly located adjacent to office building (Giuliani, Rose, & Weinshall, 2001). The same pattern can be seen in Rotterdam Central District itself, with a large taxi stand next to Rotterdam Central Station. Therefore, having UAM ground infrastructure to support and serve business districts or an area where a lot of offices are located, might have economic potential. The transport demand generated by job density could be a daily routine (commuting) trip or irregular business trip (Participant B, H, 2020).

There is also a large station in the area. With 170 thousand daily visitors (Prorail, 2019) this is an important hub in the Dutch and Randstad transport system and therefore a potentially interesting location for a vertiport. Here you can take all kinds of different means of transport, with which different distances can be covered: (international) train, metro, tram, bus, scooter, bicycle and car or taxi. There is a potential demand of UAM from and to major transport hubs, as shown by the current helicopter charter services routes in Los Angeles (Vascik & Hansman, 2017b) and current Uber long-distance trip data in Los Angeles and London (Uber Elevate, 2016). Major transport nodes are also important when it comes to intermodality, as they provide passengers with the convenience to change mode of transport almost seamlessly from one mode of transport to another (Vuchic, 2005). What is considered is that people can easily travel from their home to work, for example by tram, drone and shared scooter. This means that UAM will have to be connected to the existing (land-based) transportation system, and that the UAM ground infrastructure would be ideally located near existing transportation hubs (Participant B, G, H, I, J, K, L, Q, R, S, T, 2020). ‘In the industry, we’ve talked about the concept of the UAM hub. I think this is a really key topic. So, for example, if we use a light rail public transportation stop, that’s a prime location for an UAM hub.’ (Participant I, 2020). eVTOL vehicles could serve the first and last mile in a long distance trip, in which an airplane or high speed intercity train acts as the main leg carrier, or they could be the main transportation mode on trips up to ~ 200 km. To sum up, it is foreseeable that major transport nodes generate potential passengers in the operation of UAM (Participant A, B, G, H, I, J, L, R, T, 2020). There are also a number of important traffic axes through the area, such as the Coolsingel, the Weena and the West-Kruiskade. The Westblaak also runs just south of the area. These are axles that regularly fill up with traffic. At the same time, the space for cars will be reduced in the coming years, partly by reducing the number of lanes, for example on the Coolsingel (Gemeente Rotterdam, n.d. c) and Westblaak (König, 2020). However, the exact number of travelers coming to, from and through the area each day is difficult to determine. The number of 'extreme commuters' that travels to and from the whole of Rotterdam on a daily basis is well known, though, and ties in well with the previously discussed 'job density' factor. Between Rotterdam and the other three large cities, this number is approximately 47 thousand (and twice as much for the roundtrip). Seen across the Netherlands, the number of daily 'extreme commuters' that travels to and from Rotterdam is 269 thousand (CBS, 2020). Here, ‘extreme commute’ is an subjective term, since a distance may be long for some, but short for others. However, earlier in this thesis, it was mentioned that passenger drones will have a competitive advantage in time saving on distances above 15 to 25 kilometers, depending on the specific circumstances (3.3). The aforementioned numbers of "extreme commuters" are therefore commuters who live or work at a minimum distance of 15 km from Rotterdam. eVTOL vehicles are expected to carry passengers that are willing to pay more for getting an advantage in travel time. Often, those are persons who travel through traffic jam hot spots or long distance trips (Vascik & Hansman, 2017b), in this case at least 15 km. A high number of extreme commuters is seen as a proxy for UAM demand (Vascik & Hansman, 2017b; Rapino & Fields, 2012; Uber Elevate, 2016).

In addition, various points of interest can be found within and in the vicinity of the square kilometer. Points of interest (POI) are known as places most visited by tourists, both international tourists and local residences. Tourism symbolizes an evidence of demand for urban transportation (Albalate & Bel, 2010; Vuchic, 2005; Vascik & Hansman, 2017b; Amoroso et al., 2012). A number of these points of interest are also in the top 50 most visited attractions in the Netherlands. Points of interest in the vicinity of the square kilometer that are of interest to the public and frequently visited by them include the Markthal, Bijdorp Rotterdam Zoo, Spido Rotterdam, Erasmus Bridge, Museum Boijmans van Beuningen, Kunsthal, Maritime Museum, Rotterdam Central Station and the Lijnbaan area (Respons, 2020; Rotterdam Tourist Information, n.d.; City Rotterdam, n.d.).

Finally, the closest existing heliport that can be used for UAM is located at Rotterdam The Hague Airport. This in itself is a potential location where passenger drones could land (fig. 5) and is located about 4 km (straight line) and about 13 minutes' drive from the Central District, which is quite a long distance. The factor of utilizing existing helipads could reduce initial cost of UAM and enable short term operations, because no construction and land acquisition are necessarily needed (Porsche Consulting, 2018; Roland Berger, 2018; Participant B, K, 2020). In the area itself, 13 locations have also been pointed out as possible locations for a vertiport. To do this, the required surface area for a vertiport was initially considered. These 13 locations all meet the minimum requirement of approximately 30 m by 30 m, based on various previous studies (HeliExperts International, n.d.; Vascik and Hansman. 2019; Crown Consulting, 2018; Participant A, 2020).

Table 20 | Values of factors influencing UAM ground infrastructure placement at the location considered and compared to a random, average square kilometer in the Netherlands. Sources: Gemeente Rotterdam (2020b; 2020c), AlleCijfers.nl (n.d.), Dynamis Research & Consultancy (2020), Respons (2020), Rotterdam Tourist Information (n.d.), City Rotterdam (n.d.), CBS (2020), Google Maps.

Factors	Rotterdam Central District	The Netherlands
Population size and density	~ 10,750	416
Standardised household income [average / % high stand.]	~ € 31,800	€ 29,800
	~ 26.5%	20.0%
Office rent price	€ 200-265/m2	€ 132/m2
Jobs density	~ 20,900	214
Major transport node	Rotterdam Central Station	-
Number of (extreme) commuters (> 15 km) [G4 / total]	~ 47,000	
	~ 269,000	
Points of Interest (within 10 min. by bike)	Markthal, Diergaarde Blijdorp, Spido Rotterdam, Erasmusbrug, Museum Boijmans van Beuningen, Kunsthal, Maritiem Museum, Rotterdam Central Station, Lijnbaan area	-
Existing helipads and potential spots	Rotterdam-The Hague Airport; 13 potential spots	-

Figure 43 | Overview of the area that is used to illustrate the barriers and necessary actions on the way to UAM Community Integration.

7.3.3 Challenges to overcome and actions to take

In the previous sections, it was outlined that the Randstad is a metropolitan area that might have the potential for a UAM market. In order to fulfill this market, the task is to develop certain locations in the area to enable fruitful UAM routes. The location around Rotterdam Central Station might be such a location, with the right market circumstances in place. As was concluded from chapter 6, the breakthrough of UAM into the mobility regime will result in several changes in the dimensions of the mobility regime. These changes have different effects in the areas in which UAM will be integrated. This section further explains what these effects are, what barriers and challenges they create and what actions must be taken in response. The starting point is and remains the development of the square kilometer - Rotterdam Central District. What happens when you integrate UAM into the community here?

The barriers and actions are categorised according to the seven dimensions in the MLP. These are divided over three main categories: technology, market and industry. Each paragraph discusses the various challenges within the dimension of that paragraph. Each challenge is described in a separate section with the following structure:

- Challenge or barrier
- Explanation
- Recommendation to action

For each recommendation it is indicated whether the described action is in direct or indirect interest of the communities and why. In addition, it is indicated on what period it is recommended to start with that action, which is based on rough assumptions. Also, the expected impact or result of the action is written down. For the purpose of this thesis, the take-off of the first UAM operations, or the initialization phase, in the Randstad is assumed somewhere between 2030 and 2040, based on the existing market research. Earlier, UAM may only be a mode of transport in the biggest metropolitan areas in the world (KPMG, 2019; Porsche Consulting, 2018; Roland Berger, 2018). Therefore, the period for the recommended actions is based on a take-off between 2030 and 2040; here the year 2035 is assumed to be the starting year for the first dozen vehicles, although it may take off later. This period can simply be adjusted afterwards for regions with different take-off times.

7.3.3.1 Technology

Vehicles

Challenge 1: Cities get to deal with a new kind of vehicles

Although the technology in the form of the vehicles and their development will largely fall outside the field of municipalities, they will have to deal with these new vehicles in the operational phase. Cities are unfamiliar with it, while they will have all kinds of impacts within the cities. Examples are in the social domain, with regard to noise production, horizon pollution, privacy and safety. Logically, they will therefore want to have a say about these vehicles.

Recommended actions

- **Action Point 1.1: Contribute to the certification process of vehicles**

  To ensure that the impact of passenger drones is limited as much as possible, it is likely that cities want to have something to say about these vehicles. One way to do this is to contribute to the certification of the vehicles (Participant A, C, H, 2020). In this way, cities, in collaboration with higher governments and aviation authorities, have an influence on the vehicles that come to fly in their city. For example, they could determine that vehicles that do not meet certain technological, noise or safety standards are not allowed in their city.

Interest: direct
It is in the direct interest of cities to ensure that vehicles in their city meet certain standards.

Term: 2027-2032
Certification process of vehicles might be very slow (Uber Elevate, 2016; Community Air Mobility Initiative, 2020b; Roosien and Bussink, 2018). However, it should be finalized before the development of ground infrastructure but can only be done after (standardized) designs have been finalized.

Impact: with this action, cities contribute to the quality assurance of the UAM system.

Main executive actor(s): International civil aviation authorities like FAA and EASA, in collaboration with national and local regulators and policymakers.

Infrastructure

The integration of passenger drones in the urban mobility system requires infrastructure, of which landing, charging and energy infrastructure are considered the key components. Other pieces of infrastructure are: Unmanned Traffic Management, Service centers and Docking stations. However, these are seen as less critical parts (Crown Consulting, 2018). Because of the importance of the infrastructure, challenges and required actions within this dimension are discussed first. Within the urban boundaries, within which UAM has the greatest added value, it can be a difficult task to find infrastructure locations which are situated in such a way that the benefits of UAM are actually utilized to a sufficient extent (Participant B, F, G, J, L, M, O, Q, R, T, 2020). This has to do with a certain paradox. On the one hand, it is desirable to realize this infrastructure at locations where there is the greatest demand for passenger drone services, but on the other hand, there is a risk that it is precisely in these places that it is most difficult to do this. The various challenges and necessary actions are discussed below.

Challenge 2: Cities get to deal with a new kind of infrastructure

Just like there will be new vehicles moving through and over cities, they will have to deal with a new kind of infrastructure as well. Cities are unfamiliar with it, while they will have all kinds of impacts within the cities. Examples are in the physical and social domain, with regard to noise production, horizon pollution, privacy and safety. Logically, they will therefore want to have a say about these infrastructures.

Recommended actions

- **Action Point 2.1: Contribute to the certification process of UAM ground infrastructure**

To ensure that the ground infrastructure of UAM fits in well with the current city, it is likely that cities want to have something to say about these infrastructures. One way to do this is to contribute to the certification of the infrastructure (Participant A, C, H, 2020). In this way, cities, in collaboration with higher governments and aviation authorities, have an influence on the infrastructure that becomes part of built environment. For example, they could demand that the infrastructure should meet some minimal safety requirements.

Interest: direct
It is in the direct interest of cities to ensure that the infrastructure in their city meet certain standards.

Term: 2027-2032
Certification process of vehicles might be very slow (Uber Elevate, 2016; Community Air Mobility Initiative, 2020b; Roosien and Bussink, 2018). However, it should be finalized before the development of ground infrastructure but can only be done after (standardized) designs have been finalized.

Impact: with this action, cities contribute to the quality assurance of the UAM system.

Main executive actor(s): International civil aviation authorities like FAA and EASA, in collaboration with national and local regulators and policymakers

Challenge 3: There is a potential shortage of existing infrastructure for UAM operations

The availability of existing infrastructure is one of the key factors to enable UAM operations, especially on the short term, and an influencing factor in UAM ground infrastructure placement (table 19). The first step in infrastructure development will therefore have to be an inventory of the existing infrastructure. A lack of existing infrastructure means a missed opportunity for cost savings and limits the speed at which initial UAM services can start (Participant K, 2020; Booz Allen Hammilton, 2018). In the longer term, this barrier plays a less important role than for example challenge 4.

Currently, there is not much infrastructure in place for urban air mobility. This applies to all critical components. There are a few cities, like Los Angeles and Sao Paulo, that have already a considerable number of helipads, landing spots, to enable short-term UAM operations (Porsche Consulting, 2018). In parallel, there are cities like San Francisco and Paris, which have got even less infrastructure (Participant K, 2020), while most cities, at least in Europe, lack in existing helipads. There are not many city centred heliports (Participant B, K, 2020). 'There are probably some related to hospitals, but these are meant for emergency situations. So, they cannot be occupied with passenger drones in the future' (Participant B, 2020). This situation can also be observed within the square kilometer. There is no existing infrastructure within the area, such as a heliport, on which passenger drones can land - with or without minor adjustments. Where existing infrastructure can be found, or easily developed, that will be suitable for UAM, though, is at airports (Participant H, J, 2020). This is also the case in Rotterdam. As far as is known, the closest heliport that could be used for UAM is at Rotterdam The Hague Airport (Parkago, 2015; Google Maps). However, with a distance of more than 4 km (straight line) and at least 13 minutes of driving from the Central District, this heliport is located quite a distance away. While the airport would be an excellent location to provide UAM services, this is the reason why it may not be the preferred location to serve as a base for the square kilometer.

The question that will be of interest to many communities is to what extent the required infrastructure is already available and to what extent it is suitable for UAM. In order to obtain a good picture of this, it is important to conduct further research into this. If the conclusion is that no suitable infrastructure is available in an area, action will have to be taken in the form of realizing new infrastructure for UAM, where possible.

Recommended actions

- **Action Point 3.1: Review existing heliport and airport facilities for UAM suitability**

  Find out whether and where existing infrastructure is available and whether this infrastructure, with or without modifications, can be suitable for UAM.

  Interest: direct
  Insight into the existing infrastructure is of direct interest, because it is the simplest, fastest and cheapest way to set up the necessary infrastructure and get UAM off the ground.

  Term: 2027
  The term within which this action must be carried out differs per region. For the early adapters, the first UAM operations can be expected within a few years (before 2025). In any case, it is important for them to implement this action in the short term. In regions where the start of UAM is expected later, including the Netherlands, this action can be carried out later as well, but it is advisable to do so at least before the 2030s. Based on the outcome of this action, any follow-up actions can then be initiated on time, as can be read below.

  Impact: this action results in an overview of existing infrastructure and whether it is suitable for UAM. From this it can be concluded to what extent new infrastructure must be developed. In that case, new challenges are encountered and new actions will have to be taken. These are discussed below.

  Main executive actor(s): Urban planners and infrastructure developers.

Challenge 4: UAM ground infrastructure requires a great deal of space and such footprints may be hard to find in dense urban environments

UAM requires infrastructure to make operations possible and it consists of multiple parts (Appendix D.2). It was found that three of these parts were mentioned most often and much more than others when it was about the necessary infrastructure, namely the landing, charging and energy infrastructure, which are connected to each other. Of these parts, the landing infrastructure usually plays the largest role in spatial planning, as it requires most of the space. The charging infrastructure is usually integrated in the vertiport, and so this will be our starting point to further explain the use of space of the infrastructure below. The energy infrastructure is separate from this. The challenges involved in here are discussed later on.

The research findings suggest that it can be hard to find space for the infrastructure within the urban boundaries – given the required footprint –, especially at desired locations (Participant B, D, M, O, Q, T, 2020). There are some variations in the size of the landing infrastructure that we can expect with UAM, although these are primarily based on existing heliport requirements and eVTOL concepts that have been in development so far. Exact vertiport requirements still must be determined (Alexander, 2020), see also challenge 19 and Action Point 19.1. HeliExperts International (n.d.) notes that the place to land can vary from an open area of 400 m^2 for a small two-seat helicopter to 1000 m^2 for a medium twin-engine helicopter. Vascik and Hansman (2019) state that a landing area for one VTOL is around 712 m^2, based on the biggest eVTOL aircraft they reviewed (max. dimension of 13.72 m). Finally, (Participant A, 2020) clarified that according to Skyports the optimal space for a vertiport (or vertipad) with a single take-off and landing area (FATO) and passenger terminal is 1,125 m^2 (with the maximum dimension of the reference vehicle being 15.24m). Based on these dimensions, it can be argued that the minimum space requirement for UAM landing infrastructure, serving one eVTOL, can be around 900 m^2, or 30 x 30 m.

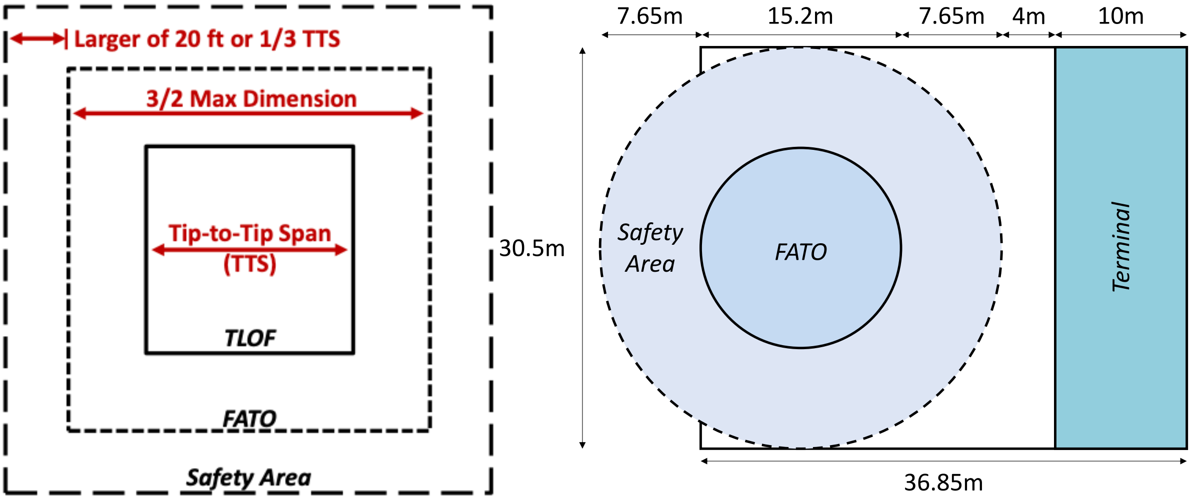


Figure 44 | The landing area (left) as proposed by Vascik and Hansman (2019) has a footprint of 712 m^2. Based upon the review of seven proposed 2-6 passenger eVTOL aircraft, the maximum dimension they found is 45 feet or 13.72 meters. The largest Tip-To-Tip Span (TTS) is 13.72 meters as well. The size of a vertipad (right) as proposed by Skyports contains a landing area and terminal and comprises a surface of 1,125 m^2, assuming a 'reference vehicle' with a maximum dimension of 15.24 meters.

However, UAM landing infrastructure needs to generate some minimum throughput of vehicles per unit of time – otherwise, it will not be commercially viable – and this might not be possible with a vertiport with only one FATO (final approach and take-off area). The reason for this is because it takes serious amounts of time for passenger drones to take-off, land, load and unload passengers and charge the vehicle. Altogether, this could take at least half an hour (Uber Elevate, 2016; Porsche Consulting, 2018), meaning that landing infrastructure with only one FATO may only be capable to handle two passenger drones per hour. Therefore, in many cases landing infrastructure requires even more space than the aforementioned 30m x 30m. To give room to more vehicles at the same time, numerous parking bays are required where eVTOL aircraft can (re)charge their batteries in case they have consumed too much energy for a next flight. But getting even remotely close to the turnaround time of five minutes put forward by Uber Elevate (2016) will also mean that the vertiport is configured in such a way that the parking bays are very close to the FATO (minimizing taxi time) and that the taxiways are not shared (to avoid traffic jams). Such a vertiport would need to be very large. Although a parking bay requires less space than a FATO, the total footprint of UAM landing infrastructure will increase with at least 189 m^2 with every parking bay added, and some room for a taxi route (Vascik and Hansman, 2019; Powell, 2020). Many of the currently proposed configurations of landing infrastructure contain room for multiple aircraft, which would typically be situated in dense districts and near existing transportation hubs (7.3.2). According to HeliExperts International (n.d.), facilities serving multiple aircraft could require up to several acres. Crown Consulting (2018) estimates the average vertiport size to be 2230 to 4645 m^2, including landing areas and additional space for loading/unloading, (fast) charging facilities, etcetera. The average vertiport may be capable of accommodating between 3 and 6 grounded vehicles at one time (though some vertiports may be larger or smaller depending on space, demand, and location). A vertiport design by Vascik and Hansman (2019), with one FATO and eight parking bays for the largest reference vehicle, requires a surface area of around 6 thousand m^2. According to Uber Elevate, the presumed ratio of the landing areas to parking spots is 1:4 (Learn, 2020). Taking the dimensions of all vertiport components into account, this would require a surface of around 3,240 m2, including the landing area, four parking bays and space for taxiing (Vascik and Hansman, 2019). According to Skyports, the optimal space for a vertiport with ratio 1:3 comprises a flat elevated surface of 2,320 to 2,790 m², based on the largest reference vehicles in the market (fig. 45) (Participant A, 2020).

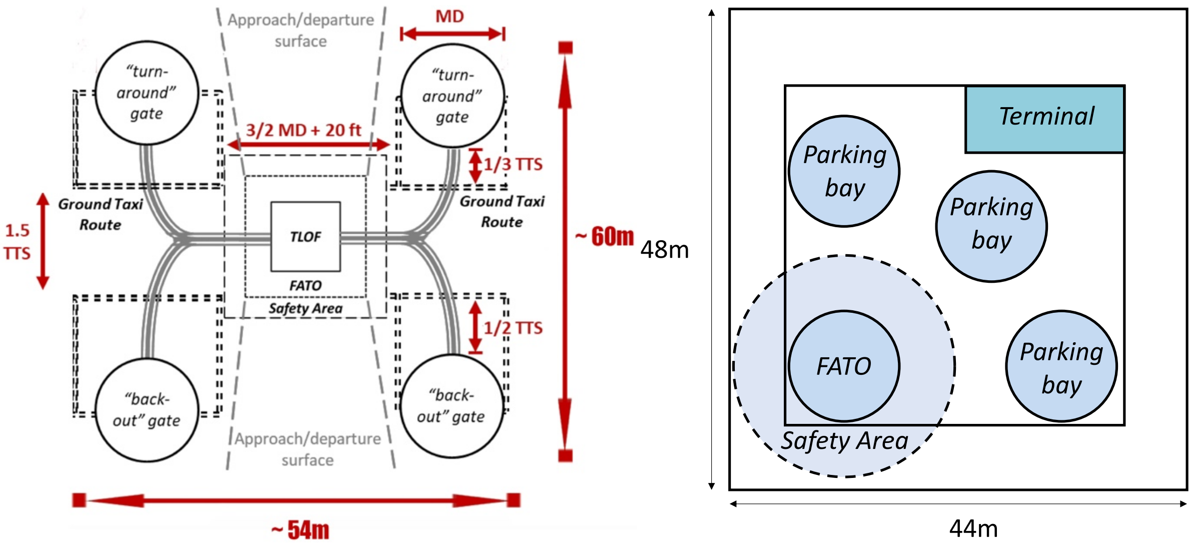


Figure 45 | A potential vertiport design with one FATO/landing area and four parking bays (left), based on the assumptions by Vascik and Hansman (2019). Based upon the review of seven proposed 2-6 passenger eVTOL aircraft, the maximum dimension (MD) they found is 45 feet or 13.72 meters. The largest Tip-To-Tip Span (TTS) is 13.72 meters as well. This vertiport would have a footprint of approximately 3,240 m². A vertiport design with one FATO/landing area, three parking bays and a terminal (right), as proposed by Skyports, has a surface of 2,320 to 2,790 m², assuming a 'reference vehicle' with a maximum dimension of 15,24 metres.

Moreover, vertiport configurations that include multiple FATOs currently need to be 200 feet (60 meters) apart under FAA regulations. Unless eVTOL aircraft can do away with the ground effect of their propulsion systems, there seems to be little incentive to change this (Powell, 2020). A configuration with one FATO on each end of the vertiport and two rows of four parking bays in between would more or less meet the current regulations (fig. 46). However, it would mean that such configurations would have to be enormous and would not likely fit in a dense urban environment.

So, vertiport configurations would easily require footprints of 2,500 m² and more. Given this fact, it can be hard to find suitable locations that are large enough to accommodate the infrastructure, let alone to find several of these suitable locations throughout a city in which tens, hundreds or even thousands of passenger drones are flying through the urban skies and need a place to land.

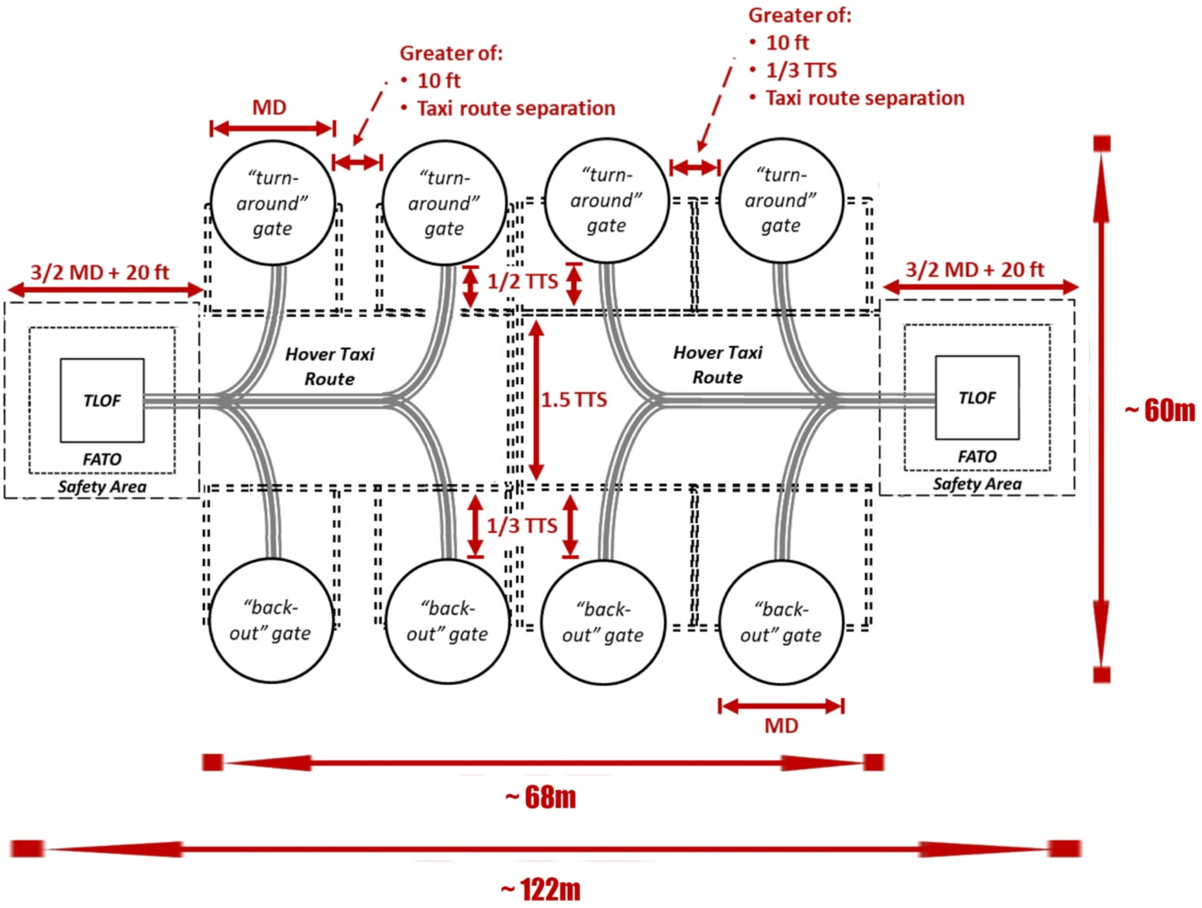


Figure 46 | A larger vertiport configuration that meets Uber's goal of a 1:4 ratio between FATOs and parking bays and that would still meet the current regulations, requiring two FATOs being separated by at least 60m. The total size is around 7,320 m², assuming a maximum dimension and Tip-To-Tip Span of 13.72 meters.

Within the square kilometer - with the help of Google Maps and the free cadastral map from the dutch Land Registry - 13 locations were found that meet the minimum requirement of 30m by 30 m (table 21) and thus offer enough space for at least one landing area. This makes them potential locations for UAM landing infrastructure. In principle, this can be seen as a significant number for an area of one square kilometer in the center of a city, although there might be cities that have less free (flat) surfaces to offer than Rotterdam (Participant B, P, 2020). The locations are divided into three categories of space: first of all, the parking lot or garage, on which various parties expect to see UAM landing infrastructure in the future (Uber Elevate, 2016; Learn, 2020; De Jager, 2020). In addition, the green space, free space where new developments could take place. And finally, the roofs of existing buildings, not being parking garages. This concerns a total of eight built and five non-built locations.

Table 21 | Overview of the locations that meet the minimum space requirement of 30m x 30m, and their footprint. Sources: Google Maps and Kadaster.

Location	Coordinates	Footprint	Room for how many aircraft, including FATO?
Parking 1	51°55'31.7"N 4°28'31.9"E	70m x 62m = ~ 4,340 m²	5
Parking 2	51°55'23.9"N 4°28'33.6"E	40m x 30m = ~ 1,200 m²	1
Parking 3	51°55'17.7"N 4°28'11.6"E	54m x 31m = ~ 1,700 m²	2-3
Parking 4	51°55'30.8"N 4°28'44.6"E	44m x 32m = ~ 1,400 m²	1
Parking 5	51°55'28.6"N 4°28'31.2"E	45m x 44m + 30m x 21m = ~ 2,600 m²	3-4
Parking 6	51°55'43.0"N 4°28'47.4"E	½ x 100m x 40m + 35m x 6m + 32m x 6m = ~ 2,500m²	3
Green space 7	51°55'33.4"N 4°28'50.3"E	113m x 32m + ½ x 32m x 17m + ½ x 32m x 28m = ~ 4,300 m²	3-6
Green space 8	51°55'15.3"N 4°28'31.6"E	80m x 49m = ~ 3,900 m²	6-7
Green space 9	51°55'19.6"N 4°28'00.8"E	45m x 38m + ½ x 45m x 45m = ~ 2,800 m²	3-4
Green space 10	51°55'31.5"N 4°28'48.4"E	½ x 68m x 65m = ~ 1,300 m²	3
Rooftop 11*	51°55'39.1"N 4°28'50.3"E	45m x 31m = ~ 1,400 m²	2
Rooftop 12	51°55'26.6"N 4°28'20.9"E	32m x 28m = ~ 900 m²	1
Rooftop 13	51°55'30.4"N 4°28'23.3"E	94m x 34m = ~ 3,200 m²	3

However, looking at the surface areas of the locations, there are around 10 locations that can accommodate more than one passenger drone. Five of these locations might have the physical dimensions to accommodate at least four vehicles, thereby meeting a ratio of 1:3. Only two or three locations have the right dimensions in place to accommodate at least five passenger drones and meet the presumed ratio of 1:4.

To elaborate on the physical impact that UAM ground infrastructure can have in cities, a deeper, illustrative look is given into location ‘Parking 1’. Figure 47 shows how this location is shaped. If a vertiport would be built over the Schiestraat, the location would be large enough to fit in the vertiport configuration on the left side of figure 45. There would also be potential for two additional parking bays, indicated by a lighter color. However, there is insufficient space for an extended taxiway and so taxiing would have to take place via the other parking bays, which might not be efficient and desirable. With these dimensions in place, a vertiport of this configuration would take up most of the surface of this location (fig. 48). While there could still be some space left in the outlined areas, this would greatly limit the possibility for other developments at this location.

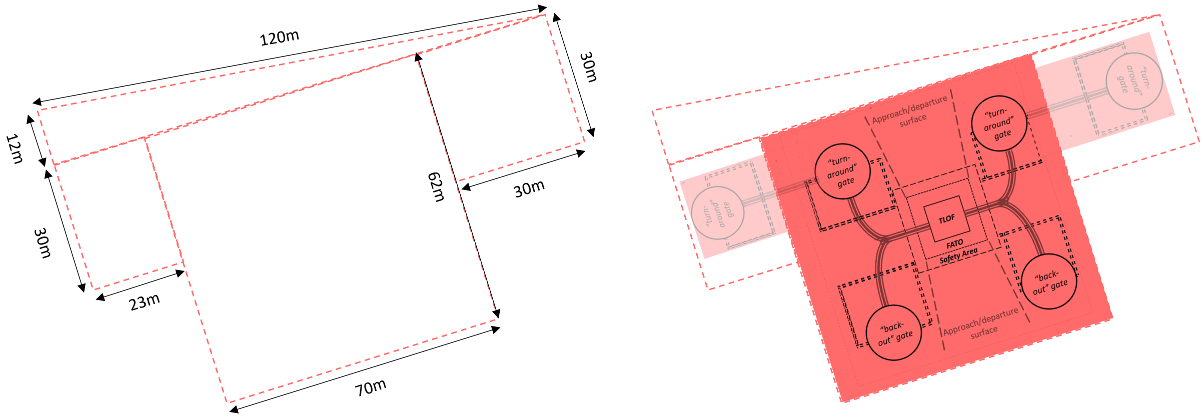


Figure 47 | Location 'Parking 1' can be drawn into four shapes, large enough to fit in a vertiport with ratio 1:4, as can be seen in figure 45.

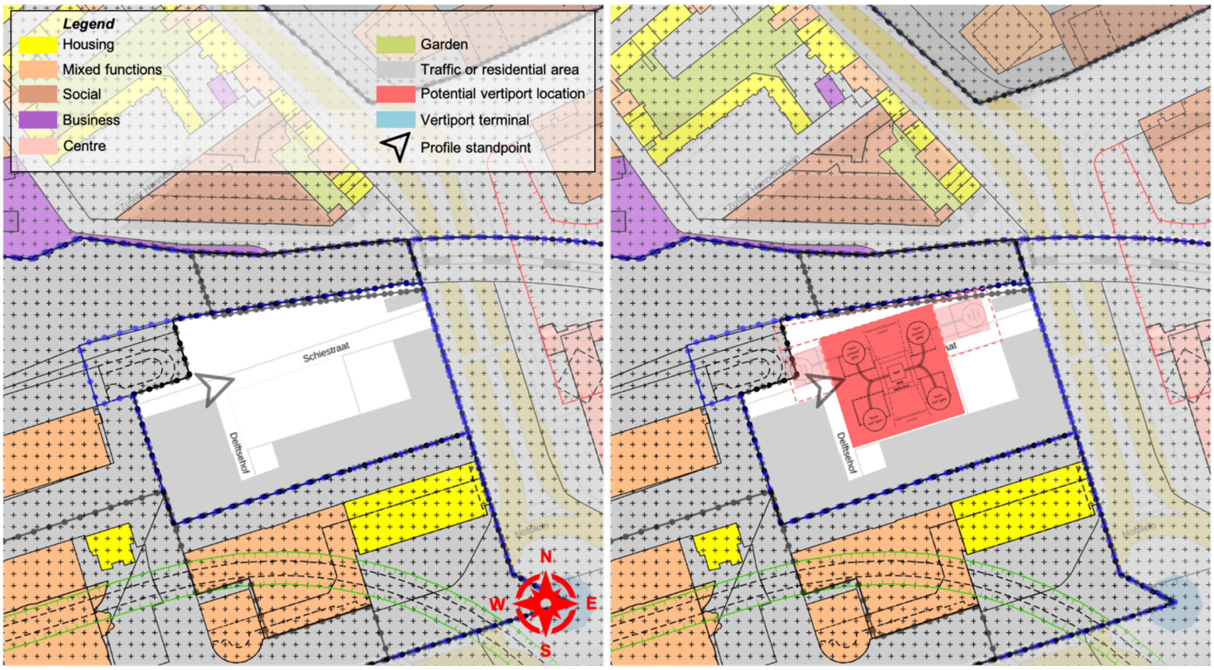


Figure 48 | The location 'Parking 1' and its nearby surroundings as seen from above. The figure shows the existing situation (left) and a possible, new situation with a vertiport fitted in (right). The legend shows the meaning of the different colours. Source: Ruimtelijkeplannen.nl

This is further clarified with figure 49, which shows the profiles of this location in the existing and new situation, as seen from the intersection between the Delftsehof and Schiestraat and looking to the north-east. In the current situation, the location consists of two parking spaces, separated from each other by the Schiestraat, which roughly runs through the middle of the profile. On the left side is first the high-frequency railway that runs to and from Rotterdam Central station and then a building with a social function (a school). On the right-hand side of the location, there are mostly post-war reconstruction buildings in which, among other things, catering and offices are located. Next to this, there is a road, the Delftsestraat, which borders houses and mixed functions (including offices).

In the new situation, a vertiport could possibly be realized on the site, which now consists of the parking spaces and the Schiestraat. Given the dimensions of the infrastructure, almost the entire width (and depth) of the location would be occupied. It would mean that a new building would have to be developed, which will be built over the Schiestraat. The result is that from this perspective only behind and in front of the infrastructure, in the light parts of fig. 48, would possibly still be sufficient space for other (construction) developments. The structure itself, on which passenger drones must be able to land and (temporarily) park, will normally not have a minimum height. However, in view of the enclosure of the Schiestraat it should in this case be high enough to enable ground-based traffic underneath. Furthermore, the dotted lines indicate that in principle the building has no maximum height and can be built as high as is technically possible and desirable. In fact, a taller structure can have several advantages, like the possibility of mixing vertiport with other functions. Besides, it would prevent or reduce obstruction by surrounding buildings and allow for faster and more horizontal take-offs and landings, which in turn would reduce travel time and energy needs. A higher structure would also reduce noise pollution on the ground, which will be discussed in more detail later in this thesis.

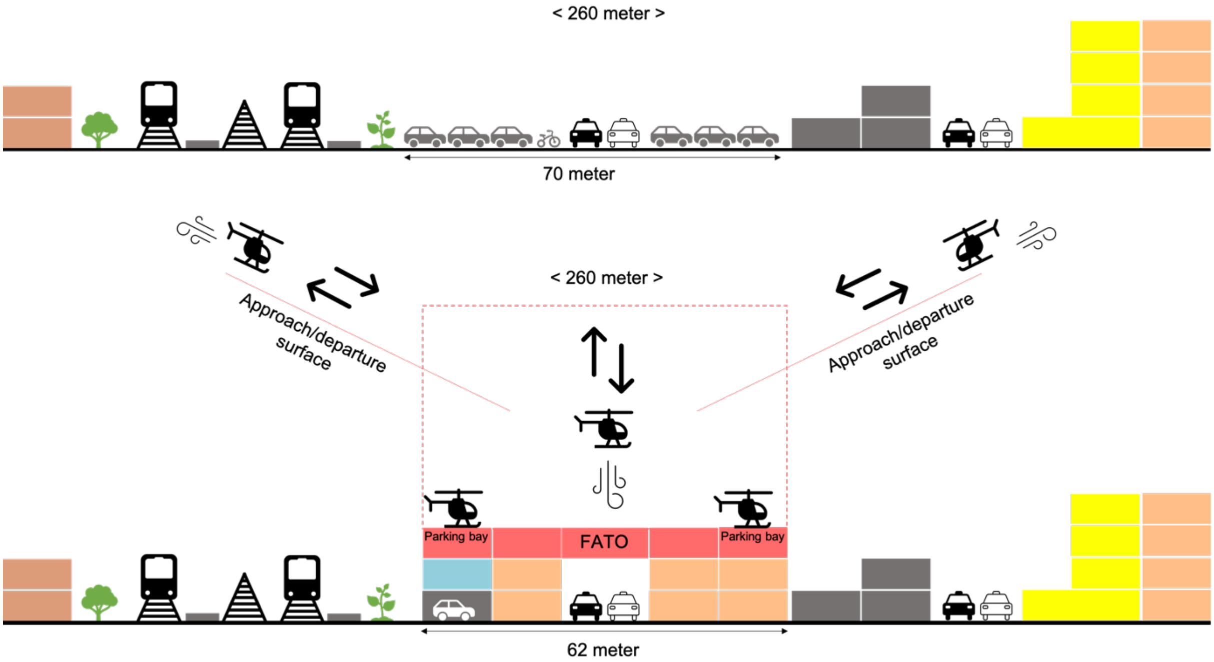


Figure 49 | Profiles of location 'Parking 1' in the existing (above) and new situation (below), as seen from the intersection between the Delftsehof and Schiestraat and looking to the north-east. The legend in fig. 48 shows the meaning of the different colours. Source: Ruimtelijkeplannen.nl

The foregoing discussion has provided insight into the scarcity of suitable locations for UAM ground infrastructure and its physical impact in urban centers. However, this does not only have to do with the available space. Moreover, there are all kinds of new (construction) developments being planned that also (want to) claim a number of these locations, including location 'Parking 1' (Gemeente Rotterdam, n.d. b) that was used above to clarify the spatial impact of UAM ground infrastructure. There are also plans for new construction for at least two other of the five non-built locations: at locations 'Green space 7' and 'Green space 10' (Synchroon, n.d.). This shows that when integrating UAM into communities, these types of plans will have to be taken into account, and there probably need to be found a way to include and combine veriports in such new construction plans. It also shows the importance of timely action and thinking ahead to prevent the number of suitable locations for UAM landing infrastructure from shrinking further.

This section has so far only looked at the use of space of the vertiport, including a landing spot, parking bays and associated charging infrastructure. However, as mentioned earlier, energy infrastructure is also required. Ideally, vertiports will be (partly) supplied with locally generated and stored energy (see also "Energy supply and solutions"). This energy can be generated, for example, by means of solar panels, wind energy, fuel cells or reciprocating internal combustion engines and stored using a battery energy storage system (BESS). The closer to the vertiport this happens, the smaller the energy loss. However, due to limited space at the vertiport location and the need to preserve open space to allow vehicles to take-off and land, energy storage may have to be charged from the grid. For ground infrastructure with some available space, BESS could be installed with other less land intensive onsite generation. Approximate BESS pad footprint requirements including ventilation space and NEC required working clearance would add another estimated 10 m^2 to 43 m^2 of space to the total ground infrastructure to store 0.2 MWh to 2 MWh of power.

Black & Veatch (n.d.) proposes onsite power generation through a FuelCell Energy system as a potential option, which uses natural gas-based fuel cells. A plant installation with 1.4 MW of capacity requires approximately 12.8 m by 17.7 m or 227 m^2 of space, with an additional space of 12.8 m by 9.1 m or 116 m^2 for maintenance. The 2.8 MW unit requires approximately 26.2 m by 12.2 m or 320 m^2 for equipment and an additional 12.2 m by 6.1 m or 74 m^2 for maintenance. Reciprocating internal combustion engines (RICEs) are seen as another option. These are machines that generate work using the combustion of a fuel, like natural gas, inside of a piston cylinder, driving the piston to create work through a shaft. The 4.2 MW and 4.4 MW engines will require approximately 15.2 m by 3.0 m or 45.6 m^2 (Black & Veatch, n.d.). More sustainable, renewable sources like solar or wind energy are may not be likely viable options for local (onsite) power generation (Learn, 2020). In order to (partly) offset the significant amounts of power consumption by passenger drones, lots of space will be required given today's energy production. Solar panels, for example, only produce approximately 155 to 169 kWh/m^2 per year (Vattenfall, n.d.).

With the addition of local energy generation and/or storage, the space required for UAM ground infrastructure increases further. There will not always be room for this, as a result of which this type of infrastructure may have to be realized further from the vertiport location.

To conclude, the use of space of the infrastructure can make it difficult to find enough suitable locations within the city boundaries. So, urban planners and city officials need to think about the size of the infrastructure footprint for a vertiport to make any net contribution to urban mobility. Therefore, one of the questions to which cities must find an answer is: where can sufficient space to realize the landing infrastructure for UAM be found?

Recommended actions

- **Action Point 4.1: Begin identifying new vertiport location opportunities, both through new development and through partnership with existing infrastructure**

  When the vertiport space requirements are known, look for those locations that meet the minimum space requirements for UAM ground infrastructure in the area where a potential market for UAM exists. In many cases, this will require new development, which is why it is important to consider the possible emergence of UAM when new developments are being planned. However, when existing buildings prove suitable, the problem of scarce space can be overcome.

  On the basis of what has been discussed above, the point of attention is mainly: where is sufficient space available or to be created?

  Interest: direct
  The infrastructure is a key component of the UAM puzzle. Without it, UAM is not possible. Therefore, it is in the cities' direct interest to get to know where there is enough space to develop this infrastructure.

  Term: 2028-2029
  The term within which this action must be carried out differs per region. For the early adapters, the first UAM operations can be expected within a few years (before 2025). In any case, it is important for them to implement this action in the short term, although it

would be logical to perform this action after the previous one. In regions where the start of UAM is expected later, including the Netherlands, this action can be carried out later, but it is advisable to do so at least before the 2030s. Based on the outcome of this action, the locations found can be further assessed on their suitability and eventually they may be (re)developed into a vertiport.

Impact: this action results in an overview of locations - being locations without existing helicopter or similar infrastructure - that meet the set minimum space requirements for UAM ground infrastructure. From this it can be concluded to what extent space is available in the desired area to develop this infrastructure, and to what extent the area can be suitable for UAM from a spatial perspective. If that is the case, new challenges will be encountered, and subsequent actions will have to be taken. These are discussed below. Otherwise, when it turns out the area lacks sufficient space for UAM ground infrastructure, a new area that is similarly attractive for UAM should be found, or it should be accepted that there simply is no room for the necessary infrastructure.

Main executive actor(s): Urban planners, infrastructure developers and aircraft operators/service providers.

Challenge 5: The costs of scarce urban space tend to be very high and the development of standalone UAM ground infrastructure alone might not gain enough revenues, while only benefiting small numbers of people

In the event that a suitable location is found for UAM ground infrastructure, urban centers will almost always involve valuable land (Visser and Van Dam, 2006; Gemeente Amsterdam, n.d.). In that case, development of stand-alone UAM ground infrastructure may not be desirable (Participant P, 2020), and this is why: let's assume that the Uber Elevate (2016) model is achievable, and a vertiport can support 48 departures per hour. This would mean that an air taxi service operating with an average of three passengers per flight (Kasliwal et al., 2019; Uber Elevate, 2016; Crown Consulting, 2018) will move 144 people from point A to point B in one hour, or around two thousand each day. This is not much, even though it is based on some very favorable assumptions. Besides, the development costs of UAM ground infrastructure are not low. For the landing and charging infrastructure combined, costs could rise to up to $4 million approximately. Each drone costs between $200 thousand and $1.2 million or even more, depending on production volume and air performance (Porsche Consulting, 2018; Uber Elevate, 2016; Crown Consulting, 2018). On the other hand, traditional infrastructures are much more expensive than UAM ground infrastructure. Deployment of a few vertiports costs a portion of developing a new metro line, road or highway (Participant I, 2020).

Table 22 | Overview of estimated vehicle and infrastructure costs, per piece.

Study	Vehicle [$]	Infrastructure [$]
Porsche Consulting (2018)	250k-1 million	4.1 million
Uber Elevate (2016)	200k-1.2 million	1.5 million
Crown Consulting (2018)	250k-500k	530k-775k

Therefore, urban planners and city officials need to critically assess whether the air taxi investment is worthwhile for their city, at least in the short term when the relevant technologies are weak and unproven. A vertiport may be nice to have, but other developments might have a higher yield, both financially and socially. In the Netherlands, for example, there are large shortages of dwellings. Currently, there is a shortage of 315,000 dwellings (Hulsman and De

Voogt, 2020) and it is expected that in 2030 there will still be a shortage of 157,000 dwellings. This will especially be the case in the Randstad (Buijs and Wolf, 2019), and some of the locations might be perfect to overcome this. Cities that opt for UAM may therefore have to find the solution in multifunctionality, where the infrastructure for UAM is combined with existing or new buildings and placed on roofs, for example in high-rise buildings or parking garages. In this way, space can be saved and a vertiport also becomes more commercially attractive (Participant A, B, F, I, J, L, M, O, P, Q, R, T, 2020).

It is up to the cities to find out what price they want to pay for having a low-volume mobility alternative, that benefits only a small number of people, and in terms of the opportunity cost of large amounts of valuable urban land.

Recommended actions

- **Action Point 5.1: Make an assessment – for example a (Social) Cost-Benefit Analysis – of the value that UAM and its ground infrastructure could deliver to cities, compared to other possible developments**

  Calculate the value that UAM - and specifically the development of ground infrastructure on expensive land - will yield for a city. Determine the financial, but also the social costs and benefits. Take a look at different ways of development, including mono- and multifunctional developments.

  Interest: direct
  This concerns a development in the city and is therefore in the direct interest of municipalities. They will have to determine whether they see sufficient added value in such a development.

  Term: 2029-2031
  This action largely depends on the chosen locations for UAM ground infrastructure and therefore cannot take place before Action Point 4.1. Because of the many factors that will be involved in such an analysis, it might take some time to carry out this action.

  Impact: by making such an assessment, it becomes more clear whether UAM really adds value to a community. Based on that conclusion, cities can make the (financial) decision to (literally) give room to UAM or not.

  Main executive actor(s): Urban planners.

Challenge 6: Existing buildings may not be suitable for UAM ground infrastructure

Due to the large use of space and high land costs, it can therefore be interesting to realize UAM ground infrastructure in a multifunctional way on new or existing buildings, in which various functions are combined. In practice, however, it may turn out that existing buildings are not always suitable for this. Various potential obstacles come into play.

First of all, the height of the building is a possible obstacle. The height of a building influences the arrival and departure paths to and from the roof of a building. In general, the lower the building, the greater the chance of obstacles around it, like neighboring buildings, utility lines and residential areas. As a result, it becomes more difficult to achieve proper arrival and departure paths, leading to longer durations for take-off and landing, a lower throughput of vehicles per unit of time and thus, a less viable business case. This entails that ideally, there are no buildings or other obstructions on three or even only two sides of the FATO. This would enable vehicles to take-off in one direction and land in the other direction, so both movements do not interrupt with each other and delays are minimized (Clauser, 2020; Powell, 2020). In theory, this challenge only applies to existing buildings, since new developments can, in principle and if the land use plan allows to, be built high enough to overcome this challenge. Therefore, looking at the Rotterdam Central District, this challenge mainly applies to locations 'Parking 2', 'Parking 3', 'Parking 5' and 'Rooftop 12'. All of these locations are surrounded by higher buildings on at least three sides. Unless the height of such locations can be significantly increased, the process of landing and take-off will take longer – or even be impossible, e.g. for safety reasons – and reduce the potential throughput of vehicles.

In addition, the load-bearing capacity of the roof plays an important role. For this it is important to know the force that the infrastructure, including passenger drone (s), exerts on a roof. The force applied by the VTOL is determined by the force generated by the gross weight of an eVTOL under a rapid descent. Some sources suggest a descent rate of 30 feet or 9.14 meters per second, or, as a rule of thumb, 1.5 times the gross weight of the aircraft. So, if a passenger drone would weigh 3,500 kg including payload, like the heavy Bell Nexus (Bell Flight, n.d.), the roof structure should be designed to carry a weight of 5,250 kg in order to account for a high descent rate. The 'static weight' of the infrastructure should be added to this to know the total weight to account for. This may be too heavy for most existing buildings: 'I would venture to say that, as a rule, most roofs as designed have little excess capacity for new added loads. So, with a very limited existing capacity expected from existing conditions, some new form of structural design would be needed to support the new flight deck, terminal building, and aircraft.' (Clauser, 2020). It will probably be commercial high-rise structures that would require potential reinforcements (Learn, 2020). This may, for example, be applicable on locations 'Rooftop 11', 'Rooftop 12' and 'Rooftop 13' in the Rotterdam Central District. However, an anticipated eVTOL weight of around 3,500 kg is not much heavier than a single existing electric automobile. So, with respect to parking structures the new load is not significant (Learn, 2020). In that sense, it seems safe to say that locations 1 to 10 in the Rotterdam Central District, which are all parking lots, garages or green spaces, will be able to carry the load of UAM infrastructure and vehicles.

But the placement of UAM ground infrastructure on the roof of an existing building also requires that, for example, 'high energy' power supply must be realized to the vehicle. The question is whether that can be achieved (Participant L, 2020). With voltages and currents of up to 800V and 750A respectively (equals 600kW), high levels of power would need to be distributed towards the rooftop of the building. To facilitate this level of power provision, being selective with vertiport locations is needed. Only those which can support the modelled sustained loads can be selected, while using stationary storage systems to facilitate peak load balancing (Learn, 2020). It seems likely that this challenge will again mostly play a role with commercial buildings, like locations 'Rooftop 11', 'Rooftop 12' and 'Rooftop 13' in the Rotterdam Central District.

Furthermore, in many buildings there are little nuances that are going to be impactful (Participant M, Q, 2020). For example, a roof may not be completely straight, so that no continuous, straight surface of at least 30m by 30m can be used. This is the case, for example, at the locations "Parking 2", "Parking 3" and "Parking 4" in the Rotterdam Central District. You will also find all kinds of installations on many buildings, such as an elevator structure, cooling installations, solar panels and wires, so that a passenger drone cannot simply land on the roof. This is also the case at the locations "Rooftop 11" and "Rooftop 13".

It is because of these kinds of obstacles that, if possible, adjustments will have to be made, but more often chosen for new developments (Participant C, J, L, M, P, Q, T, 2020) which will partly persist the problem of use of space.

Recommended actions

- **Action Point 6.1: Perform a structural analysis on every rooftop consideration that is a potential location for UAM ground infrastructure to check the weight-bearing capacity**

  Analyze the existing stock of buildings for their carrying capacity and take the total load, including UAM ground infrastructure and the heaviest VTOL aircraft, as the defining point. The question at stake relates to the number of buildings that do / do not have sufficient load-bearing capacity, and to what extent it is possible to apply structural reinforcements without hampering the existing functions.

  Interest: (in)direct
  The importance for the municipality is seen as more indirect than direct. This particular action employs more importance to infrastructure developers and building owners.

  Term: 2030-2031
  After locations have been found that may be suitable for UAM ground infrastructure, this action should be carried out in case the location comprises an existing building.

  Impact: this action results in an overview of existing buildings – not existing helicopter or similar infrastructure – being or not being able to carry the total load of UAM ground infrastructure and VTOL aircraft. From this it can be concluded to what extent the existing building stock can be used to provide for locations to build UAM ground infrastructure on. Based on that conclusion, further development decisions for the infrastructure can be made. The conclusion might have large consequences for the actual location at which the infrastructure can be realized, and so it might affect the business case. Because, when it turns out the area lacks sufficient locations – in this case existing buildings – to build UAM ground infrastructure on, a new area that is similarly attractive for UAM should be found, or it should be accepted that there simply is no room for the necessary infrastructure.

  Main executive actor(s): Construction or engineering companies, like TNO.

- **Action Point 6.2: Make an assessment of the state of the existing building stock and their suitability to accommodate UAM ground infrastructure on their roof**

  Assess the existing stock of buildings for their suitability for UAM ground infrastructure. Do this by looking at the points above. The questions at stake relate to the number of buildings that are / are not suitable, which obstacles can be found and to what extent it is possible in such cases to make the necessary adjustments to the roofs, without affecting the existing functions.

  Interest: direct
  The importance for the municipality is seen as more indirect than direct. This particular action employs more importance to infrastructure developers and building owners.

  Term: 2030-2031
  After locations have been found that may be suitable for UAM ground infrastructure, this action should be carried out in case the location comprises an existing building.

Impact: this action results in an overview of existing buildings – not existing helicopter or similar infrastructure – being or not being suitable for UAM ground infrastructure. From this it can be concluded to what extent the existing building stock can be used to provide for locations to build UAM ground infrastructure on. Based on that conclusion, further development decisions for the infrastructure can be made. The conclusion might have large consequences for the actual location at which the infrastructure can be realized, and so it might affect the business case. Because, when it turns out the area lacks sufficient locations – in this case existing buildings – to build UAM ground infrastructure on, a new area that is similarly attractive for UAM should be found, or it should be accepted that there simply is no room for the necessary infrastructure.

Main executive actor(s): Construction or engineering companies, like TNO.

Challenge 7: There is not enough space and it is too costly to park the total fleet of a passenger drone market in the inner city outside operating hours

While the majority of passenger drones will be in the sky during a large part of the operational hours, the whole fleet will be on the ground outside of this period. And thus, these vehicles will all need a place to park overnight. As was stated earlier, a parking bay requires an estimated 189 m^2 of space. When there is a large fleet of vehicles, the required number of square meters increases quickly. With a passenger drone fleet like the one that was estimated for the Randstad (~ 550 vehicles), this would already mean a total required footprint of approximately 100 thousand m^2, not taking into account the required taxi and take-off and landing areas. Adding those factors would aproximately more than double this footprint to a good 200 thousand m^2 (Vascik and Hansman, 2019), with the largest part probably realized in or around the four big cities. Taking into account that there will even be a lot of cities with a larger fleet of vehicles, it will be a considerable, (too) expensive and probably unlikely task, requiring to much space, to solve in the inner city.

Recommended actions

- **Action Point 7.1: Search for viable solutions to park the eVTOL fleet outside operational hours**

  It is up to urban planners to find a solution to this challenge. Since parking large numbers of vehicles is unlikely to be possible within the city, the solution will have to be found outside the city. It is an idea to designate multiple locations for this, given the large surface area that is required. Perhaps this could be done in industrial or business parks, harbours or at airports. However, in the search for suitable parking locations, an important point of attention is that they should not be placed too far from the vertiport network. This prevents the vehicles from having to drive (too) many unprofitable kilometers without passengers. Taking this into account makes that the efficiency of the system can be safeguarded as much as possible. Luckily, case study city Rotterdam does have some of these places. In the vicinity of 'Rotterdam Merwe Vierhavens' (fig. 42), for example, this may be realized at 'Heijplaat'. Another potential location to park some vehicles would be Rotterdam The Hague Airport.

Interest: direct
This action is in the direct interest of local authorities. Since the service is offered in their city, they will also have to take into account parking options for the vehicles in their spatial planning, especially since these cannot be realized too far from vertiports and will therefore often fall within the municipal boundaries.

Term: 2028-2029
While potential landing sites are to be found, places to park the whole fleet of drones outside of the operational hours should be found in the meantime.

Impact: this action (partly) determines how many vehicles there is, literally, space for, also in the (local) market.

Main executive actor(s): Urban planners, infrastructure developers and aircraft operators/service providers.

Challenge 8: High-level energy demand requires adaptations to the energy grid and innovative energy solutions

Passenger drones obviously need energy to operate. There are different possible energy sources, like electricity, hydrogen and conventional fossil fuels. It is not yet certain which energy source will ultimately prevail (Participant C, E, H, 2020; 6.1.2), but most of the passenger drones currently under development are designed for electric propulsion. In relation to this characteristic, there are different relevant aspects that need to be considered in this barrier.

First of all, the energy demand is important. In general, the energy demand of one vehicle is considered to be of a significantly high level, higher than, for example, the electric car. Due to gravity, lifting a mass from the ground requires a lot of energy. However, several factors determine the exact amount of energy required. These include:

- The weight, including the vehicle, passengers, luggage and battery itself;
- The speed of flying;
- The distance covered, both horizontally and vertically;
- The aircraft design;
- All kinds of external factors, such as weather conditions.

These factors vary considerably among the many vehicle concepts. A vehicle that is relatively light and performs short-range missions at relatively slow speeds will require significantly less power, and a smaller battery, than a vehicle that is heavy and performs long-range missions at high speeds. The energy demand will therefore partly depend on the market that emerges and the business model that best suits a particular city or region (see also "user practices" in this chapter). At places where the intra-city use case is the dominant market model, for example in the major world cities, the energy requirement of a vehicle will be lower – due to the smaller weight (smaller vehicle and fewer passengers per vehicle), shorter distances and lower speeds – than in an intercity market, where larger vehicles with more passengers and higher speeds will be more efficient. To give an idea of the power requirements of passenger drones, figures for a number of studies and vehicles have been included in table 23. In Appendix D.1, other specifications of these and other vehicles can be found as well. In general, the vehicles with a high battery capacity target are also vehicles with a higher weight and greater range. It is also noticeable that mainly the larger vehicles, with room for more passengers, are also the vehicles that can travel longer distances, for example between different cities. They need a relatively large amount of energy for this. Finally, the figures make clear that the take-off and landing phases of a flight require much more energy than the cruise phase of a flight. This once again illustrates why it is important for vehicles – from both an energy and time efficiency perspective – to have short take-off and landing phases. This can be accomplished if there are few obstacles around the landing infrastructure, as mentioned earlier in this chapter.

Table 23 | eVTOL energy requirements for different vehicle configurations and according to different studies. Sources: Crown Consulting (2018), Uber Elevate (2016), Volocopter (2019), Bacchini and Cestino (2019), Polaczyk et al (2019), Bartini (n.d.), Opener (n.d.).

Study/Vehicle	Aircraft concept	Battery capacity target [kWh]	Vehicle weight [kg] / seats [#]	Take-off and landing [kW]	Cruise [kW] (cruise speed)	Range [km]
Lilium Jet	Fixed-wing vectored thrust concept	320	2,000 5	-	- (300 km/h)	300
Uber Elevate		140	1,800 4	500	71 kW (240 km/h) 120 kW (320 km/h)	320
CityAirbus	Quadcopter	110	2,200 4	-	- (120 km/h)	30
Crown Consulting		100	- 4	-	- (240 km/h)	> 120
Pop.up Next	Quadcopter	70	2,000 2	-	- (150 km/h)	50
Bartini Flying Car	Tilt-wing	64	1,100 4	318	91.8 kW (300 km/h)	150
Kitty Hawk Cora	Hybrid	63	1,224 2	228	63 kW (180 km/h)	100
Davinci ZeroG	Multicopter	52.8	240 1	-	- (70 km/h)	-
Volocopter	Multicopter	~ 50	900 2	500-1000	- (100 km/h)	30
Lilium Jet	Fixed-wing vectored thrust concept	38	490 2	187	28 kW (252 km/h)	-
E-Hang 184	Quadcopter	14.4-17	260 1	42.1	34.6 kW (100 km/h)	30-40
Opener BlackFly	Hybrid	12	142 1	-	- (128 km/h)	64
Average		86.4				

Although table 23 is an incomplete selection of eVTOL vehicles within a still developing market, the required battery capacity of this selection of vehicles is more than 40% higher than that of electric cars, with an average of 86.4 kWh compared to 60.6 kWh. The main differences between the two transport modes, however, lie in the fact that the same battery capacity provides a considerably lower range in a drone than in a car (EV Database, n.d.). Moreover, the Urban Air Mobility business model almost always requires (much) short(er) charging times. The goal is to achieve the necessary charge for an air taxi journey in 10 minutes or less during peak operational hours, with longer deep cycle charging being accomplished during off hours. Once this is achievable, turnaround time between flights can be significantly reduced, allowing for a higher volume of throughput (Alexander, 2020).

Achieving a minimum turnaround time is important to achieve high vehicle productivity (Uber Elevate, 2016). Before the EV/AV revolution can fully pave the way for eVTOLs to become reality, the industry must put in place the electric infrastructure that can handle the highly distributed, yet often concentrated volume of EV charging — on the ground. This is to help facilitate an efficient Urban Air Mobility (UAM) transportation system take off. Black & Veatch (n.d.) found out that urban air mobility would leverage power infrastructure similar in function and scale to that required by transit and heavy-duty EVs, which are just about to hit their hockey stick moment.

Therefore, fast chargers will be needed to charge batteries with a capacity of (well) above 100 kWh in such a short time. It is assumed that these vehicles will be charged by DC current provided from ground stations where the voltage will be up to 800V and the current will be up to 750A per pad. This means that 600 kW chargers are required to charge 100 kWh in 10 minutes, while a typical passenger vehicle DC fast charging typically ranges from 50kW-350kW (Black & Veatch, n.d.; Learn, 2020). Now imagine: a city, possibly Rotterdam, has several vertiports (e.g. fig. 42), all with space for several eVTOL vehicles (e.g. fig. 45). When during peak hours (almost) all places are occupied, several vehicles must be charged at the same time per vertiport. Due to time constraints, this must be done at the highest possible charging capacities (currently estimated at 600 kW). The regional model developed for the Houston by NASA Langely Research Center area estimated the number of vehicles charging at each vertiport throughout the day, based on random number information (Kohlman and Patterson, 2018). A similar vertiport with three or four charging stations (e.g. fig. 5) could require approximately 18.75 to 25 MWh of energy per day, assuming 600 kW chargers (Black & Veatch, n.d.). The question is to what extent the power grid of a city is able to support these power requirements of multiple vertiports (Powell, 2020). That is why energy supply is a potential challenge.

Thinking about the existing power grid, it is more or less laid out like a spoke and wheel model (fig. 50). There is a centralised area, usually a power plant, where power with a very high voltage is generated. As that power leaves the power plant, it moves away from this generation point towards a substation. These smaller substations then reduce this high voltage power to a medium level of voltage power. When the power subsequently moves further away from the centralised distribution system, it will step down again as it comes into a lower voltage that goes to the end user, like homes and businesses (Participant I, 2020; Black & Veatch, n.d.).

So, in order to rapidly charge eVTOL batteries and enable the high utilization rates that are required for a commercially viable market, these vehicles are going to need the high level of power that is available 'directly at the power plant' (Participant I, 2020), or at least more upstream of the network. Depending on the site selection (Learn, 2020), existing property supply and location on the distribution network, the addition of high power EV charging load may require equipment upgrades to either grid elements or building facilities. As power levels tend to decrease down the network, upgrades are more likely to be required as EV load size increases. So, the electrical grid will have to change to allow these facilities to operate in multiple areas throughout a city, which will be an interesting infrastructure constraint. As additional upgrades are required upstream on the network, the cost and duration of time needed by the utility to get power to site may also increase (Participant I, 2020; Black & Veatch, n.d.).

Although not just related to vertical flight, but more broadly related to our move towards sustainable energy, a big change in the concept of power generation in a centralised spot is what will likely (need to) happen. That will change into a concept of distributed areas where (sustainable) power is more locally generated at the necessary high voltage levels, close to the end consumer: a decentralised smart grid (Participant A, H, I, J, M, 2020), enabled by ICT technologies (6.1.2). Whereas an existing, centralised natural gas power plant may produce 100 MW of power today, small power producers like windmills or solar panels may produce a portion of this power on the same piece of land. By spreading out these new power producers over a network of multiple locations around the area that power is generated for, a distributed, more local power grid is created that can provide the same amount of energy but added up on a larger piece of land. So, this would result in multiple areas where power is generated, versus a centralised spot from which the power must travel long distances. In this context, the development towards a more local, distributed power grid could go in two ways. These distributed generation locations could attract all kinds of other developments, like vertiports and/or charging facilities. On the other hand, the development of vertiports could push the demand for localised power generation (Participant I, 2020). As already mentioned in the "Infrastructure placement" section, some fuel cells or reciprocating internal combustion engines may be options to facilitate local power generation. With up to 4.4 MW of power, they could generate up to 40 GWh of energy in a year. However, due to the use of natural gas, both techniques are not fully sustainable (Black & Veatch, n.d.). Therefore, they do not fully comply with the goal towards sustainable urban mobility. This emphasizes the importance to generate sustainable energy in order to keep the promise of being a sustainable means of transport (see also further below). However, as was mentioned in the “Infrastructure placement” section as well, the required amount of space will be too large for onsite sustainable power generation. This is also illustrated in the square kilometer of the Rotterdam Central District, which contains two roofs with solar panels. One these is located at location ‘Rooftop 11’, while the other is the rooftop of Rotterdam Central Station. The latter one contains the largest surface of solar panels: 10,000 m^2. With this surface, "only" 300 MWh of energy is generated annually, which is good for just under 100 households (Potters, 2018), but does not come close to the potential power demand at a vertiport. With perfectly situated solar panels producing 155 to 169 kWh/m^2 per year (Vattenfall, n.d.), power generation through solar energy only becomes comparable and competitive to the above-mentioned options from approximately 100,000 m^2 of solar panels. However, with a net surface area of 12.1 to 17.9 km^2 that is suitable to place solar panels on, a city like Rotterdam has the potential to generate 1300 to 2150 GWh of energy in 2030 within its own municipal boundaries (Gemeente Rotterdam, 2019). This may offer prospects for local, fully sustainable energy generation in a broader area around vertiports.

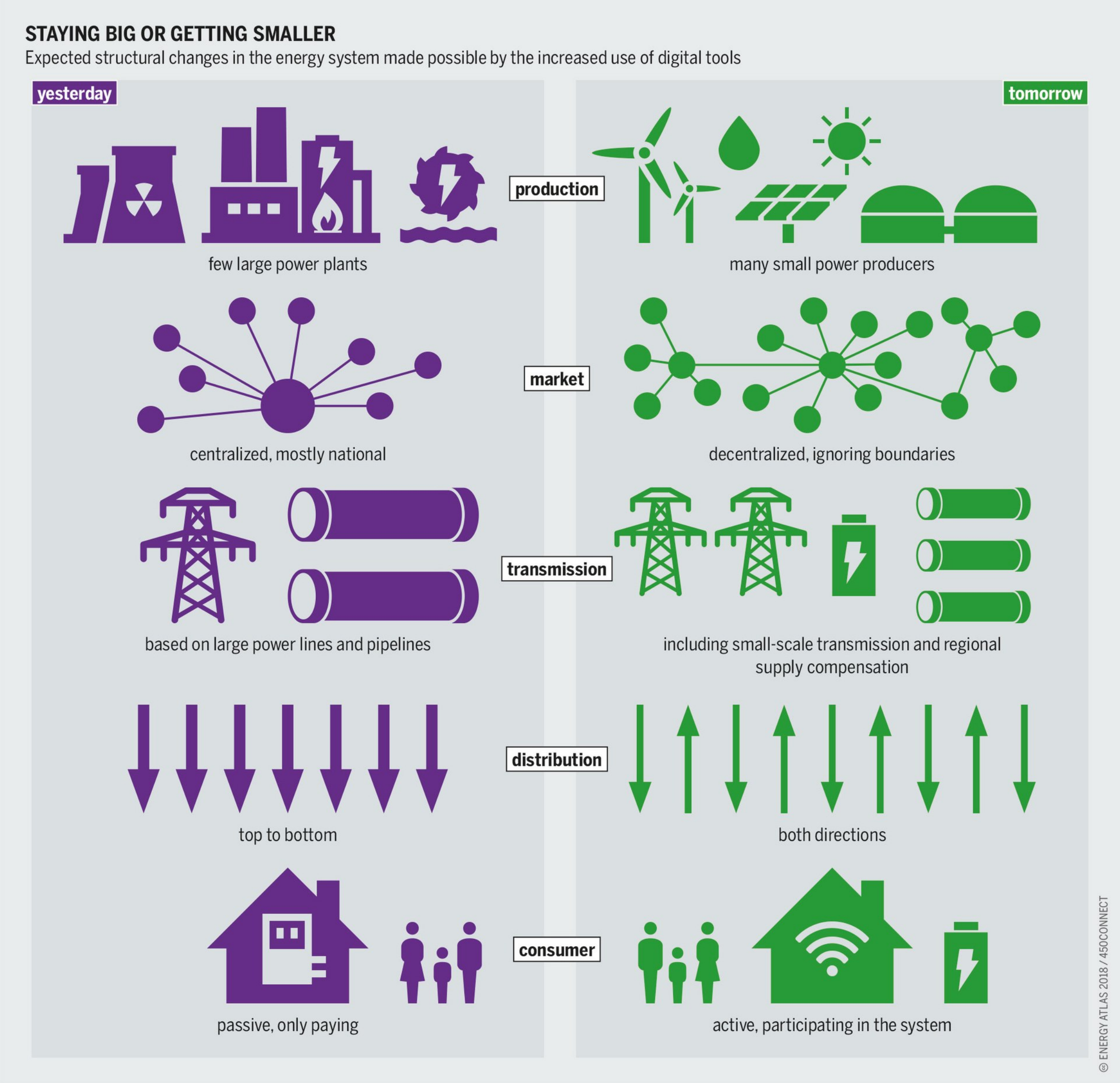
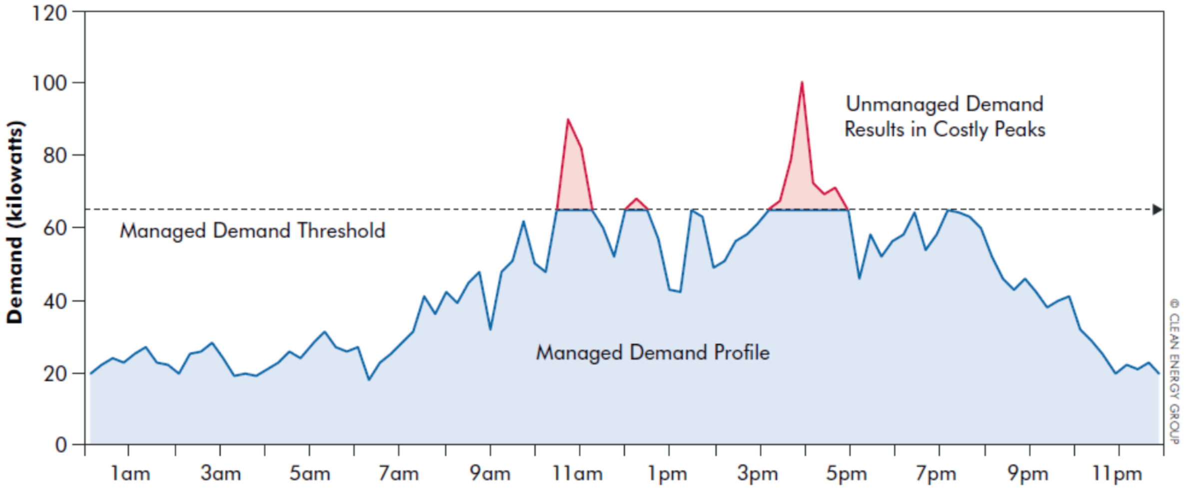


Figure 50 | The layout of the existing power grid versus the envisioned decentralised smart grid of tomorrow (Heinrich Böll Foundation et al., 2018).

In addition to local energy generation, local energy storage can also help guarantee a properly functioning energy network (Participant J, 2020). Especially during peak hours, the demand for energy will be high, sometimes too high. Due to imposed demand charges, this can result in high(er) energy prices, resulting in high costs (fig. 51), with adverse effects for the business case of UAM and the vertiport concerned in particular. By storing the surplus of energy at times when more energy is generated than consumed, it can be used during peak hours for charging the passenger drones (or possibly other purposes), and costs can be saved. This is done as follows. Energy storage can help reduce energy and demand charges. Demand charge reduction is achieved by reducing the peak consumption and energy arbitrage reduces the energy charges. Energy arbitrage is the practice of purchasing and storing electricity during off-peak times, and then utilizing that stored power during periods when electricity prices are the highest. The cost savings that can be achieved are dependent on three factors; (1) the utility rate, (2) shape of the local load and (3) capital cost investment. To determine the optimized solution for a site, the final load based on charging schedule for each site will need to be evaluated to determine the system size. It is important to understand both the onsite load as well as the rates that are applicable to the site to properly size the battery energy storage system (BESS). The larger the storage capacity of the BESS, the more the system costs, so the analysis using hourly load data (sub- hourly if available) is needed to balance the system cost with the additional benefits (bill reductions) the BESS may provide. Properly sized energy storage systems can have a positive return on investment for large "peaky" loads such as the one shown in fig. 51. The potential cost savings that can be achieved by deployment of energy storage will vary by vertiport and its individual charging profile (Black & Veatch, n.d.).



Through the deployment of an energy storage system, peak demand can be effectively capped at a specified level—significantly reducing utility demand charges. Assuming a demand charge of $10 per kilowatt and peak demand reduction from 100 kilowatts to 65 kilowatts each period (as shown here), energy storage could reduce the customer's demand charge by $350 per billing period, amounting to an annual savings of $4,200.

Figure 51 | How energy storage can reduce demand charges. Source: Clean Energy Group (n.d.).

Some of the vertiports will have "peaky" profiles similar to that in fig. 51, thus they will be good candidates for onsite energy storage. The optimal design for each site would need to be determined using capital cost, site tariff and load shape (Black & Veatch, n.d.).

To sum up, a decentralised smart grid is mainly needed to:

- Accommodate increasing electricity demand;
- Provide high levels of power, currently available at the power plant, at distributed areas to enable very fast charging of large batteries;
- Enable local, sustainable energy generation;
- Enable local energy storage (European Commission, 2013c).

Recommended actions

- **Action Point 8.1: Map the actual energy demand of the passenger drone fleet**

  The actual energy demand that passenger drones will be responsible for is not yet entirely clear. The total amount of energy required depends on many factors. Of course, the size of the market is important, so it is important to know how many passenger drones will burden the electricity grid. But the use case and related vehicle type also play a role. Use cases for shorter distances and smaller vehicles require less energy than use cases for longer distances and larger vehicles, but the energy demand for the former is more concentrated than for the latter. In addition, the number of vertiports (i.e. charging locations), their distribution over a certain area and the number of vehicles that are supplied with power per vertiport per day are important for charting the concentrations of energy demand across the network.

  Interest: direct
  This action provides insight in the energy demand by passenger drones. It is about the pressure on the city's power grid, and therefore in the direct interest of the cities.

  Term: 2025
  The term within which this action must be carried out differs per region and can be done after strong market estimations can be done. For the early adapters, the first UAM operations can be expected within a few years (before 2025). In any case, it is important for them to implement this action in the short term. In regions where the start of UAM is expected later, including the Netherlands, this action can be carried out later, but it is advisable to do this at least before the 2030s. Based on the outcome of this action, any follow-up actions can then be initiated in good time.

  Impact: by carrying out this action, insight is gained into the degree of load on the energy network by passenger drones. Based on this insight, it can be assessed to what extent adjustments to the existing network are necessary.

  Main executive actor(s): Grid operators, in collaboration with aircraft operators.

- **Action Point 8.2: Understand electric grid capacity and what needs to be done to facilitate broader transportation electrification, including UAM**

  This action, which follows the action mentioned above, provides insight into the capacity of the energy network of a city. By comparing this capacity with the energy demand of the passenger drone fleet, it can be assessed whether the existing energy network is sufficiently suitable for supplying energy to these vehicles. Based on this, those locations for UAM ground infrastructure can be selected which can support the modelled sustained loads. If those locations are not available, or if they are not suitable due to other factors, adjustments will have to be made to the network. It is especially important that not only the required amount of energy can be supplied, but that this can also be done in a short time, and therefore high power is required. It has already been discussed what adjustments could be made. A decentralised, distributed smart grid might be a good option, whereby power generation takes place more locally and energy is locally stored to handle peak demands. It is up to cities to research how this can be shaped, in collaboration with network operators, among others.

Interest: direct
UAM requires electrical energy from a city's energy network. When a city chooses UAM, it must be a well-functioning system to deliver on its promises. Crucial for this is that the vehicles can be supplied with sufficient power quickly. If that is not possible, the required minimum throughputs will not be achieved and the city will be left with vertiports that do not work optimally and yield too little benefits. It is therefore of direct importance for cities to look at their energy network and what may need to be changed in it.

Term: 2026-2028
This action can be carried out once it is known what kind of energy loads can be expected, which should result from the previous action.

Impact: this action provides insight into the extent to which the energy network needs to be adapted. With this insight, a city can prepare for the future, with broader transportation electrification.

Main executive actor(s): Urban planners, local officials and grid operators.

- **Action Point 8.3: Find out how energy can be locally stored in an economically viable way**

  Local energy storage can be a good answer to peak demands. However, whether it is economically beneficial depends on several factors, including the price of land, the size of the peaks, the demand charges and the cost of the storage facility itself. Taking these factors together, it can be calculated if local energy storage at a vertiport is economically viable.

  Interest: direct
  Local energy storage helps municipalities prevent peak loads in their city and thus affects the interests of their citizens, and therefore also the direct interests of the municipality.

  Term: 2029-2030
  Once it is known how the energy demand of drones will impact the energy grid, steps can be taken to find out if and how energy must be stored.

  Impact: with the help of this action it can be determined whether local energy storage is desired. This means that the action may have an impact on the required surface area for UAM ground infrastructure (see also “Infrastructure placement”).

  Main executive actor(s): Infrastructure developer and grid operator.

Challenge 9: The promise of being a sustainable means of transport also requires sustainable energy generation

As the previous challenge made clear, there are several options for (local) power generation to provide passenger drones with the necessary energy. However, they are not all equally sustainable, but one of the promises of UAM is that it will be a sustainable means of transport that fits in the overall goal of sustainable urban mobility. The most important factor in this is the exclusion of greenhouse gas emissions. Even if the vehicles fly on sustainable, zero-emission electrical energy, this should mean that the generation of that energy must also take place in an (equally) sustainable manner. If this is not the case, the problem of greenhouse gas emissions will only be moved upstream in the chain, from the vehicle to energy production. In that case, UAM would not be as 'green' as it promises to be. That is why it is important to strive for energy generation without fossil fuels (Participant C, I, K, 2020). However, how the electricity which powers the vehicles is produced (coal, nuclear, solar, wind) is entirely dependent on the location of the operation (Powell, 2020). As was discussed previously, fully renewable energy generation to offset the total energy consumption of passenger drones requires a lot of space. Therefore, it will be challenging, and maybe unlikely, to take place 'onsite' if a vertiport is situated in an urban area (Learn, 2020).

Recommended actions

- **Action Point 9.1: Research the possibilities of (local) sustainable power generation that is required for UAM**

  Review the available options for providing passenger drones with sustainably generated energy. Could it be possible to use enough surrounding roofs to generate solar energy, or are there fields, water surfaces or infrastructure in the vicinity that could be used for this? Are there places in the area for a wind farm? Are there opportunities for bioenergy or geothermal energy? And what about hydropower, for example? And what other options are there?

  Interest: direct
  Sustainable energy generation contributes to the achievement of a city's sustainability objectives. It is therefore in the direct interest of the city.

  Term: 2029-2031
  Once it is known what measures must be taken to provide a sufficiently working power grid, options to provide vertiports with sustainable power that is locally generated must be researched.

  Impact: this action provides the necessary insight into the (im)possibilities of sustainable power generation for passenger drones. It helps in choosing a suitable energy source. It contributes to insight into the extent to which UAM can fulfill its sustainability promise and whether it therefore also fits in with a city's sustainable urban mobility plan.

  Main executive actor(s): Urban planners, infrastructure provider and grid operator.

Challenge 10: There is still no consensus on how passenger drones will eventually be charged

Charging the passenger drones is an important component within UAM. As mentioned, it is a requirement that the vehicles can be supplied with energy in a short time, something that is currently still a hurdle to be taken. Most concepts are currently based on conductive charging, whereby the vehicles are charged with (fast) chargers with capacities up to 600 kW (Uber Elevate, 2016; Black & Veatch, n.d.; Porsche Consulting, 2018; Crown Consulting, 2018; Booz Allen Hamilton, 2018). But a battery swapping system is also mentioned as a possibility (Uber Elevate, 2016; Volocopter, 2019; Crown Consulting, 2018; Booz Allen Hamilton, 2018). Both techniques have advantages and disadvantages (fig. 52). The turnaround time of a battery swap can be much shorter than of conductive charging, with approximately 90 seconds to five minutes versus more than 10 minutes. On the other hand, a battery swapping system requires more batteries per vehicle than conductive charging, where the battery remains in the vehicle for its lifetime. Because a battery requires a considerable investment, with more batteries the costs are also considerably higher. However, this can be used to create a system that is comparable to an energy storage system. By charging the (extra) batteries outside peak hours (for example at night), energy is stored in them and peak demands can be prevented. However, such a system does require more space than a charging station. Moreover, a swapping system can cause a significant logistics burden. Ensuring an appropriate distribution of batteries across all vertiports is required, which may require ground trucking of batteries between vertiports. Finally, changing batteries causes an additional certification challenge of reconfirming overall vehicle flight safety, which is not the case with conductive charging (Uber Elevate, 2016; Volocopter, 2019).

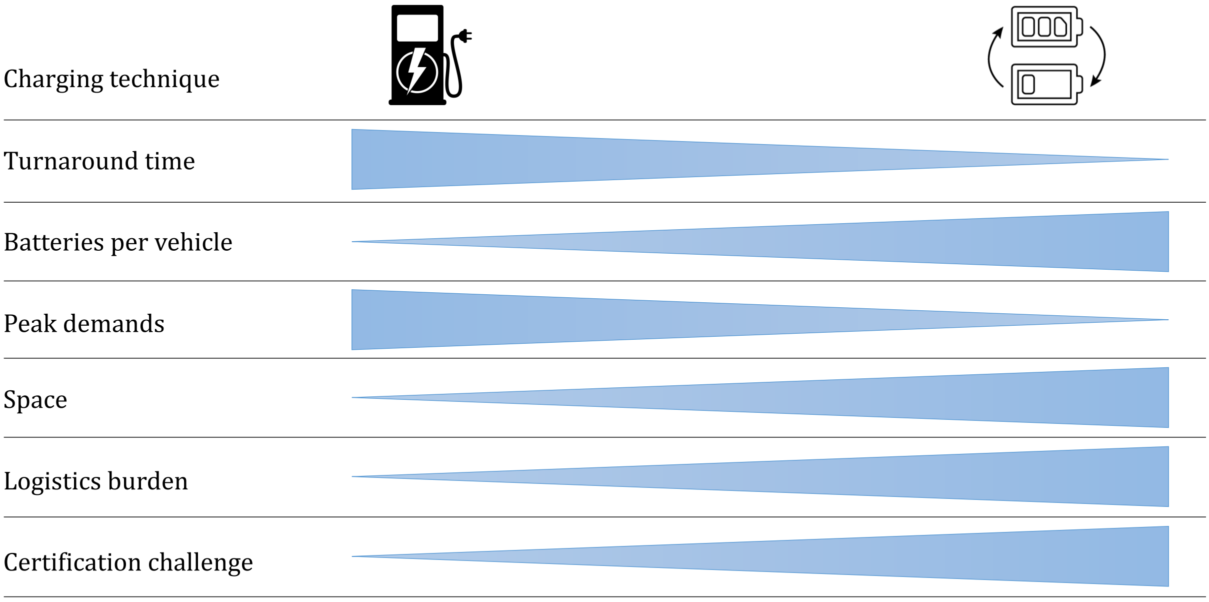


Figure 52 | Pros and cons of two battery charging techniques: conductive charging and battery swapping (Uber Elevate, 2016; Volocopter, 2019).

Another option could be (wireless) inductive charging. The technique has several advantages over conductive charging. It potentially makes charging more user-friendly and easier than charging with a cable. After all, no additional actions are required on departure and arrival, such as plugging and unplugging a plug. This saves time, improves the turnaround time and thus contributes to a potential increase of vehicle throughput. In addition, the technology is a solution for the increasing number of objects in public space. A wireless charging station is easier to fit in than a charging station. With respect to battery swapping, wireless charging has almost the same advantages and disadvantages as conductive charging. However, the technique must still be further developed for large-scale, public application (Elfrink et al., n.d.).

To sum up, there are still several options to charge eVTOL vehicles. Although most concepts currently known assume a model with conductive charging, there are other options that have some advantages over the latter charging technique, which might be worth to consider. Er is dan ook nog geen volledige consensus over hoe passenger drones het best geladen kunnen worden (Participant E, I, L, M, 2020).

Recommended actions

- **Action Point 10.1: Assess the suitability of the different charging solutions**
  Assessing the different charging solutions provides insight into whether one solution is better than another. Based on this action, charging systems could be standardized, which benefits the drone industry.

  Interest: (in)direct
  The way in which vehicles are ultimately charged is partly in indirect interest and partly in the direct interest of cities. It is primarily an interest of service providers and network operators. However, as argued, the way of charging has an effect on the space and energy network of a city, among other things. In this sense, it is also in the direct interest of the city to research which charging techniques can/will be used.

  Term: 2021-2022
  The different options to charge the vehicles must be assessed in an early stage, so it can be a part of the standardization process of both vehicles and infrastructure.

  Impact: this action helps, among other things, to provide insight into the space and capacity required on a city's electricity grid.

  Main executive actor(s): Aicraft designers and operators/service providers and infrastructure developers.

7.3.3.2 Market

User practices

Challenge 11: There is no 'one size fits all' business model: air taxis in their current form are not automatically suited to all cities, just because they might be appropriate for one particular city

UAM includes many possible applications (Appendix D.3). Within the transport of passengers alone, various use cases are possible, of which the airport shuttle, intra-city air taxi and intercity air taxi are the most frequently mentioned. Whether UAM is of added value for a city and which application (s) is most suitable depends entirely on the specific circumstances. It is likely that there is a market for UAM in the large, densely populated megacities like New York City, with high incomes. For such a city, an intra-city air taxi and airport shuttle could add value. However, in smaller urban regions such as the Randstad, the cities are probably too small for passenger transport within one and the same city and an intercity application could have greater value. This shows that only specific use cases will fit in a particular city, instead of a general one being appropriate for all of them. Cities should question themselves which use case(s) that can be (Participant Q, R, S, 2020).

Recommended actions

- **Action Point 11.1: Make an analysis of mobility challenges and gaps in a city**

  Before it can be determined whether and in what form UAM is suitable for a city, it is particularly important to map out the existing (transport and) mobility system (Participant L, 2020). What do the passenger flows within the market area look like? Which routes have long travel times (due to congestion, for example) and can a lot of time be saved?

  Interest: direct
  It is in the direct interest of cities to do research on this. After all, it concerns their own mobility system and it is their interest to know where problems exist, so that they can be solved if necessary.

  Term: 2020-2021
  In principle, this action can be carried out on a short-term and regular basis, as it does not depend on other actions. This way, a city can monitor the state of the mobility system at all times.

  Impact: with this action, knowledge is gathered about possible challenges in the existing mobility system. Based on this knowledge, policy can be made in the form of solving the problems in a way that best suits them, possibly UAM.

  Main executive actor(s): Local policymakers, urban planners, urban mobility advisors and other ecosystem stakeholders.

- **Action Point 11.2: Conduct a market research to find out which use case(s) are a good and viable fit for the community**

  After carrying out the previous action, people know where improvements in the mobility system are possible and / or necessary and it can be investigated how UAM can contribute to this. It is important to find out how UAM fits into the mobility plans of a city. Does it contribute to the goals it has? In this type of research, actions in the social field can also help, which will be discussed later on at challenge 11. An example is entering into conversations with the community, which should eventually form the demand side of the market. The ultimate end user can provide insight into his concerns and wishes. In addition, the execution of pilot projects can provide insight into how UAM implements the necessary improvements in the mobility system in practice.

  Interest: direct
  It is in the direct interest of cities to do research on this. After all, it concerns their own mobility system and community in which UAM could get a place.

  Term: 2022-2024
  Such a research can largely be carried out in the short term. However, a longer duration will probably be required for the pilot projects.

  Impact: this action in fact determines whether and how UAM can be an addition to a city and its mobility system. The action thus determines the further course of the transition.

  Main executive actor(s): Urban planners and urban mobility advisors, in collaboration with civil aviation authorities.

- **Action Point 11.3: Evaluate how UAM can be connected to the existing mobility system**

  For the operation of UAM and the entire mobility system, it is also important to consider connecting UAM to the existing mobility system for multimodality (Participant B, I, J, K, L Q, R, T, 2020). The better the connection between different modalities, the more user-friendly the system becomes for the end user. This can stimulate use and people may leave the car at home more often. It is therefore also important to set up UAM routes that are complementary to existing modalities, and find strategic vertiport locations, e.g. near existing transportation (hubs).

  Interest: direct
  A properly functioning mobility system and UAM service is in the direct interest of a city. It plays a role in the attractiveness of a city. Moreover, without proper connection of UAM to other modalities, the potential is not fully utilized.

  Term: 2025-2027
  When it is known what kind of market opportunities there are for UAM in a city, it can be evaluated how to connect UAM to the existing mobility system in an optimal way.

Impact: By performing this action, UAM, and the overall mobility system, can be (further) optimized.

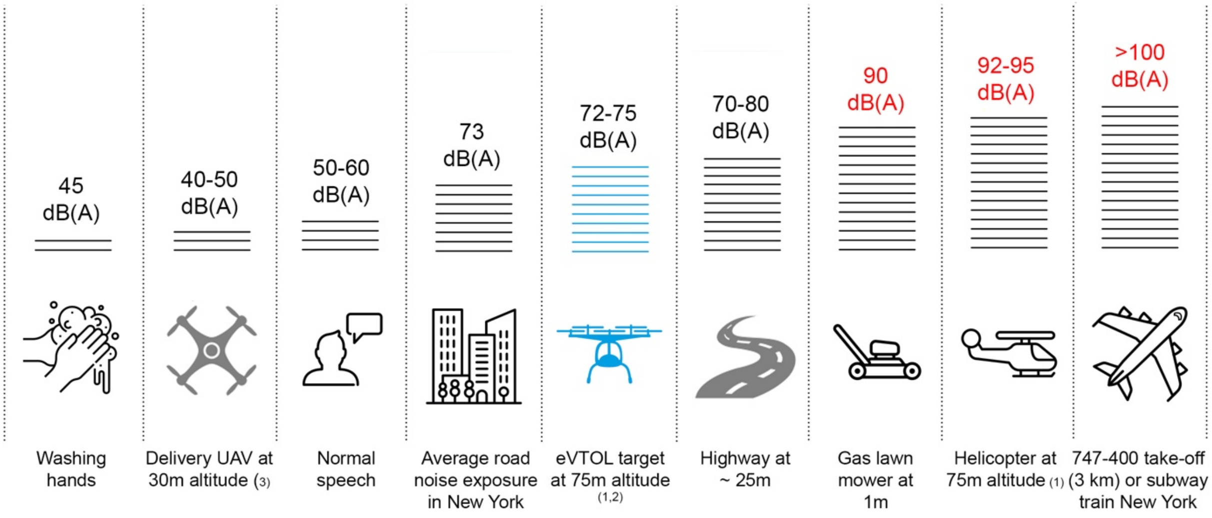
Main executive actor(s): Urban planners, urban mobility advisors and local officials.

Culture and symbolic meaning: the social acceptance and embracement of UAM

Challenge 12: There might be high social resistance against UAM ground infrastructure placement and UAM operations at certain locations

Although passenger drones are able to provide several benefits to people, like unparalleled speed in urban mobility, the emergence and presence of significant numbers of unusual and novel large air vehicles in an urban region and someone's 'backyard' might rather have a negative attitude at first. As the nuisance of these vehicles will especially be expressed around landing infrastructures, people might develop a "not in my backyard" attitude towards these vertiports. This is challenging, but it is uncertain how challenging it will be. At the moment, there are only a few studies that deal with this topic (Participant S, 2020). Social resistance against these facilities in urban areas is considered as an important barrier towards scaled operations by the majority of the participants in the research, and in the literature as well. This section elaborates on the different aspects that are related to and could constrain social acceptance.

The **noise** that eVTOL's will produce is one of the issues that was mentioned most often during the interviews in terms of community impact. It is argued that, when many passenger drones are going to fly through and over cities, the community will be very annoyed by the noise they produce (Participant B, C, F, G, H, I, Q, S, 2020). Although it is expected that eVTOL's will be quieter than helicopters (Participant B, 2020), they will still produce a significant amount of noise (around 75 dB(A)), which is comparable to levels adjacent to highways (fig. 53). Especially when larger fleets emerge, this will be a problem (Crown Consulting, 2018; Volocopter, 2019). At times that the vehicles will fly at a high enough altitude, this impact might be not too big, but the vehicles will especially be loud during take-off and landing (Participant B, 2020; Volocopter, 2019). Therefore, many people will argue that they do not want a vertiport very near to them (Participant B, I, 2020). Also, people could demand that you can only take off or land a limited number of times. (Participant C, 2020). In fact, this is very much in line with what can be seen with traditional airports, which tend to be in remote areas, just because of the noise impact, among others. It is because of this that people do not like to see an airport and many flights in their area either (Participant B, I, 2020).



N.B. prolonged exposure can damage hearing from 80 dB(A).

1 Assumes scenario of 3-6 vehicles flying in close proximity while approaching heliport/vertiport at altitude of 250 feet (based on assumption that vertiport can accommodate 3 eVTOLs at any given time).

2 Based on 67-dB(A) VTOL noise projected in Uber elevate paper.

3 Assumes even distribution of all delivery vehicles in operation over all roads in San Francisco city proper (<3 drones per mile)), so at any given square mile no drone would be flying over the same receiving vessel; flight altitude of 100 feet.

Figure 53 | Expected noise level of UAM operations compared to other sources. Sources: Crown Consulting (2018), J.H. Boelens (Volocopter)).

In the Netherlands, only 1% of the households is currently exposed to similar or higher noise levels (> 70 dB(A)) (Ministerie van Infrastructuur en Waterstaat et al., n.d.). By integrating UAM in a community, this percentage is likely to increase. Looking at the square kilometer of the Rotterdam Central District, almost all locations that have the right spatial dimensions in place are situated closer to the nearest dwellings than 75 meters (table 24). In such situations, this results in even greater noise pollution for residents than the target level of 72-75 dB(A), and the noise production may be even louder than that of highways. This might become a significant challenge.

Table 24 | Maximum distances of the locations in the Rotterdam Central District to the nearest dwellings. Sources: Google Maps,Kadaster, Ruimtelijkeplannen.nl.

Location	Distance to nearest dwelling
Parking 1	≤ 50m
Parking 2	≤ 67m
Parking 3	≤ 20m
Parking 4	≤ 70m
Parking 5	≤ 20m
Parking 6	≤ 42m
Green space 7	≤ 15m
Green space 8	≤ 10m
Green space 9	≤ 15m
Green space 10	≤ 70m
Rooftop 11*	≤ 40m
Rooftop 12	≤ 95m
Rooftop 13	≤ 35m

To elaborate on this specific social impact that UAM and the positioning of its ground infrastructure can have in cities, a deeper, illustrative look is given into location ‘Parking 1’ by means of figures 54 to 57. Figure 54 gives an insight of the noise pollution levels at and around this location, as seen from above. The left side of the figure shows the existing noise pollution levels for some buildings in the surroundings of the site. It can be deduced from this that the cumulative noise exposure of the buildings examined is currently 51 to 72 dB(A) during the day. At night this is 42 to 63 dB (A). In a new situation, in which there is a vertiport on the site, the noise pollution from passenger drones taking off, landing and flying past is added to this. As was mentioned earlier, Uber expects that up to 48 departures per hour will take place from a vertiport, which is a significant number. The right-hand side of figure 54 shows from above how this new noise exposure can be expressed during the take-off and landing of the vehicles. It is assumed that drones behave as a point source in terms of noise production, so that the sound is mainly radiated from the purple circle - within which the FATO is situated - over a spherical surface. The radiated sound energy is then spread over a surface that is proportional to the square of the distance from the source. The imaginary sphere through which all the sound passes then gets an ever-increasing surface at a greater distance. The noise level will then decrease by 6 dB for every doubling of the distance. The circles in the figure form a two-dimensional representation of such a sphere. The starting point is the lower range of the target level of 72 dB (A) at 75 meters from the source - in this case the vertiport. The other circles have been drawn on this basis. In figure 55 the same has been done for the profiles of this location in the existing and new situation, as seen from the intersection between the Delftsehof and Schiestraat and looking to the north-east. The vertical component of the noise exposure is also visible in this image now.

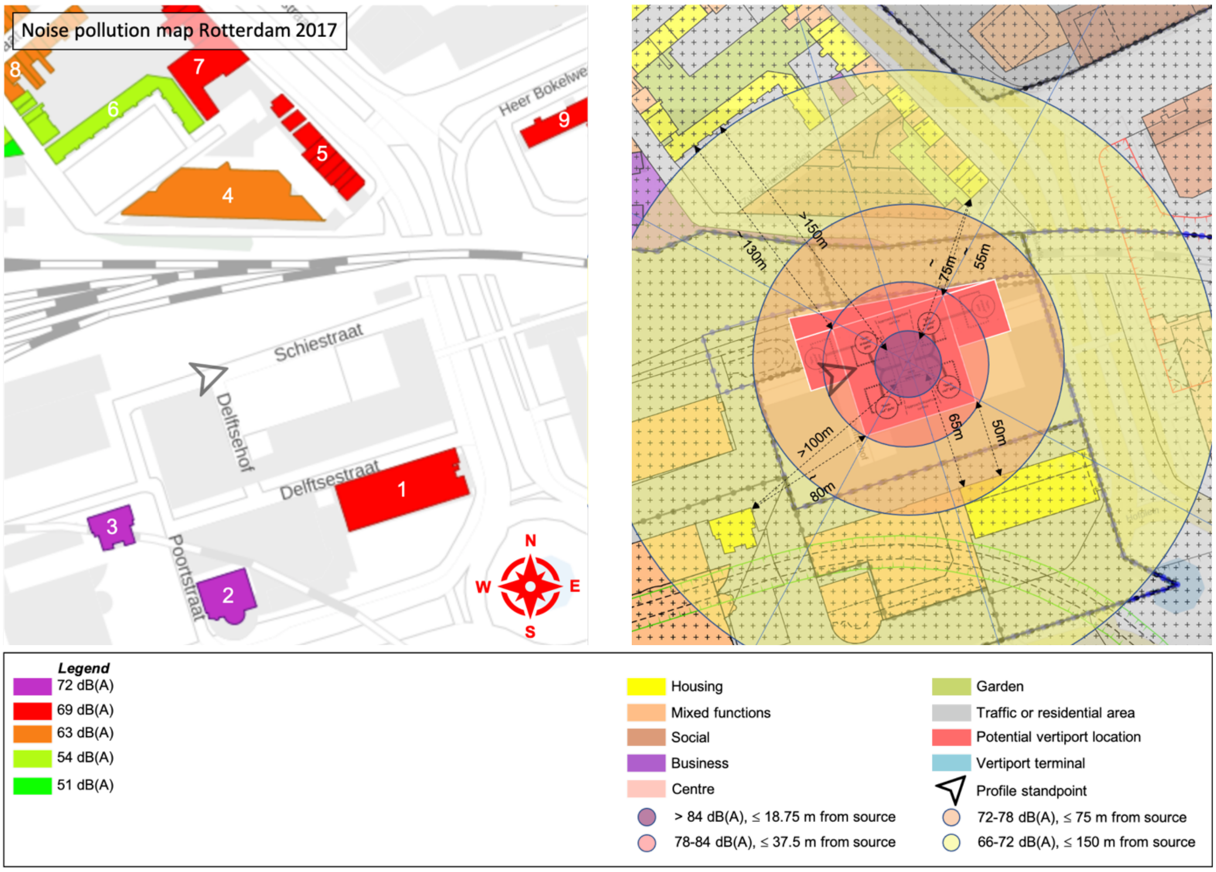


Figure 54 | The location 'Parking 1' and its nearby surroundings as seen from above. The figure shows the existing, cumulated noise exposure – caused by road, rail and air traffic and industry – to some buildings in the area (left) and the possible noise pollution resulting from passenger drones landing and taking off from a vertiport in a new situation (right). The colors on the left side illustrate the noise impact to which these buildings are exposed in the current situation. The colored / shaded buildings on the right side illustrate the use of the buildings according to the zoning plan, while the colored circles illustrate the additional noise pollution caused by vertical take off and landing. Sources: Ruimelijkeplannen.nl, Gemeente Rotterdam (2017).

However, both figures assume an apparently stationary sound source. What cannot yet be seen is how the noise exposure is expressed when the source starts to move. Since this concerns a means of transport, the noise source will of course move. However, the center of gravity of the noise exposure will continue to be concentrated around the landing infrastructure, due to the relatively high density of vehicles and low flight altitude around vertiports. The noise exposure due to moving passenger drones is proposed as shown in figures 56 and 57.

The proposed vertiport configuration assumes flight paths in two directions. For location "Parking 1", these are located in the northwest and southeast. The passenger drones will therefore mainly fly in and from these directions, so that the noise pollution around this location will also concentrate in these directions. In figure 56, in the horizontal plane, the round circles of figure 54 are therefore stretched in the same directions.

In addition, passenger drones will move in the vertical plane by means of landing and take-off. Above the FATO, depending on the surrounding buildings, they will move straight up or down for a certain number of meters. The further landing or take-off will take place diagonally in the intended direction. After all, the shorter the vertical distance that must be covered, the shorter the travel time and the smaller the energy requirement. In figure 57 the round circles in the vertical plane of figure 55 have therefore been stretched in the same directions. Appendix F provides a more detailed illustration of this. It can also be noted that the higher the vehicles fly, the less the noise pollution on the ground. As mentioned earlier, it can therefore make sense in terms of noise exposure to situate a vertiport as high as possible.

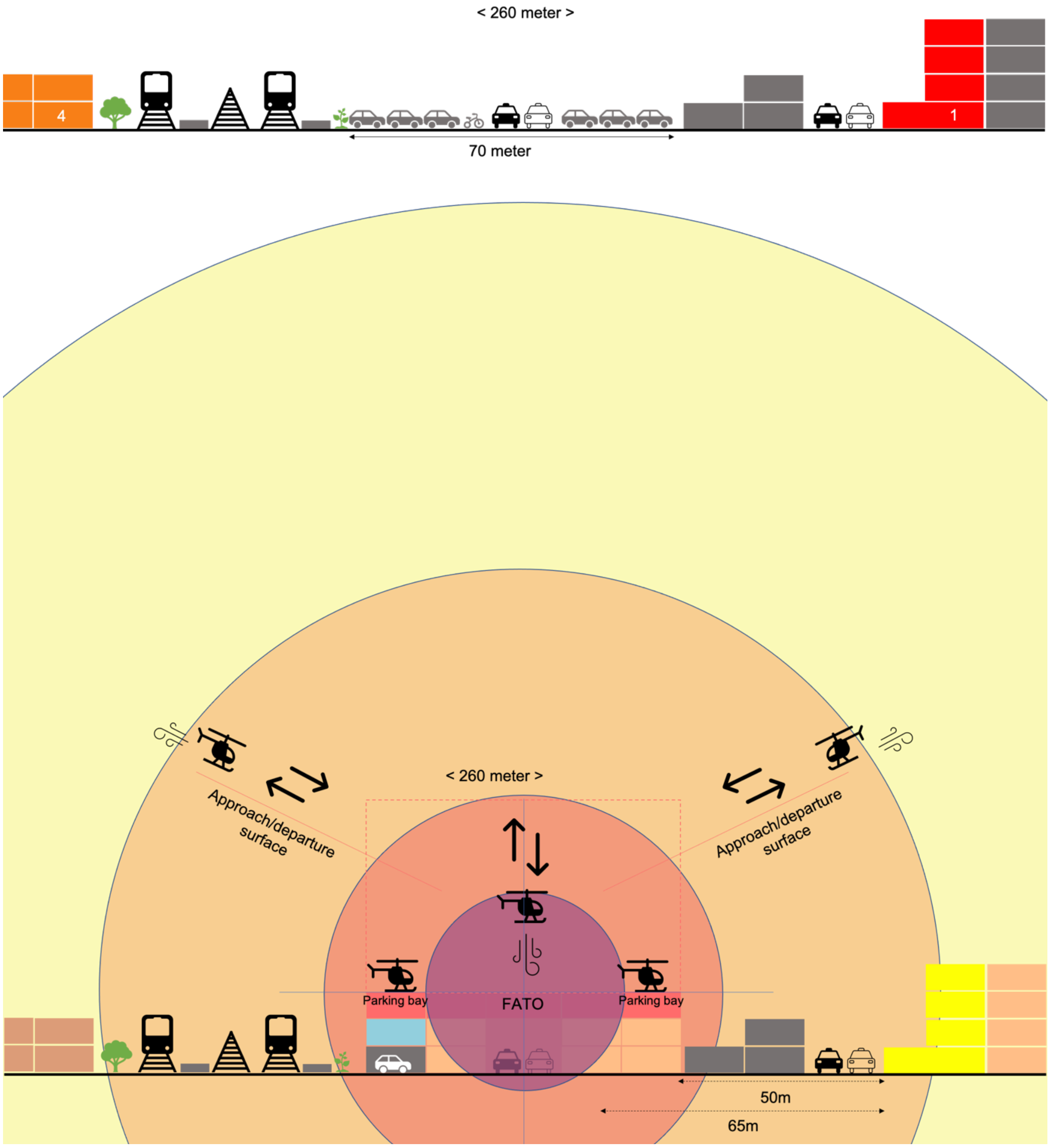


Figure 55 | Profiles of location 'Parking 1' in the existing (above) and new situation (below), as seen from the intersection between the Delftsehof and Schiestraat and looking to the north-east. The figure shows the existing, cumulated noise exposure – caused by road, rail and air traffic and industry – to some buildings in the area (above) and the possible noise pollution resulting from passenger drones landing and taking off from a vertiport in a new situation (below)). The circles illustrate the noise production of a passenger drone that touches the FATO surface after a vertical landing or before a vertical take-off. The colored / shaded buildings illustrate the noise impact to which these buildings are exposed in the current situation. In the new situation, the colored / shaded buildings illustrate the use of the buildings according to the zoning plan. See also the legend in figure 54. Sources: Ruimelijkeplannen.nl, Gemeente Rotterdam (2017).

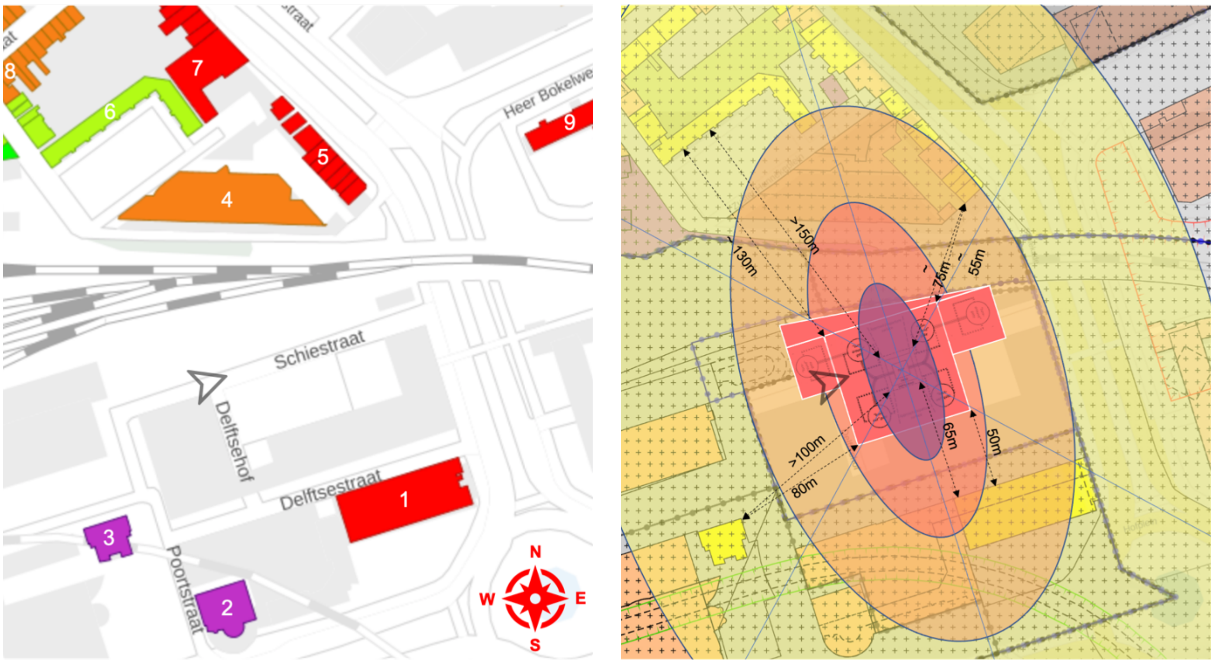


Figure 56 | The location 'Parking 1' and its nearby surroundings as seen from above. The figure shows the existing, cumulated noise exposure – caused by road, rail and air traffic and industry – to some buildings in the area (left) and the possible noise pollution resulting from passenger drones that land, take-off, hover and cruise near a vertiport in a new situation (right). The colors on the left side illustrate the noise impact to which these buildings are exposed in the current situation. The colored / shaded buildings on the right side illustrate the use of the buildings according to the zoning plan, while the colored circles illustrate the additional noise pollution caused by the motions of passenger drones. See also the legend in figure 54. Sources: Ruimelijkeplannen.nl, Gemeente Rotterdam (2017).

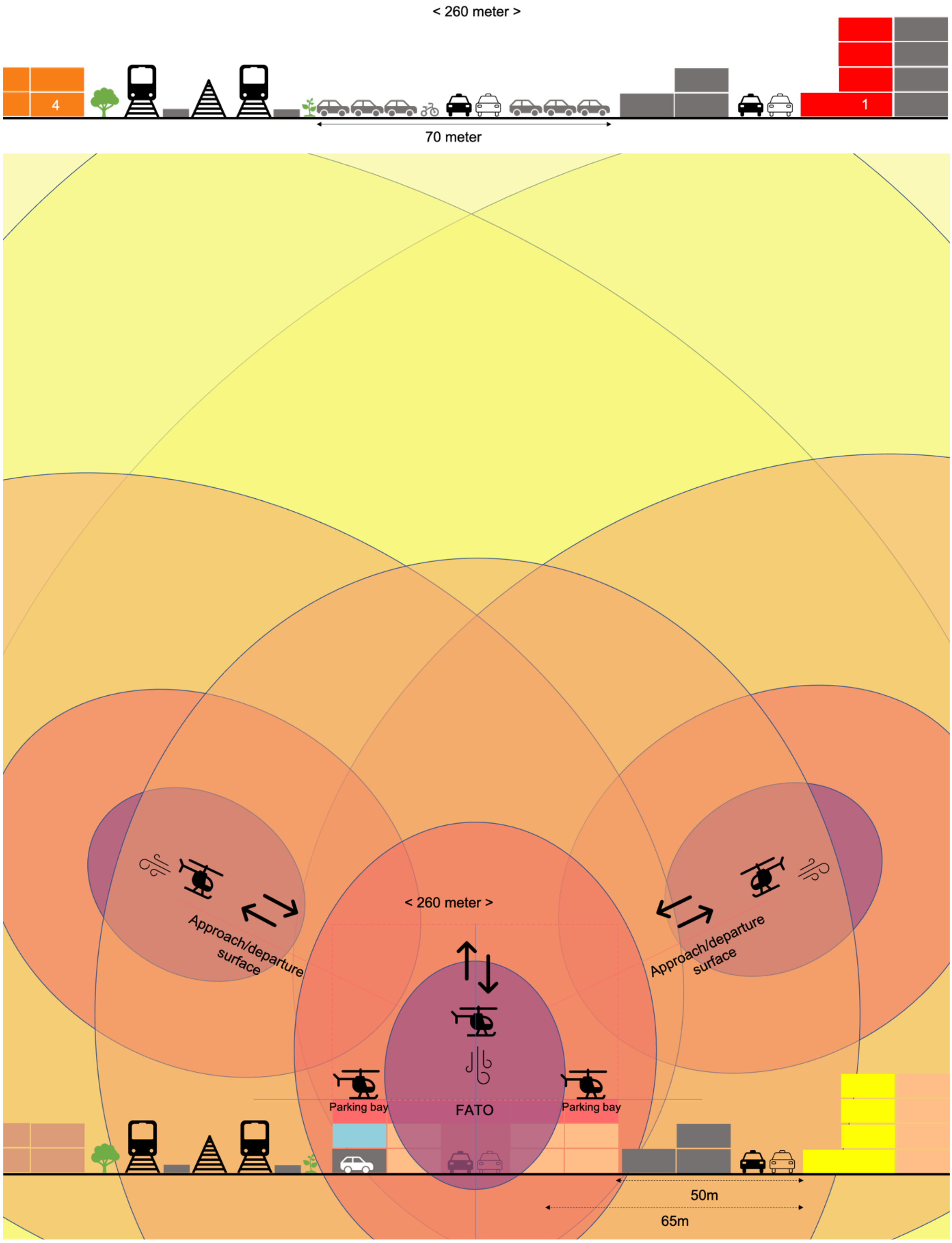


Figure 57 | Profiles of location 'Parking 1' in the existing (above) and new situation (below), as seen from the intersection between the Delftsehof and Schiestraat and looking to the north-east. The figure shows the existing, cumulated noise exposure – caused by road, rail and air traffic and industry – to some buildings in the area (above) and the possible noise pollution resulting from passenger drones landing and taking off from a vertiport in a new situation (below)). The extended circles illustrate the noise production of passenger drones that are in motion and vertically land or take off from the FATO and cruise to or from the vertiport. The colored / shaded buildings illustrate the noise impact to which these buildings are exposed in the current situation. In the new situation, the colored / shaded buildings illustrate the use of the buildings according to the zoning plan. See also the legend in figure 54. Sources: Ruimelijkeplannen.nl, Gemeente Rotterdam (2017).

With this estimate of the noise exposure from passenger drones, a provisional assessment can be auctioned about the social consequences of realizing a vertiport at a location such as this one. This was done by comparing the existing noise exposure with the additional noise exposure caused by passenger drones, as shown in table 25. These are assumptions.

Table 25 | Comparison between the existing cummulated noise exposure for some selected buildings around location 'Parking 1' and assumed additional noise pollution by passenger drones.

Building	Current cummulated noise exposure (dB(A))	Additional noise pollution (dB(A))
1	69	~ 72-78
2	72	~ 69-72
3	72	~ 69
4	63	~ 72-78
5	69	~ 72
6	54	~ 69-72
7	69	~ 69-72
8	63	~ 67-70
9	69	≤ 66

Based on these assumptions, a large part of the environment around the proposed UAM ground infrastructure will be exposed to a greater, additional noise exposure compared to the current situation. For this study, the focus mainly was at noise nuisance for residents and therefore the yellow shaded buildings in the above figures are of particular importance. It can be seen that many of the residential buildings can be exposed to additional noise pollution if a vertiport is realized at a location like this, with an estimated maximum of approximately 78 dB (A). This mainly concerns buildings 1 and 5 to 8. This means there is a risk that the noise nuisance would increase significantly for a number of residents. By situating the infrastructure as proposed, residential building 3 would be somewhat spared in this scenario, especially because this building would fall outside the flight path. This also shows that there might be chances to limit the noise pollution for citizens by careful planning of vertiport developments and flight corridors.

On the other hand, existing noise levels in the megacities of this world are probably higher, and as a result the integration of UAM in those cities will presumably make a smaller difference in terms of noise pollution.

Another kind of community impact is the **visual or horizon pollution** that passenger drones will cause (Participant B, G, H, L, 2020). Currently, it is still relatively quiet in the air just above a city and that is something that is going to change. This difference can also be observed in figures 55 and 57. As a result, 'you will of course also get effects in a city with horizon pollution, that you will always see drones flying around.' (Participant L, 2020). 'I think most inhabitants of a city simply don't want to imagine a sky where maybe one hundred drones will be flying.' (Participant B, 2020). Because passenger drones are supposed to fly at relatively low altitudes, it is reasonable to expect that they will indeed have a visual impact on the urban community. In fact, this perception is quite comparable with the horizon pollution that people experience from windmills, against which there is often a lot of resistance (Planbureau voor de Leefomgeving, 2019c). The question is how socially acceptable the visual pollution by passenger drones will be. Therefore, it is considered a significant impact that should be taken into account. When UAM takes off, it will mean that our skies will not be as clear anymore as they have used to be.

A third community impact that was mentioned is related to the **privacy concerns** that people have about drones (Participant H, P, S, 2020). Privacy abuse may be caused by the introduction of UAM. It is an aspect that has sparked a lot of discussion since the introduction of drones as well

(Galic et al., 2020). Unlike other vehicles, drones and eVTOL's could violate the privacy of people due to the low flying altitude (and possible camera on board), is the perception of people.

Furthermore, UAM may have an impact on the (perceived) **safety** in a city (Participant B, C, D, E, M, 2020). If an accident with a passenger drone happens, the damage caused will likely be relatively big compared to accidents with ground-based vehicles, especially when it happens right above a city. Also, the chance of such an accident will increase when it becomes busier and busier in the urban skies. An accident like this could also happen when people with bad meanings abuse an eVTOL as a weapon to harm the safety of a city, whether it is in person or digitally. This could very much affect the development of the industry.

To sum up, there are at least four major factors that play a role in the social impact UAM will have. These create a risk that people will oppose against a vertiport in their vicinity. Various actions can be taken on this.

Recommended actions

- **Action Point 12.1: Begin (and maintain) stakeholder conversations with the community to provide information on UAM as well as understand their wishes and concerns**

  The actions in the social domain of Urban Air Mobility mainly relate to communicating the advantages and taking away the concerns as much as possible (Participant E, H, 2020). By entering into dialogue and discussion about UAM with citizens, municipalities have the opportunity to educate citizens about UAM and argue what it will bring to the city and what benefits it will have for citizens (4.3.3). They can also listen to the concerns of citizens. By responding to these concerns in the urban planning process, plans can be improved, and support can be created.

  A part of this action should be the conduction of a research to find out what the exact opinions of people are in a specific community regarding UAM. It is recommended to do a 'zero measurement' to find out about people's opinions beforehand and do the same research once in a while after UAM operations have started, to see how people's opinions have changed. The results of the studies can be published (Participant S, 2020).

  Interest: direct
  It is in the direct interest of municipalities to involve their citizens in a radical technological transition such as this one. It is a technology that will undoubtedly have a significant impact on the social level. It is precisely these kinds of changes that people often have a natural resistance to. Including them in the process makes it possible to create support.

  Term: 2020-2040>
  The term of this action runs from now, or at least as early as possible, until (far) in the future when the first commercial flights will be carried out. This is recommended because of the novelty of the concept and the great social impact it can have. That is why it is important to maintain a dialogue with the community, at least until the moment that people have become more used to (large numbers of) drones in an urban environment.

Impact: when this action is implemented early by municipalities, they provide themselves with the opportunity to be ahead of the public opinion as much as possible. This can (partly) prevent the 'Urban Air Mobility' dossier from acquiring a widespread negative image and already falling behind with the people in advance.

Main executive actor(s): Planners, local officials and environmental managers/advisors, in collaboration with the industry (drone operators, infrastructure providers), community organizations and other ecosystem stakeholders.

- **Action Point 12.2: Start pilot projects in safe, distant environments to introduce people to UAM**

  Conducting pilot projects is a good way to support the previous action and to find out how UAM works in practice. They can help to discover what is going well and what is not (yet). In the case of social acceptance and resistance, it is the way to introduce people to this new technology and to see how they react to this new technology (Participant C, D, G, J, Q, R, S, T, 2020). This, together with the previous action point, can reveal people's concerns.

  These types of projects could, for example, start in showrooms and with Virtual Reality tools, and thereafter in reality outside the busy inner cities, where the social impact is low, and safety is less an issue. There UAM can be introduced to the first people, in a safe environment. For example, vehicles could be demonstrated in port areas such as the Maasvlakte (Participant C, 2020). When people become more comfortable with the technology, projects can then be started in low disturbance areas and gradually merge into more crowded cities (Participant J, 2020).

  Interest: direct
  It is in the direct interest of municipalities that want to introduce UAM that pilot projects are carried out. In this way they can observe in practice how UAM works or can work in their city and where the needs and concerns of their residents lie.

  Term: 2021-2035
  The first vehicles can already fly (short distances) and the first pilot projects are already being carried out, for example in cities such as Singapore (Volocopter) and Guangzhou (EHang). Although the market in these cities will develop earlier, it would not be a bad idea to start these types of projects early on (also in the Randstad), provided that they are financially feasible and responsible. With a long duration of regular pilots, there is plenty of time for research into possible use cases and social impact and people have time to get used to the technology.

  Impact: the pilot projects will be a first introduction to UAM in practice. Where plans for UAM are still being made, partly based on theoretical expectations, it will only become apparent in practice how UAM really works and how it is responded to. They offer the opportunity to gain insight into where UAM currently stands and which teething problems need to be eliminated. Are there any major technical challenges left? And does the public react positively, negatively or neutrally? Pilot projects might therefore have a major impact on the further developments of a radical transition like UAM.

Main executive actor(s): Planners, local officials and environmental managers/advisors, in collaboration with the industry (drone operators, infrastructure providers), community organizations and other ecosystem stakeholders.

- **Action Point 12.3: Work proactively to tackle social concerns through policy**

There are various, proactive ways to tackle the social concerns. Policy can be used to reduce these concerns in collaboration with industry and community groups. For example, noise-related and safety requirements for vertiports and vehicles could be defined (see also challenge 1, 2 and 17).

Also, the acceptable social impact across different categories of land use such as residential, institutional, recreational, commercial, industrial and agricultural could be estimated. Subsequently, guidelines on the main concerns could possibly be set. Among these are likely to be noise production, horizon pollution, privacy and security. To ensure that these factors remain within socially acceptable values, for example, a minimum distance from UAM ground infrastructure to homes could be established. On this basis, it could be determined how socially acceptable potential vertiport locations are. What urban planners could do, for example, is to take the factors noise nuisance, horizon pollution, privacy intrusion and security into account and make a selection of those locations that are far enough away from dwellings. This not only concerns the horizontal distance, but also the vertical distance. Building the infrastructure at higher altitudes might be a good idea, since vertiports that are located close to the ground place arriving and departing aircraft very near the surrounding areas which negatively influences all of the factors that were mentioned (Clauser, 2020). So, locating the infrastructure at sufficient distance, either horizontal and/or vertical, limits the nuisance for citizens as much as possible and maximizes the safety level.

Besides, vertiport locations should be considered where the aircraft noise can blend with the existing background noise (Participant J, 2020). At places where already a significant amount of noise is produced, noise pollution from UAM could be relatively lower.

Moreover, defining preventive measures (e.g., creation of noise overlay zones), operational measures (e.g., flight-routing, hours of operation; see also challenge 16) and abatement measures could be considered, like the possibility of making (small) adjustments to surrounding buildings. This could include, for example, noise-resistant facades or windows to limit noise nuisance (Participant J, 2020), but also foils on windows to guarantee the privacy of residents (Meesterfolie, n.d.).

Interest: direct
It is in the direct interest of municipalities to guarantee the well-being of citizens as much as possible.

Term: 2021-2035
The various measures that are part of this action should start early, but play out over a long period of time.

Impact: this inventory provides insight into the different opportunities that cities have to proactively to tackle social concerns through policy and secure public support for UAM.

Main executive actor(s): Local policymakers, community groups, manufacturers and standards organizations.

- **Action Point 12.4: Take-off with those use cases that are most socially accepted**

As discussed, the introduction of UAM may encounter considerable resistance due to various negative externalities. This resistance will mainly arise when only a small part of the people sees added value in or derives from UAM, for example due to the relatively high (initial) price that must be paid for a flight, which makes that especially in the beginning it is mostly the 'elite' who will travel with drones (3.3.4). In that case, it is wise to start with those use cases that (do) have their (social) value, for everyone or at least a large part of the population. Such use cases have a greater chance of support from the population. Use cases that can be considered are first responses such as the air ambulance, police and firefighter. But also applications in inspection, for example in infrastructure, agriculture or parcel delivery, could have either a lower disturbance level or a greater social value (Booz Allen Hamilton, 2018). Subsequently, use cases with a greater social impact, such as the air taxi, can be gradually introduced.

Interest: direct
It is in the direct interest of municipalities that want to introduce UAM in their cities to promote public opinion about drones. This can be done by starting with those use cases that have the most social value.

Term: 2035
The market may launch in de middle of the 2030's. This can best be done with low impact, socially accepted use cases.

Impact: the impact that can be expected from this action is positive. Starting with those use cases that have the most social value seems most socially acceptable and therefore increases the chance of successful introduction of subsequent use cases.

Main executive actor(s): City officials and aircraft operators.

Challenge 13: UAM faces the risk of becoming a symbol of the superiority of the elite

This challenge is strongly related to the above challenge, about the possible social resistance to UAM. However, here it is even more about the symbolic meaning of the UAM system. In the course of this thesis, the advantages and disadvantages of UAM have been reviewed several times. These play a major role in the symbolic meaning that UAM can acquire. In 6.2.7 the various, possibly positive and negative sides of this are discussed. Due to the price level of UAM, there is a risk that the benefits will only accrue to the small group that can afford this new modality, while the vast majority of the population will only experience the disadvantages. As one might imagine, UAM will not sell for five dollars a ride. Especially in the beginning, it will be quite more expensive than any cab ride, and much more expensive than public transportation (4.3.4). Over time, when the market can be scaled up, this price level will fall, but the price is not expected to fall below that of a taxi. Therefore, the people who actually can afford it will be limited, resulting in a relatively small market. This could make UAM a luxury good and create **social tension** (Participant B, H, I, J, 2020).

‘We talked to the UN about it and they say: on one hand this is a kind of thing that we would rather not have because it could allow a kind of elite that is not touching the ground any more, while the people are suffering on the ground. But on the other hand, it’s a thing that we actually should want, because it allows for everyone to connect, in parts of the world that are getting less and less connected.’ (KS, 2020). Depending on the eventual customer price level of UAM, it could create a sort of class distinction where upper class higher income individuals are avoiding traffic and are flying, and middle and lower class people are being stuck in traffic. In such a situation, it becomes even more difficult for the government to argument that this is a good thing to implement. Once a positive image cannot be achieved, it is likely to fail. Therefore, this challenge must be taken into consideration.

Recommended actions

- **Action Point 13.1: Establish or frame a positive symbolic meaning of UAM and ensure that the cost-benefit trade off will always tend towards overall benefits for the community**

  To prevent UAM from becoming a symbol for the rich, it is important to highlight its positive value. An attempt will also have to be made to make UAM accessible to a wider audience, e.g. through subsidization or high occupancy rates of air taxis. If that turns out to be (financially) impossible, it will in any case have to be guaranteed that the negative side effects are limited and that the overall cost-benefit trade-off is positive for society.

  Interest: direct
  It is in the direct interest of governments, especially in the Netherlands, to treat people equally as possible and try not to exclude them from services.

  Term: 2020-2040>
  Throughout the development period, efforts will have to be made to maximize the value of UAM to society. That is why a lead time has been chosen for this action until at least 2040.

  Impact: Hopefully, this action will ensure that UAM will mainly be seen as a positive addition to society.

  Main executive actor(s): Planners and state/local officials.

7.3.3.3 Industry

Actor network

Challenge 14: New stakeholder collaborations are required between stakeholders that have never collaborated before

On the one hand, there is still a lot of uncertainty about which parties these are, on the other hand it is already clear that for the development of UAM, new actors will have to come together who have not worked together before. The best example of this is the meeting of large, international (aviation) organizations such as Airbus with local governments. As also discussed in 6.2.5, this can be a complex process (Participant J, 2020). These aircraft operators now suddenly have to dive into the complicated headache world of local politics and stakeholders.

Recommended actions

- **Action Point 14.1: Develop a stakeholder map with all relevant actors**

  First of all, it is important to identify which actors have a share in UAM's Community Integration (Participant Q, R, S, 2020).

  Interest: direct
  It is in the direct interest of municipalities to identify who they are dealing with.

  Term: 2020-2021
  In order to get started with UAM energetically, a stakeholder map must be developed in an early stage.

  Impact: when this is clear, one knows with whom to work and one can proceed to the next step.

  Main executive actor(s): (Inter)national authorities, like the European Commission and the Ministry of Infrastructure and Water Management, and local governments.

- **Action Point 14.2: Establish an overarching forum of stakeholders**

  Bringing together stakeholders is a good step to initiate collaboration. This concerns stakeholders from the technology side and the regulatory side, but also representatives from city planning, from the industry who is using drones, from industry who is providing drones and services, grid operators, and also representatives from, for example, the public (Participant R, 2020). The Dutch Drone Delta in the Netherlands, for example, is a good start of such an organization, but should eventually be expanded with stakeholders like drone operators, manufacturers, infrastructure providers and the like.

  Interest: direct
  It is in the direct interest of municipalities to set up such a form of cooperation. Getting to know each other well, about a new and complex phenomenon, increases the chance of success.

Term: 2022
This organization should be set up after the relevant actors have been identified and continued beyond the start of the market.

Impact: such an organization offers opportunities to share and produce (new) knowledge. In this way, strengths are bundled and the chance of success increased.

Main executive actor(s): (Inter)national authorities, like the European Commission and the Ministry of Infrastructure and Water Management.

Challenge 15: The roles of potential stakeholders are not yet fully known

An important challenge in the actor network relates to the division of roles. There is still a lot of uncertainty about which role different stakeholders should represent (Participant C, F, G, H, O, P, Q, R, S, 2020).

An example of this is in the organization of drone traffic. In the Netherlands, practically every form of transport currently has its own manager. For example, LVNL regulates the organization of air traffic and Rijkswaterstaat is responsible for traffic management and water management. The drone traffic, which takes place in the low airspace, is in fact somewhat in between them (Participant C, G, 2020). In fact, cities suddenly have to concern about the airspace in addition to all the other tasks in their portfolio. They are confronted with vehicles flying in the air, while until now they have not really had much to do with them (Participant O, P, 2020). Will they have a say about this, for example where and in what numbers drones can fly? (Participant Q, 2020). An important step is therefore to determine what the role of the municipality should look like in this. The question that is often asked but still unanswered is who will be responsible for the organization of drone traffic. Will it be the aviation authority, road authority, the city, or another and perhaps new organization? (Participant C, F, G, H, O, P, 2020).

But the infrastructure is also an example. Which actor – the UAM provider, the city, or any other party – is going to organize this and how far does the role of the municipality in this reach? (Participant R, 2020).

Recommended actions

- **Action Point 15.1: Define the role of the different stakeholders**

  It is important to define who acquires or assumes which role. Find out which role logically fits with the normal range of duties of an actor. It is also important to consider who takes 'ownership' over the concept: will there be fragmented ownership over roles and responsibilities, or is the establishment of a new exclusive agency a better idea? It is specifically important for municipalities to know what their role will be, which stakeholders they will be dealing with and how they relate to them.

  Interest: direct
  It is in the direct interest of cities to map out the division of roles. It determines the amount of power they will have and what they can and cannot say. It thus has a major influence on the realization of UAM.

Term: 2023-2024

In order to get started with UAM energetically, the division of roles must be determined at an early stage.

Impact: this action creates clarity. Actors get to know where they stand and what to do. Whereas parties currently often do not know what to do, this action enables the next steps to be taken in the transition.

Main executive actor(s): Overarching stakeholder forum.

Challenge 16: The infrastructure developer might not be the owner of the identified suitable and desired location

Due to the scarcity of space, a significant share of UAM ground infrastructure might be developed on top of existing buildings. Generally, these buildings are not be owned by the infrastructure developer or operator. Within the Rotterdam Central District this will be the case, for example, at locations 2 to 6 and 11 to 13, although, in the Netherlands, the municipality often manages a number of parking garages. The absence of ownership raises the complexity even more, since the developer and operator will be dependent of the owner of the building. First of all, it makes it more difficult to develop the infrastructure. The owner of the building must be open to this. However, assuming this is the case, there are other issues. In practice, for example, passengers will have to gain access to the roof in some way. Realizing all kinds of separate access routes, including a lift, for only a relatively limited number of passengers will be very expensive.

Recommended actions

- **Action Point 16.1: Find a way to collaborate with the owner of the building**

The absence, or division, of ownership requires collaboration between the developer / operator of the infrastructure and the owner of the building.

Interest: (in)direct

This action is mainly in the interest of infrastructure developers and less in the interest of the municipality.

Term: 2030

Collaborations with building owners should start once suitable locations for UAM ground infrastructure are found on existing buildings.

Impact: collaboration with and cooperation from a building owner, in case of infrastructure placement on an (existing) building, will be key. This actions determines the chances of infrastructure development on top of a building and thereby the number of available locations.

Main executive actor(s): Infrastructure developer.

Sectoral policy

Policy is needed in order to enable UAM operations, while at the same time paying attention to the possible negative side effects of the system.

Challenge 17: Current regulations do not allow drones in most urban areas around the world

UAM in the intended form is not possible under the existing regulations. Existing rules generally prohibit flying drones in urban areas, as they rely heavily on public safety and security concerns (see also 6.2.6 and Appendix C.6 and D.6). This is also reflected in the Randstad (fig. 41). On this map, the red-colored areas represent areas where it is prohibited to fly a drone ('no fly zones'). As can be seen, these are mainly urban areas. Outside the red areas it is allowed to fly with a drone, but under strict, restrictive conditions with regard to VLOS, maximum altitudes and the like. For example, a drone must be in sight of the pilot at all times, which will cause problems when drones start flying autonomously. The maximum flight altitude in the Netherlands is also 'only' 120 meters, while eVTOL aircraft are supposed to fly at altitudes of several hundred meters and above a kilometer.

Recommended actions

- **Action Point 17.1: Develop regulation that enables the intended UAM operations, while respecting the social values of the community**

  It is important for the drone industry that a regulatory framework will be created that allows to take off, depart terminal areas, fly, interact with other aircraft, approach, and land within urban areas. This implies that regulations with regard to VLOS, flying over populated areas, maximum altitudes and the like will need to change in order to make (autonomous) commercial drone services in urban areas possible. However, this does not mean that drones should not have any restrictions. In order to enhance public acceptance, it remains very important to keep the social impact of drones in mind. That is why guidelines will still have to apply that limit noise nuisance, horizon pollution and privacy intrusion as much as possible and guarantee safety. As stated earlier, this may include distance guidelines for vertiports. But rules can also be drawn up that determine where, when and how drones may operate in local areas ('flight corridors'). For this action, municipalities should work together with (inter)national civil aviation authorities.

  Interest: direct
  It is in the direct interest of cities to take up the regulation part of the UAM puzzle. It directly affects what is and what is not possible in their city.

  Term: 2020-2026
  Regulation is something that often requires a lot of time (Participant C, 2020; Alexander, 2020). According to Alexander (2020), it can take at least six years to go through a formal rulemaking process. And so, it will be one of the key actions and should be carried out very early on.

  Impact: as a key part of enabling UAM, this action suddenly opens up the sky for scaled air traffic in the lower airspace of cities. In this way, it is in fact one of the starting points for industry to develop.

Main executive actor(s): International civil aviation authorities like FAA and EASA, in collaboration with national, regional and local regulators and policymakers

Challenge 18: There is a patchwork of existing regulation that hinders the development of the industry

Sectoral policies currently differ from country to country. Each country has its own regulations and has its own position with regard to drones, which makes for an unclear patchwork. As a result, drone operators will face different regulations in each country they will fly in. This does not benefit smooth developments of the drone industry.

Recommended actions

- **Action Point 18.1: Standardize regulation internationally in collaboration with other countries**

  Standardization of sectoral policy, and in particular in the field of regulation, is therefore desirable. A standardized, internationally agreed policy will make it easier for operators to offer their service in every city.

  Interest: indirect
  This action is mainly in the interest of air taxi operators who want to offer their service in different locations. This makes it in the indirect interest of cities, although standardization of regulation makes it easier for them to attract operators to their city.

  Term: 2020-2026
  The timeframe for this action is the same as for the previous, as both must be complementarily executed.

  Impact: the impact of this action, like the previous one, will be significant. It has the potential to accelerate the industry, as operators everywhere have to deal with the same regulations and can thus easily enter different markets.

  Main executive actor(s): International civil aviation authorities like FAA and EASA, possibly in collaboration with national, regional and local regulators and policymakers

Challenge 19: UAM ground infrastructure may be or become inaccessible for some eVTOLs

Currently proposed vertiport configurations are largely based on the requirements used for heliport designs, which were once based on the performance characteristics of helicopters. These were retrieved from a research conducted in 1987, which is referenced in several R&D documents by the Department of Transportation and FAA (Alexander, 2020). This means that the heliport requirements are based on technology which is at least more than 30 years old. With eVTOLs being very (i.e. more) technologically advanced vehicles – at least that is what we expect – the requirements for vertiport infrastructure might be different, among others in terms of land use. Tests with eVTOL vehicles should be accomplished in order to successfully develop defensible, standardized vertiport requirements.

However, even when new UAM ground infrastructure configurations are designed, they will be based on eVTOL concepts currently in development. At the moment, there are well over 200 eVTOL air taxi designs, each of them unique and driven by a number of technical, economic, commercial, and social factors (Robert Thomson, 2020). This causes two potential problems. The first one has to do with standardization of vertiports. Currently, designers do not have the obligation to create passenger drones that fit within a certain size and configuration. This means that the standardization of vertiport configurations is not yet underway. The problem that this causes for urban planners, is that at the moment an air taxi operator is allowed to configure a vertiport for its own air taxis, there is a significant risk that it creates a monopoly for that first operator. As a result, other eVTOL vehicles may or might not be able to utilize that infrastructure, because it may not fit the size of it or is not compatible with the charging infrastructure. But there may also be a mismatch in terms of business models, which plays a role in processing models of customers and terminal design (Powell, 2020).

However, there is another problem on the horizon, which has to do with technological development. This problem is due to the fact that with future technology, other types of aircraft than those currently thought of may become reality. Vehicles that are larger, can transport more people and thus perhaps have greater added value are an example of this. When we design UAM ground infrastructure purely on the basis of today's well-known vehicle concepts, we would therefore cut ourselves off. Larger vehicles would not be able to use this infrastructure, while reconfiguring a vertiport for them would be an unnecessarily expensive and perhaps impossible task. There is a risk that the city would be stuck with outmoded, low-volume air taxis while larger, more efficient ones have to operate from another, presumably sub-optimal, location. Urban planners and city officials should carefully think about these opportunities now (Powell, 2020).

Recommended actions

- **Action Point 19.1: Create standardized vehicle and UAM infrastructure requirements to enable proper urban planning and uniform utilization by all operators**

The industry should together come up with standardized requirements for both eVTOL vehicles and infrastructure (Participant I, K, 2020). In this way, proper urban planning can be enabled and it must be guaranteed that every vehicle concept fits every ground infrastructure configuration. As a result, uniform and high-frequency use of the infrastructure can be ensured, the value of the infrastructure is maximized and monopolies are prevented.

To do so, some stakeholders will have to work in close cooperation, like the aircraft designers, infrastructure developers and charger manufacturers.

Interest: direct
It is very important for the municipality that this action takes place. This can guarantee the greatest possible and sustainable value of the system for the city. Also, with this action point being completed – and the exact space requirements of UAM ground infrastructure being known – city officials and urban planners will be able to properly plan the rollout of these developments throughout a city or metropolitan area

Term: 2020-2026
It is advised to start early with this action. When the requirements are known, more precise planning can be undertaken.

Impact: this action opens the door towards more precise urban planning for UAM ground infrastructure. Knowing the exact (space) requirements can make the difference between a location being suitable or not for the necessary infrastructure, and being able to accommodate a vehicle more or less. Until then, it is basically a matter of making calculated assumptions. Also, it results in matching requirements for eVTOL vehicles and UAM ground infrastructure. It prevents that cities will have to deal with unwanted situations in a later stadium, like low-frequent use of infrastructure and emergence of monopolies.

Main executive actor(s): International civil aviation authorities like FAA and EASA, in collaboration with aircraft designers, infrastructure developers, charger manufacturers, national and local regulators and policymakers

- **Action Point 19.2: Guarantee network neutrality for UAM ground infrastructure**

  Standardizing vehicles and infrastructure alone does not guarantee that every vertiport is accessible to every drone operator. Therefore, urban planners, politicians, and regulators should focus on each city's traffic-specific pain points to make sure they can provide test beds in a timely fashion and guarantee network neutrality for eVTOL infrastructure. Such neutrality for vertiports is particularly crucial during the initial infrastructure build-out and should apply to all key traffic hubs to ensure the vertical mobility ecosystem does not become dominated by monopolies.

  Interest: direct
  It is very important for the municipality that this action takes place. This can guarantee the greatest possible and sustainable value of the system for the city.

  Term: 2027
  This action should be carried out just before the first infrastructure developments could take place.

  Impact: this action prevents that cities will have to deal with unwanted situations, like low-frequent use of infrastructure and emergence of monopolies.

  Main executive actor(s): Local policymakers, politicians, regulators and urban planners.

Techno-scientific knowledge

Challenge 20: Generally, cities lack the necessary knowledge about UAM

In the current state, there is usually a lack of the necessary knowledge within municipalities. In fact, this applies to all of the points discussed earlier. However, specifically spoken about 'techno-scientific knowledge', this seems to relate mainly to the airspace aspect, which is a logical consequence of the fact that cities previously had little to do with urban air traffic. This means that there is a lack of knowledge with regard to the organization and management of airspace. There is no one in the city that has knowledge about this kind of thing and the question is: will they need to develop this kind of knowledge? (Participant Q, 2020). Echter, ook op andere punten kan nieuwe, wetenschappelijke kennis vereist zijn binnen steden.

Recommended actions

- **Action Point 20.1: Evaluate which technical-scientific knowledge is lacking and must be developed within the municipality**

  Knowledge development provides a better insight into the complex matter of UAM. It is important that all the necessary knowledge is available within the system. When certain knowledge is lacking, there is a risk of missing important things and it becomes a challenge to develop a well-functioning, optimal system. This may mean that municipalities can rely on the knowledge of other actors or have to develop it themselves.

  Interest: direct
  It is in the direct interest of municipalities to get a picture of the knowledge available, both within themselves and among other stakeholders. Action can be taken on this and, if necessary, new knowledge can be gathered.

  Term: 2021-2026
  By developing knowledge at an early stage, it is avoided as much as possible that things are missed or delayed at a later stage. It is assumed that knowledge development will take at least several years and might be an ongoing process before the start of the market.

  Impact: this action contributes to a thorough system development.

  Main executive actor(s): Overarching stakeholder forum.

8 Conclusion & Discussion

This chapter will give an answer to the research questions that have been formulated at the start of this thesis. First of all, the four sub questions will be answered, after which an answer will be given to the question how the transition of Urban Air Mobility can be realised in communities. Furthermore, strengths and limitations of the research will be outlined, and the chapter will be concluded with suggestions for future research.

8.1 Answering the research questions

The aim of the first sub question was in principle to find out when, where and how UAM contributes to the realization of more sustainable urban mobility. The exact formulation of the question was,

How does UAM contribute to the realization of more sustainable urban mobility?

This thesis discusses the problems existing mobility systems often face. Many of these problems are related to the structure of the current mobility regime, which is strongly based on the car. This has resulted in congestion problems, air pollution and greenhouse gas emissions, but also safety and the space that automobility demands are important points. With continued urbanization and the expected growth of car mobility, there is a risk that these problems will persist or even worsen. The goal of cities is therefore to make the urban mobility system more sustainable. A mobility transition is required. An important part of this is reducing car use. Cities have several options they can use for more sustainable mobility, which roughly consist of public transport, active transport, governance and innovations and mobility services, as discussed in 4.2. However, despite investments, no clear trend can yet be recognized towards a more sustainable mobility system. This may be due to shortcomings of the alternative options. It therefore does not appear likely that the mobility problems mentioned will be resolved quickly.

Urban Air Mobility may give cities a new means of transport: the air taxi. People can fly from A to B at high speeds with a passenger drone. UAM provides a number of advantages that alternative means of transport do not have. The main advantage is the short travel time. At distances above 15 to 25 kilometers, a passenger drone is faster than the competition, while it uses sustainable fuels and thus flies emission-free. At the same time, UAM requires relatively little space: apart from a place to land, hardly any infrastructure is needed, where alternatives do. After all, drones fly through the air, and thus have the potential to take part of the transport into the air. Moreover, by flying autonomously, drones must prevent human error and thus become a safer means of transport. In this way, UAM has the potential to address many of the above-mentioned urban mobility problems.

However, further research has shown that UAM is not always, if not often, the "holy grail" and will usually only contribute to more sustainable urban mobility under specific conditions. First of all, the price level limits the target group that will (be able to) use UAM. Obviously, there is some degree of uncertainty about how the price level moves, but with a price well above that of a taxi, few people will be willing to use this service. Moreover, only a few people can be transported in a drone, much less than in a train, for example. In addition, UAM only proves its real added value over longer distances, both in terms of time and energy efficiency. Only from 15 to 25 kilometers is a passenger drone normally faster than any alternative, while only from longer distances a passenger drone, almost completely filled with paying passengers, is also more energy efficient than, for example, an electric car. Since the average (urban) travel is shorter, the number of suitable trips for UAM is further limited.

All these factors mean that UAM is or can be a sustainable means of transport, but that the market is expected to be so small that this means of transport is also unlikely to be the ultimate solution on the way to a more sustainable urban mobility system, just like the existing sub-altern regimes. UAM will most likely have a niche role in sustainable mobility and become one of the subaltern mobility regimes, in terms of market share still below existing subaltern regimes like public and active transport. UAM will be a suitable mode of transportation in specific places, for specific people and under specific circumstances. These specific places will mostly be larger and denser urban areas, with a high GDP. The main target group, at least at the start and in the near-term, consists of high-income people. Furthermore, UAM will mainly flourish on longer distances, under circumstances in which much travel time can be saved by bypassing congested or lacking ground connections. Although vertical mobility still holds the promise to relieve some pressure from particularly congested urban hot spots, this will only be some. This means that UAM will, generally spoken, not be the ultimate solution for sustainable urban mobility, which specifically means that it will not solve the congestion problem and will not have a major effect on reducing pollutant emissions. However, this does not mean that UAM will in no case be of added value. It is important to note that it can become a crucial part of an integrated solution to mitigate our growing transportation woes, by improving the connectivity and accessibility of urban areas that adopt this new mobility mode, among others.

The second sub question was formulated to make a qualitative assessment of the impact that UAM will have in cities. This question was defined as,

How does UAM interfere in the current city?

In this thesis it has been found that UAM can have a significant impact in cities in three areas in particular: space, energy and society. The spatial impact stems from the infrastructure to be developed. Although relatively little infrastructure is required compared to other means of transport, one piece of infrastructure (i.e. a vertiport) does have a very large surface. With a vertiport of approximately 2,500 m2 (one FATO, three parking bays), the spatial impact of UAM at a local level will be considerably greater than that of other means of transport, such as a tram or bus, and somewhat similar to a metro station or small train station. This makes vertiports developments that cannot simply be fitted into an urban center. Good urban planning is required.

The impact on the energy domain is expressed by the loading of passenger drones. These vehicles are expected to require more energy, in a shorter time, than electric cars. To meet this requirement, an energy infrastructure would be required, which is comparable in function and scale to that required by transit and heavy-duty EVs. To charge the high capacity batteries in approximately 10 minutes, they require high charging capacities (~ 600 kW). To be able to guarantee this, adjustments to the energy network may be necessary.

The impact of drones is also expected to be significant in the social domain. This stems from at least four main factors, which are discussed in order of (the expected) magnitude. Passenger drones, for example, produce a significant amount of noise. Although this varies per vehicle, the noise production is estimated to be approximately 72-75 dB (A) at a distance of 75 meters. This makes the noise impact comparable to that of a highway at a distance of 25 meters, which we can consider to be significant. Another aspect is horizon pollution. Although this factor is less easy to measure, people often resist new developments that change or limit their view in any way. This is also reflected in the development of wind turbines, among other things. It is therefore expected that horizon pollution will also play a role in the field of UAM. There is also the factor of privacy. For many years this has been one of the main issues when it comes to the use of drones. People are often afraid that their privacy will be violated when a, now still small, drone flies overhead. It is likely that this will be no different when drones start transporting people commercially. Finally, safety plays an important role. Usually people are very wary when it comes to aviation. A crash often causes great concern, as was also seen with the Boeing 737 Max. Strict safeguarding of safety is therefore of great importance.

The third sub question is somewhat related to the previous and was aimed to find out some of the most important challenges to overcome, in order to integrate UAM in the community. It was defined as follows,

What challenges or barriers can be identified that must be overcome for UAM to reach the urban mobility regime level?

Within all dimensions of the MLP, a challenge can be found when it comes to the community integration of UAM. However, it appears that the main changes to take place within the urban mobility regime are in the dimensions of infrastructure, sectoral policy and culture. This is in line with the challenges and barriers that are encountered on the way to the future. It is therefore assumed that the main challenges in the context of UAM Community Integration relate to these dimensions. Therefore, these are highlighted in this conclusion.

Currently, the existing regulations regarding drones can perhaps be seen as the greatest limitation of UAM. With current regulations, it is impossible to provide a UAM service as it is prohibited to fly in urban areas. There are also strict restrictions outside these areas. For example, the pilot is obliged to keep the drone in sight (VLOS), which would create difficulties for autonomous drones. There is also a maximum height, in the Netherlands currently of 120 meters. These and other rules mean that UAM is not yet possible in such areas.

However, if the correct regulations are in force, it could in principle be possible to start offering UAM services. This is when the other challenges come into play: those of infrastructure and the social community. There is a certain paradox in both. As discussed, the infrastructure consists of a number of main components: the vertiport, including charging infrastructure, and the energy network. With a view to the operation of the system and the market, it is desirable to realize this infrastructure in those places where there is the greatest demand for a UAM service. In this thesis the main factors that play a role in this are discussed. In short, these places are located in dense urban areas. However, the paradox lies in the fact that it is precisely these areas where the development of the necessary infrastructure is the greatest challenge. After all, all kinds of challenges arise in these areas, especially in the spatial and social domain (in addition to the aforementioned domain of legislation and regulations). For example, one will encounter the very scarce space in the city. Finding locations that meet the minimal space requirements for veriports of approximately 2,500 m2 will turn out to be a challenging job. When we add to this the desire to generate sustainable energy locally - in order to meet the energy needs and to fulfill the 'green credentials' of UAM - a gigantic surface is created that would be required for the realization and power supply of a vertiport. This involves other challenges, such as the financial feasibility and social value of a low-volume service in a city with expensive land, the suitability of existing buildings in case of a multifunctional solution, dependencies on other actors (eg building owners), the parking of all vehicles on even larger surfaces, etc. To come back to the spatial paradox: on the one hand, a vertiport is desirable in a city, because it reaches most people from there; on the other hand, a vertiport is not desirable in a city, because it takes up a lot of the scarce, precious space here, while it serves a limited number of people and therefore may have limited social value.

The same kind of paradox can be found in the relationship between infrastructure development and the social domain. Here too it is desirable to realize the infrastructure in those places where there is the greatest demand for a UAM service: urban areas. This will reach most people and allow as many people as possible to use the service. However, this will generate a lot of resistance on a social level. Just as people do not want to live near an airport or have an apartment building in their backyard, it is likely that - because of the aforementioned expected impact - they will also oppose a vertiport near their home. To come back to the social paradox: on the one hand, a vertiport is desirable in a city, because it reaches most people from there; on the other hand, a vertiport is not desirable in a city, because it can cause a relatively large amount of nuisance and thus evoke social resistance, while it serves a service for only a limited number of people and therefore has limited social value. So there is a risk that a small group will enjoy the benefits, while the majority will experience the side effects.

Another major challenge within the infrastructure dimension resides in energy supply. As stated, high payloads are required to provide the vehicles with energy. The question is whether the existing energy network can handle this.

In short, UAM comprises a complex set of challenges and conflicts of interest. Cities will have to find an answer to this in order to realize a properly functioning UAM system.

The final sub question was asked to identify actions that communities, or more precisely, cities can take in order to deal with these challenges and prepare themselves for the community integration of UAM. It was defined as follows,

Which actions can communities take to prepare themselves for UAM?

Following on from the previous sub-question, various actions can be distinguished that communities can take to respond to the existing challenges and thus prepare for UAM Community Integration. Here, too, a number of actions can be distinguished that are considered important and these are therefore highlighted.

With regard to the existing, restrictive regulations, it is important that cities come up with new, standardized regulations in collaboration with national and international regulatory organizations. It is important for the drone industry that a regulatory framework will be created that allows to take off, depart terminal areas, fly, interact with other aircraft, approach, and land. This implies that regulations with regard to VLOS, flying over populated areas, maximum altitudes and the like will need to change in order to make (autonomous) commercial drone services in urban areas possible. However, safeguarding the public interest cannot be ignored. That is why legislation must continue to provide for certain rules or guidelines with regard to noise, horizon pollution, privacy and safety, for example by setting minimum distances from people.

There are a number of important actions within the infrastructure dimension. Cities will have to make an inventory of existing infrastructure, which may be found at airports, for example. They must also look for potential locations for new infrastructure to be developed. First of all, attention must be paid to the market criteria discussed earlier. It is important to develop the infrastructure in locations with the best market opportunities. But the available space is also important. Vertiports work best when they have a ratio of one FATO to three to four parking bays. For these types of configurations, a surface area of at least 2,500 m2 is required. For locations based on existing buildings, it is also important to investigate whether these are sufficiently suitable for the installation of infrastructure on the roof. This includes a structural analysis and the presence of any obstacles on the roof. It is also important to consider the social costs and benefits arising from the location, taking into account, among other things, the social impact within the environment. Finally, the local power capacity is an important concept in the choice of location.

The latter brings us to another set of important actions related to the energy network. It is important for municipalities to map out the impact of UAM on the network and to compare this with the capacity of the network. Based on this, it must be decided whether, in general or locally, adjustments to the network are required to meet the energy demand of the drones. Decentralized generation and storage of energy may be required. Furthermore, a solution must be found for sustainable generation. After all, given the promise of being a sustainable means of transport, passenger drones also require sustainable energy generation. Finally, research will have to be carried out in this domain into various charging solutions. Currently, roughly three different ways can be distinguished: battery swapping, conductive charging and inductive charging. Although conductive charging is generally assumed, they all have their advantages and disadvantages.

Within the social domain it is important to start informing and educating the community at an early stage. This manifests itself in communicating the benefits that UAM can offer, but also in listening to the concerns that people have. By taking these concerns seriously, support can be created. This could be done, for example, by addressing these concerns within the regulations, including provisions on where, when and how drones may fly. This allows the social impact and thus resistance to be limited as much as possible. Pilot projects can also help with this. These can provide insight not only into possible use cases and flaws, but also into the public's reactions to the new technology. By starting this early on, the community will have time to get used to drones.

In short, there are many actions that cities can use to prepare for the community integration of UAM. For the other actions, please refer to chapter 7 and the roadmap.

Together, these research questions contributed to providing insight into what is involved in the community integration of UAM. This allows an answer to the main question, which reads as follows,

How can the transition of Urban Air Mobility be realised in communities?

This thesis has shown that there is a lot involved in the transition from two-dimensional to three-dimensional urban transport, or Urban Air Mobility. The transition is driven by large-scale developments such as urbanization, mobility growth and climate change, and technological innovations such as battery and communication technologies and automation (fig. 58). In addition, there are internal frictions in the existing mobility system, such as congestion, which require new, sustainable mobility solutions.

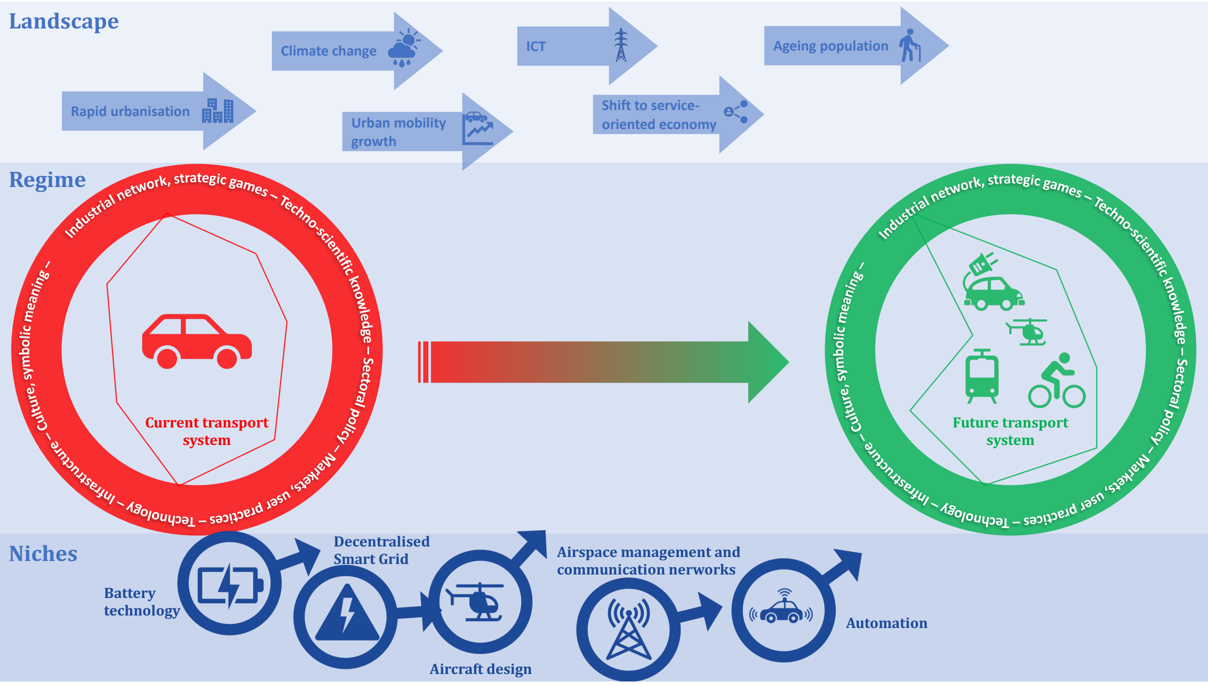


Figure 58 | The MLP applied to the transition of UAM.

The UAM mobility concept will, as an addition - in the form of a niche market - lie within the existing mobility regime. It is able to reduce local or regional problems in specific places with specific applications. For example, it can offer people a new mobility option for relatively low investments and contribute to improved connectivity in a city.

However, UAM requires changes in all dimensions of the mobility regime (fig. 58 and 59) and within the community. It has been found that with these changes UAM has a substantial impact on the city in a number of areas: space, energy and society. The changes come with a wide range of challenges, across all dimensions. In order to realize the transition of UAM in communities, cities will have to take actions to meet these challenges and enable the required changes.

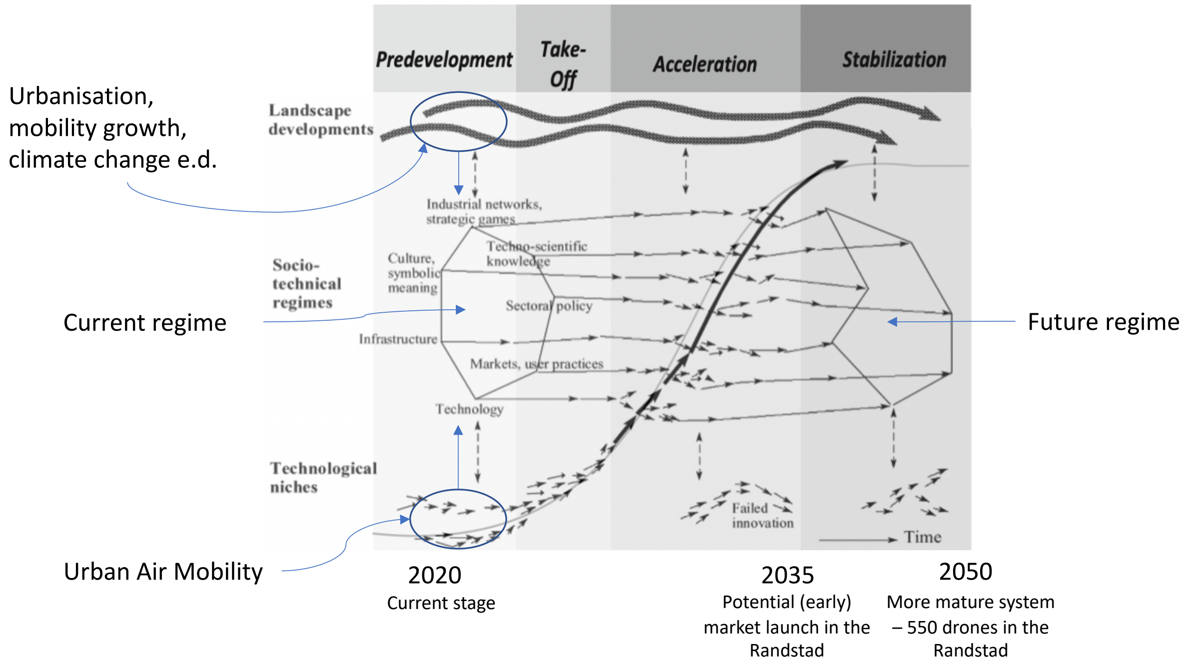
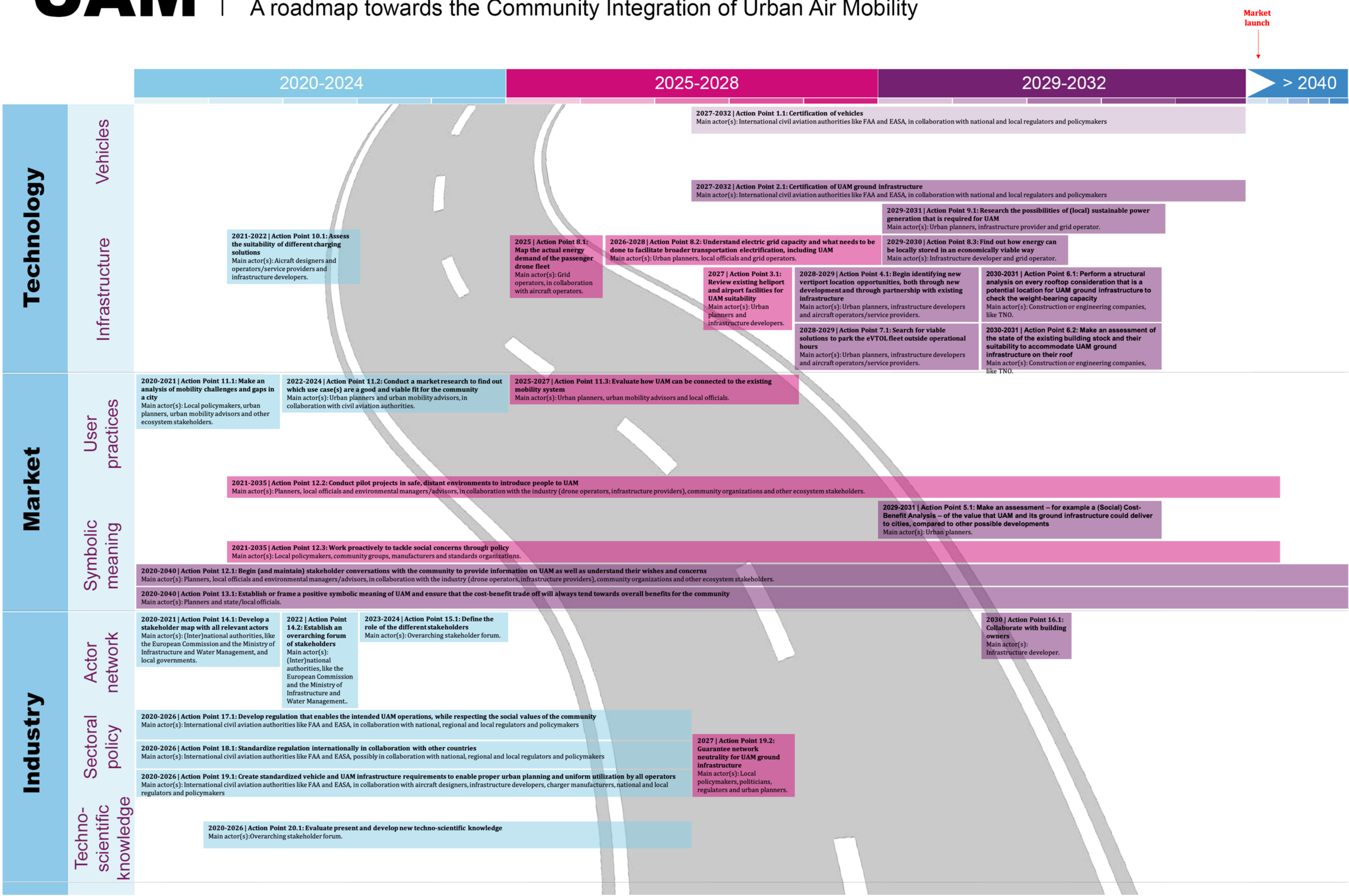


Figure 59 | The current and future stages of the transition of UAM.

We are currently still at the beginning of this process (fig. 59). At this stage, it is the pioneers who test their "radical innovations" through pilot projects and gradually learn more about putting the transition into practice through learning processes. There are therefore still far from major changes in the mobility regime that are aligned to UAM. In order to enable this, this thesis proposed some of the more important actions that communities can take for the community integration of UAM. These are outlined in the final roadmap on the next page, which should give the final answer on how the transition of UAM can be realized in communities.

UAM | The future of electric passenger drones

A roadmap towards the Community Integration of Urban Air Mobility



Technology

Vehicles

2027-2032 | Action Point 1.1: Certification of vehicles
Main actor(s): International civil aviation authorities like FAA and EASA, in collaboration with national and local regulators and policymakers

Infrastructure

2027-2032 | Action Point 2.1: Certification of UAM ground infrastructure
Main actor(s): International civil aviation authorities like FAA and EASA, in collaboration with national and local regulators and policymakers

2029-2031 | Action Point 9.1: Research the possibilities of (local) sustainable power generation that is required for UAM
Main actor(s): Urban planners, infrastructure provider and grid operator.

2021-2022 | Action Point 10.1: Assess the suitability of different charging solutions
Main actor(s): Aicraft designers and operators/service providers and infrastructure developers.

2025 | Action Point 8.1: Map the actual energy demand of the passenger drone fleet
Main actor(s): Grid operators, in collaboration with aircraft operators.

2026-2028 | Action Point 8.2: Understand electric grid capacity and what needs to be done to facilitate broader transportation electrification, including UAM
Main actor(s): Urban planners, local officials and grid operators.

2029-2030 | Action Point 8.3: Find out how energy can be locally stored in an economically viable way
Main actor(s): Infrastructure developer and grid operator.

2027 | Action Point 3.1: Review existing heliport and airport facilities for UAM suitability
Main actor(s): Urban planners and infrastructure developers.

2028-2029 | Action Point 4.1: Begin identifying new vertiport location opportunities, both through new development and through partnership with existing infrastructure
Main actor(s): Urban planners, infrastructure developers and aircraft operators/service providers.

2030-2031 | Action Point 6.1: Perform a structural analysis on every rooftop consideration that is a potential location for UAM ground infrastructure to check the weight-bearing capacity
Main actor(s): Construction or engineering companies, like TNO.

2028-2029 | Action Point 7.1: Search for viable solutions to park the eVTOL fleet outside operational hours
Main actor(s): Urban planners, infrastructure developers and aircraft operators/service providers.

2030-2031 | Action Point 6.2: Make an assessment of the state of the existing building stock and their suitability to accommodate UAM ground infrastructure on their roof
Main actor(s): Construction or engineering companies, like TNO.

Market

User practices

2020-2021 | Action Point 11.1: Make an analysis of mobility challenges and gaps in a city
Main actor(s): Local policymakers, urban planners, urban mobility advisors and other ecosystem stakeholders.

2022-2024 | Action Point 11.2: Conduct a market research to find out which use case(s) are a good and viable fit for the community
Main actor(s): Urban planners and urban mobility advisors, in collaboration with civil aviation authorities.

2025-2027 | Action Point 11.3: Evaluate how UAM can be connected to the existing mobility system
Main actor(s): Urban planners, urban mobility advisors and local officials.

2021-2035 | Action Point 12.2: Conduct pilot projects in safe, distant environments to introduce people to UAM
Main actor(s): Planners, local officials and environmental managers/advisors, in collaboration with the industry (drone operators, infrastructure providers), community organizations and other ecosystem stakeholders.

Symbolic meaning

2029-2031 | Action Point 5.1: Make an assessment – for example a (Social) Cost-Benefit Analysis – of the value that UAM and its ground infrastructure could deliver to cities, compared to other possible developments
Main actor(s): Urban planners.

2021-2035 | Action Point 12.3: Work proactively to tackle social concerns through policy
Main actor(s): Local policymakers, community groups, manufacturers and standards organizations.

2020-2040 | Action Point 12.1: Begin (and maintain) stakeholder conversations with the community to provide information on UAM as well as understand their wishes and concerns
Main actor(s): Planners, local officials and environmental managers/advisors, in collaboration with the industry (drone operators, infrastructure providers), community organizations and other ecosystem stakeholders.

2020-2040 | Action Point 13.1: Establish or frame a positive symbolic meaning of UAM and ensure that the cost-benefit trade off will always tend towards overall benefits for the community
Main actor(s): Planners and state/local officials.

Industry

Actor network

2020-2021 | Action Point 14.1: Develop a stakeholder map with all relevant actors
Main actor(s): (Inter)national authorities, like the European Commission and the Ministry of Infrastructure and Water Management, and local governments.

2022 | Action Point 14.2: Establish an overarching forum of stakeholders
Main actor(s): (Inter)national authorities, like the European Commission and the Ministry of Infrastructure and Water Management..

2023-2024 | Action Point 15.1: Define the role of the different stakeholders
Main actor(s): Overarching stakeholder forum.

2030 | Action Point 16.1: Collaborate with building owners
Main actor(s): Infrastructure developer.

Sectoral policy

2020-2026 | Action Point 17.1: Develop regulation that enables the intended UAM operations, while respecting the social values of the community
Main actor(s): International civil aviation authorities like FAA and EASA, in collaboration with national, regional and local regulators and policymakers

2020-2026 | Action Point 18.1: Standardize regulation internationally in collaboration with other countries
Main actor(s): International civil aviation authorities like FAA and EASA, possibly in collaboration with national, regional and local regulators and policymakers

2020-2026 | Action Point 19.1: Create standardized vehicle and UAM infrastructure requirements to enable proper urban planning and uniform utilization by all operators
Main actor(s): International civil aviation authorities like FAA and EASA, in collaboration with aircraft designers, infrastructure developers, charger manufacturers, national and local regulators and policymakers

2027 | Action Point 19.2: Guarantee network neutrality for UAM ground infrastructure
Main actor(s): Local policymakers, politicians, regulators and urban planners.

Techno-scientific knowledge

2020-2026 | Action Point 20.1: Evaluate present and develop new techno-scientific knowledge
Main actor(s): Overarching stakeholder forum.

8.2 Strengths and limitations

Within this research, several strengths and limitations can be discerned which will be discussed in this section. First of all, since this research was conducted from within a company, this helped in getting into contact with interviewees. However, the affiliation with the university was emphasized when contacting these interviewees, in order to avoid the bias that the information given in the interview would be used for different purposes other than the thesis. Also, it was clarified that potential confidential information could be protected for third parties. By presenting the research in this way, it was avoided that people would give politically correct answers instead of their actual opinion.

Another strength was the fact that a variety of interviewees was contacted and spoken to. This resulted in a good picture of the mutual dependencies of various subsystems and thus the complexity of UAM. However, since UAM is in such an early stage of the transition, it sometimes turned out that the interviewees were also still searching in the world of UAM. The result was that not all information was always very useful. This especially applied to the interviewees from the different municipalities. That was a bit disappointing, since this research aimed to find out what cities can do in this transition. Besides, it was initially planned to conduct some interviewees with drone manufacturers, like Volocopter and EHang, who have already carried out plenty of test flights in urban environments. This could have provided useful information from practice. However, they could not be reached for an interview.

Still, this thesis has been able to give relevant insight in the challenges that cities will face when it comes to the integration of UAM in their city and community. Additionally, by including many references to participants of the research in the description of the results, a thick narrative has been created. According to Creswell (2014) this is a strength of a qualitative type of research, as it conveys many perspectives about the issue at hand, and therefore creates a more realistic and richer image of the results, also contributing to the validity of the findings.

Something that in retrospect was experienced as a limitation or shortcoming of the research is the fact that the scope has been kept very broad. Obtaining sufficient depth in the research was therefore somewhat more difficult. On the other hand, little or no research had been done into the community integration of UAM, and exploring the broad field of UAM could be a good start for more in-depth follow-up research.

8.2.1 Graduating during the Covid-19 pandemic

Another special limitation of the study is the fact that it was conducted at the time of the Covid-19 pandemic. Shortly after the start of the empirical research activities, this pandemic led to a worldwide lockdown from the beginning of March. Among other things, it resulted in the cancellation of the NASA UAM Ecosystem Working Groups, organized in Washington, D.C. for 300 industry attendees, who should have laid the foundation for my empirical research. This made contact with the prominent figures in the industry difficult and also caused some delay in obtaining sufficient respondents. In addition, the pandemic meant that contact with interviewees, the graduation committee, colleagues at APPM and fellow students largely took place digitally. This was not always as optimal as physical meetings. Perhaps a study in a world without Covid-19 would have yielded an (even) richer set of data and thus a better end result.

On a personal level, the pandemic mainly affected social contact and the space for relaxation. The measures to contain the virus limited everyone's freedom, including mine. Personal meetings with family and friends were not always possible. Relaxation activities were also partly eliminated, for example due to the suspension of the national football competition and the closure of gyms and catering establishments. As a result, there was not always a suitable outlet to clear the mind.

8.3 Suggestions for future research

The outcome of this research on transition actions for the community integration of UAM, also distinguishes some next steps which may be taken by other researchers in future investigations. Whereas this research took a broad, exploratory view, future research could narrow down on the discussed topics. In fact, all of the recommended actions contain implicit research questions that ask for an answer. However, to point out a few, it would be interesting to take on with the topic of infrastructure development. An interesting research would be to find out more about vertiport placement. Where could this be done best, taking into account the different interests from a spatial, financial and social perspective?

Also, it would be worthwhile to focus deeper on the subject of energy. Especially what kind of adjustments to the energy grid that are needed, would be an interest topic for future research. Important to include will be, of course, the expected energy requirements and current capacity of the grid. Solving this question would solve a large part of the UAM puzzle.

But there is also an important question in the social domain. This relates to the social acceptance of drones. An interesting study is to look at how people react to drones in practice and which factors play an important role in this.

Another important question is what the division of roles within the field of UAM should look like. Many interviewees indicated that this is still unclear and would like to see this change. For example, who should be responsible for the organization of drone traffic?

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APPENDIX

Appendix

Appendix A: Example interview guide

Exploring the city integration of the sustainable three-dimensional urban mobility transition: barriers, policy and impact

Marcel Kool, MSc student Construction Management and Engineering, TU Delft

Pages 1 and 5 are provided to give a little bit of broader context of the graduation research. Pages 2 to 4 contain the interview questions.

Empirical data collection

External factors such as climate change and urban population growth open a "window of opportunity" for a regime shift from two-dimensional mobility to electric three-dimensional mobility in the urban network. The emergence of Urban Air Mobility in fact comprises two transitions: both in the mobility and energy domain.

The question is, however, how these transitions integrate in cities. Questions that rise are, for example, how the stepwise implementation of UAM in cities can look like, where and how UAM interferes in the current city and how UAM affects the local tasks and question in terms of national and local governance and policy.

Research questions

Main research question:
How can the transition of Urban Air Mobility be realised in communities?

Sub-questions:

1. *How does UAM interfere in the current city?*
2. *What challenges or barriers can be identified that must be overcome for UAM to reach the urban mobility regime level?*
3. *Which actions can communities take to prepare themselves for UAM?*

Interview Guide

- Introduce myself
- Explain the goal of this research and what the purpose is of this interview. The thesis aims to give more insight into the city integration of Urban Air Mobility. The questions are asked from the viewpoint of the city.
- Ask whether the interviewee is okay with the interview being recorded, and how they want to be referred to in the final report. Explain that the transcript of the interview will be sent to the interviewee in order to check whether everything has been written down correctly. Finally, ask whether the interviewee is interested in receiving the final report.

  Ice-breaker: Have you already flown (in) a drone yourself?

Questions

Introduction

- Can you tell something about yourself and about your role?

Minimum needed data:

  - *Role in the company*

General questions

1. Why is UAM important for our future society?
2. What is your vision for UAM?
3. How would you assess the suitability for UAM of the current city?

Challenges and impact

Imagine a city that only knows a two-dimensional mobility system (which most cities do). This city wants to leverage the sky and make the transition to a sustainable three-dimensional mobility system by enabling UAM. Given the characteristics of UAM:

4. What major challenges, barriers or constraints can you identify regarding the **city integration** of UAM and why?

Supporting questions:

  - *What could constrain the UAM adoption in a city?*
  - *What are the UAM infrastructure/city integration challenges?*
  - *What are the spatial challenges to take air mobility into the city?*
  - *What are the policy challenges to take air mobility into the city?*

Given the **city integration** of UAM, it will undoubtedly have an impact on the city as we know it today. However, the exact impact is not clear yet.

5. Where, how and why do you expect UAM to interfere in the city? Think for example about the different (sub)systems in the city.

4. How do you expect UAM to affect the spatial design and use in a city?

5. How can cities deal with these barriers and impacts? In other words: how should the city change in order to be prepared for and accommodate UAM?

6. How do you think UAM should be implemented, strategically, to realise a valuable and socially responsible transportation network?

Supporting questions:

- *How can cities integrate UAM in their spatial design?*
- *How will UAM integrate in our cities? What will be its position in the overall (mobility) system / mobility regime and why?*
- *What are the (dis)advantages of UAM compared to other sustainable transportation modes?*
- *Where and how (much) will UAM affect and change the urban mobility system?*
- *Where and how (much) will UAM affect and change the built environment?*
- *Where and how (much) will UAM affect and change the energy network?*
- *Where and how (much) will UAM affect the community?*
- *Meanwhile, the impact on other aspects or subsystems may be reduced through the adoption of UAM. Which aspects or subsystems are these and why is the impact reduced?*

- *How and where will vertistops, vertiports or vertihubs be integrated in the city (and what will that mean to a city and the built environment and buildings in particular)?*
- *Where and how will the charging infrastructure be integrated in the city (and what will that mean to a city and the built environment and buildings in particular)?*
- *How will the energy demand be affected and how can cities still guarantee a sufficiently working energy grid?*
- *How is the sustainability component guaranteed in the transition?*
- *What are the Design Parameters In Urbanized Territories that are of importance to realise UAM in a city?*
- *What are the opportunities that UAM provides to a city?*
- *How should a UAM network look like?*

Minimum needed data:

- *The most important barriers and impacts and how to deal with them.*

Policy

The transition towards three-dimensional urban mobility will likely require action from the government as well.

7. How will UAM affect the local tasks and question in terms of national and local governance and policy?
8. What (policy or planning) measures can national and local governments take to intervene and guide this development in the best possible way?
9. How are the roles in the sustainability transition divided?

Supporting questions:

- *How can cities stimulate this development?*
- *What would you advise local governments to do to responsibly integrate UAM in cities and ensure a well working system, while avoiding possible negative impacts?*

Pathway

So, as a final remark to this interview: several tasks in different domains must be completed to make UAM possible.

10. How would you do this? Can you tell me what you see as important steps on the road to city integration of UAM?

Supporting questions:

- *What are important steps to make UAM part of the transportation regime in a city?*

Minimum needed data:

- *The necessary steps to guide the project from start to a mature mobility network in cities, taking into account the Multi Level Perspective framework by Geels (see Appendix). Insight must be gained about how to come from niche level and break through the barrier with the regime level, finally settling in the regime level, and thus becoming part of the mobility system.*

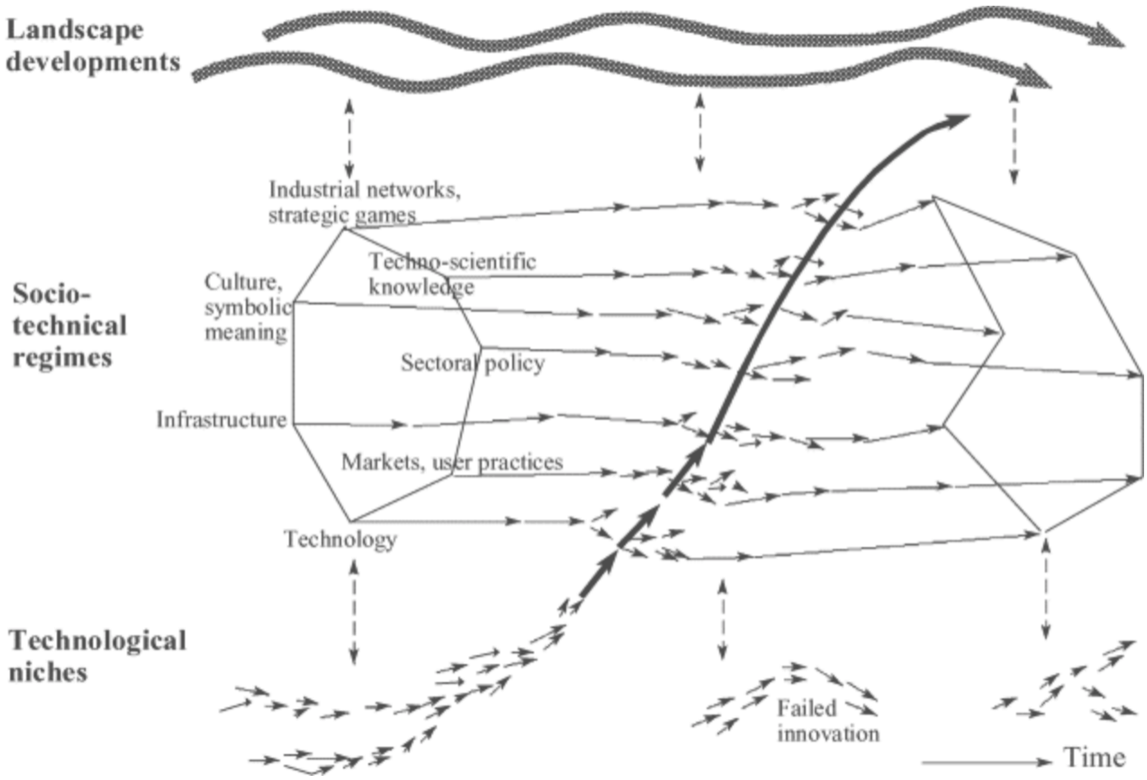
Other questions

11. Considering the MLP framework (see Appendix), do you expect that the UAM transition will influence largescale, long-term and exogeneous developments in the socio-technical landscape, like urbanisation, urban structures or any other similar developments? And how?
12. To what extent is the current energy supply sufficient if UAM is integrated in a city?
13. How to ensure sufficient landing/take off, charging and energy supply in cities?

Wrapping up

- Is there any relevant information that I have missed?
- Are there other people I should talk to? – Snowballing
- Thank the interviewee for his/her time.

Background information



Appendix B: Overview of interviewees

Reference	Organisation	Type	Position	Date
Participant A	SkyPorts	Infrastructure provider	Infrastructure Manager	17/02/2020
Participant B	Roland Berger	Consultancy	Management Consultant (aerospace)	21/02/2020
Participant C	Rijkswaterstaat	Government	Processmanager Drones	24/02/2020
Participant D	Hogeschool Rotterdam	Academia	Senior lecturer Intelligent Mobility	06/03/2020
Participant E	North Central Texas Council of Governments	Government	Principal Transportation Planner	11/03/2020
Participant F	DFW Airport	Aviation	Environmental Project Manager	11/03/2020
Participant G	Antea Group	Consultancy	Projectmanager Smart Mobility	18/03/2020
Participant H	Hovecon	Consultancy	UAM Specialist	20/03/2020
Participant I	Black&Veatch	Consultancy	Project Manager	
Participant J	MVRDV	Urban design	Senior Urban Expert	01/04/2020
Participant K	Airbus Urban Mobility	Aviation	Operation Manager - City Integration and Infrastructure Development	01/04/2020
Participant L	Dutch Drone Delta / Airhub	Integrator	Drone Consultant	02/04/2020
Participant M	Valqari	Infrastructure provider	CEO	10/04/2020
Participant N	Valqari	Infrastructure provider	Director of Strategic Partnerships	10/04/2020
Participant O	Gemeente Enschede	Government	Policy advisor Domain Physical & Economy	04/05/2020
Participant P	Gemeente Enschede	Government	Urban planner	04/05/2020
Participant Q	Gemeente Aachen	Government	Projectmanager for Urban Air Mobility	14/05/2020
Participant R	Hamburg Aviation	Aviation	Project Lead Windrove & UAM	20/05/2020
Participant S	Gemeente Hamburg	Government	Hamburg Ministry of Economy, Transport and Innovation	20/05/2020
Participant T	Gemeente Ingolstadt	Government	Department for Urban Development and Building Law	29/05/2020

Table 26 | Overview of interviewees.

Appendix C: The current state of UAM with respect to the mobility regime

C.1 Vehicles

The current state of technology in our (urban) mobility system is based on a number of components. Here, the most important ones in the eye of UAM are discussed. First of all, the vast majority of traffic takes place on the ground. Urban transport that does leverage the sky is mostly done by helicopters. They use a single large rotor, which is not economical to operate and maintain and produces significant amounts of noise (KPMG, 2019). Besides, in urban transport in general, and air transport in particular, the control is still mainly in the hands of people. While autopilot techniques are being developed, it may still take time for traditional modes to be completely autonomous (EHang, 2020 and KPMG, 2019). Also, most of our current transport runs on fossil fuels, although there is an increasing trend towards electrically-powered motors with zero emissions for some transport modes. However, this trend has not reached large scale traditional air traffic yet, since the current battery technology is not sufficient to enable flying the required distances (Porsche Consulting, 2018). Finally, current air traffic is managed by a traditional air traffic management system.

All of these technologies make that it is currently not possible and inefficient to operate air vehicles in urban areas. New technologies are needed to change this. These can be found in Appendix D.1.

C.2 Infrastructure

Since there is currently very little air transportation in most cities around the world, the urban mobility system is mainly designed for ground transportation purposes. Therefore, current urban infrastructure exists of roads, railways and stations, waterways, sidewalks, bicycle paths, pipelines, energy grid and the like. There is not much infrastructure in place for urban air mobility. There are a few cities, like Los Angeles and Sao Paulo, that have already a considerable number of helipads, landing spots, to enable short-term UAM operations (Porsche Consulting, 2018). In parallel, there are cities like San Francisco and Paris, which have got even less infrastructure (Participant K, 2020), while most cities, at least in Europe, lack in existing helipads. There are not so much, let's say, city centred heliports (Participant B, K, 2020). There are probably some related to hospitals, but these are meant for emergency situations. So, they cannot be occupied with passenger drones in the future (Participant B, 2020). Where existing infrastructure can be found, or easily developed, that will be suitable for UAM, though, is at airports (Participant H, J, 2020).

On the other hand there are subaltern transport regimes. public transport has a negative cultural representation. It is seen as people transport, slow, infrequent, fragmented and disproprionately used by the poor, elderly and disadvantaged, etcetera (Moradi & Vagnoni, 2017 and Hodson et al., 2015).

Non-motorised transport regimes, like walking and cycling, are seen as healthy, but slow ways of mobility. They are considered travel modes of last resort (Moradi & Vagnoni, 2017).
Finally, drones are hardly part of the mobility system today. However, public opinion regarding drones is not always positive at the moment, due to concerns about improper use, use by criminals and accidents (PWC, 2019).

C.3 Markets, user practices

The user practices of existing transportation modes vary per mode, but the majority is meant to transport people and goods. Some modes, like non-motorised ones, are rather suitable to travel shorter distances, while other ones are able to travel longer distances, like the car and train. Also, some modes can be private and/or owned and may be more flexible, like cars, while other modes, like public transport, are for shared use and are less flexible.

C.4 Culture, symbolic meaning

In the current transport regime, in which automobility is the dominant mode, (owning) a car is often more than just a means of transport for consumers. It is also a symbol for freedom, choice, progress, wealth, modernity, status, convenience and speed. Furthermore, people experience positive feelings like the 'joy of driving' and 'love affair with the car' (Geels, 2012).

C.5 Industrial networks, strategic games

The notion of socio-technical regimes encompasses not only firms and the activities of engineers, but also other social groups such as users, policy makers, special-interest groups and civil society actors. This concept thus helps overcome the tendency, which is prominent in innovation studies, to view manufacturers, such as the car industry, as the pivotal actors in regimes (such as automobility). Although car manufacturers are undoubtedly an important actor (who exert much influence through their product offerings, marketing strategies and political lobbying), automobility regimes are also sustained by habits of use, prevailing normality, and mindsets and established practices of professionals, such as transport planners, whose logic and choices help to reproduce a regime (Geels, 2012).

According to Geels and Kemp (2000), in addition to designers and managers, users, policy makers and social groups (eg Greenpeace, consumer association) also influence the direction of technical development. The regime rules are therefore wider than the search heuristics and technical standards of engineers, they also include the evolved requirements of users (performance requirements), the rules of the market, the rules and regulations of governments, the procedures and views of insurance companies, banks. and providers of capital. The rules of the socio-technical regime are thus supported by a heterogeneous network of social groups (fig. 60).

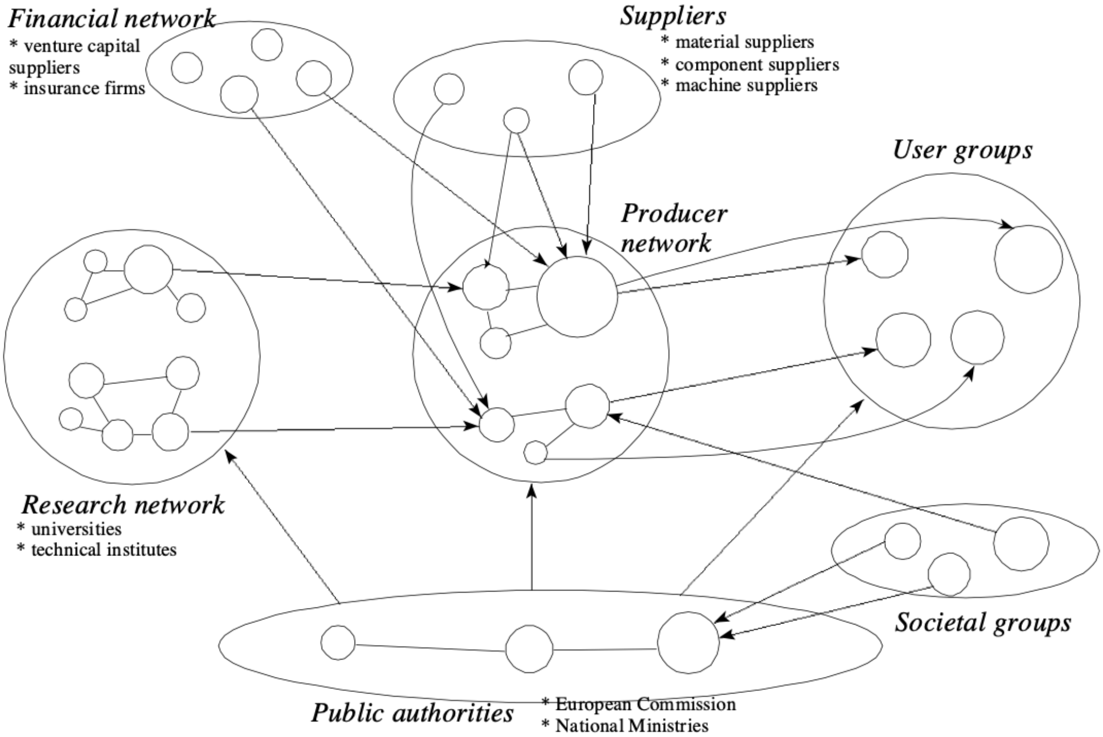


Figure 60 | The multi-actor network of a socio-technical regime (Geels and Kemp, 2000).

The European Commission (2019) identifies a wide field of actors involved in urban mobility. The main stakeholders identified include cities and their networks, stakeholders active in urban mobility and road safety fields, national and local administrations, as well as citizens living in cities.

The following stakeholders can be identified:

- Public Administrations at national, regional and local level.
- Other public sector actors such as public transport operators and authorities; police (for road safety aspects) and schools; employers, trade unions and professional organisations active in transport sector; European and international organisations dealing with transport issues;
- Citizens and organisations representing civil society, consumers and users; NGOs dealing in particular with urban mobility and environment;
- Private sector actors (and their associations) directly or indirectly affected by the UMP package, such as:
    - Businesses located in urban areas
    - Companies that are producers or consumers of urban mobility vehicles and equipment (such as ITS (intelligent transport services) technologies)
    - Operators of new mobility services (e.g. bike sharing schemes)
    - Logistics operators. (European Commission, 2019)

C.6 Sectoral policy

As a critical tool in the hands of government to influence behaviour, regulation may support, hinder or act neutrally in the adoption and development of new technology. When new products and technologies emerge, the adaptability and suitability of existing regulatory frameworks is put to the test (International Transport Forum, 2018).

As drones are the latest addition to objects flying in regulated airspace, the regulation of commercial drones at national level has typically begun with the extension of existing regulatory frameworks for the aviation sector to commercial drone operations, given the similarities between manned and unmanned aircraft (Jones, 2017). However, regulatory regimes designed for different and older technologies are in many instances not adapted to many drone use cases. In some cases, drones may be in a regulatory void with very little control over their particular conduct. As a result, aviation standards, laws and regulatory approaches require constant updating (Clarke and Bennett Moses, 2014).

Currently aviation is built on the development of international standards, translated into national laws that enable such a global industry to operate in a very similar fashion around the world (International Transport Forum, 2018). The fragmentation of national regulations clearly reflects different sensitivities to the public safety risks posed by drones. However, it may also slow down the uptake of drone technologies in countries with the most restrictive regimes and could render operations economically unviable in countries with very high regulatory requirements (EH, 2020).

Right now there are only limited regulations for very specific occasions that allow you to actually operate a drone and especially passenger drones (Participant B, 2020). For example, it is forbidden to land in cities like San Francisco and Paris (Participant K, 2020). At the national level, the rationale for updating and even introducing regulations when dealing with commercial drones is mainly underpinned by public safety and security concerns (Stöcker et al., 2017). Similarly to existing aircraft, drones can pose threats to people and property in the case of technical failures, collisions or hijacking. However, in contrast with manned aircraft, drone activity is more heterogeneous and is therefore harder to anticipate. In addition, the costs of detecting drones violating rules and related investigations are higher (Clarke and Bennet Moses, 2014).

National regulations have to date displayed a wide range in their level of restrictiveness of drone activity, going from effectively banning commercial drones licensing to promoting very permissive regimes. In the space of a few years, the different national regulations adopted across the world have shown considerable divergence. The main areas of dissent have emerged around:

- BVLOS operations: "Beyond visual line of sight" means flying an unmanned aircraft without the pilot having to keep the unmanned aircraft in visual line of sight at all times. This means that the drone's remote pilot must be able to respond to or avoid other airspace users by visual means as the safest way to reduce the risk of collisions and other accidents. The number of countries offering derogations and allowing BVLOS under special permits has increased in recent years, but the basic requirement of VLOS has remained in place in most countries.
- Flying over populated areas: the second most common restriction to commercial drones is the operational ban over populated areas, usually cities and large public events. While it is not difficult to understand why such restrictions are in place, they also limit drone operations where their benefits may be highest: in urban settings (International Transport Forum, 2018).

Other common elements of recently approved drone regulations include:

- Administrative rules (e.g. pilot's licence and training, aircraft registration, insurance requirements)
- Operational limitations (e.g. maximum weight, flight altitude restrictions)
- Airspace management rules (e.g. flight authorisation, restricted flying zones, maximum altitude) (Jones, 2017; Stöcker et al., 2017).

The proliferation of national rules and laws in recent years also highlights one of the main issues that regulators are grappling with while they try to promote the safe use of commercial drones: that the potential damage of incidents involving drones is also largely unknown given the absence of historical records. The weight of commercial drones may be only one of the criteria determining their potential damage and hence appropriate insurance requirements, for example; other factors such as speed, the material and characteristics of the airframe and the presence of parachutes also play a role (International Transport Forum, 2018).

This diversity also reflects the reality that there are various categories of commercial drones, differing in size (weight), flight altitude, the role of the pilot (if any), the degree of autonomy and the purpose of the drone operation. The requirements across administrative, operational and airspace rules are modulated based on the different characteristics of commercial drones in most national regulations (International Transport Forum, 2018).

For a global summary, the most comprehensive review of national regulations carried out to date (Jones, 2017) identifies a handful of countries where outright bans (e.g. Argentina, India, Morocco) or effective bans due to very restrictive regulations (e.g. Chile, Colombia, Nigeria) are in place and no commercial flights have been approved. Next, around 20 countries permit drone use for commercial purposes under the requirement of VLOS and a limit of one drone per pilot. Population restrictions often accompany VLOS and experimental BVLOS operations – these are allowed in 11 countries, including the United States, on a case-by-case basis. In countries like France, Canada and Poland drones cannot fly over heavily populated areas and are only allowed in certain zones. Towards the more permissive end of the spectrum, in China, administrative rules vary significantly depending on the mass and type of drones but operations including BVLOS are authorised once all requirements are complied with. Drone delivery is explicitly banned, however. National regulations are in constant flux, resulting in most recent changes across the whole spectrum from abolishing flight bans (e.g. in India) to establishing procedures to allow flights over heavily populated areas, e.g. for France (International Transport Forum, 2018).

C.7 Techno-scientific knowledge

A broad field of knowledge is required in the transportation domain. Looking at transport as a socio-technical system, knowledge is needed with regard to the vehicles, supporting infrastructure, markets and user practices, the actor network, policies and culture, among others (Geels, 2005).

Appendix D: A vision for the future of UAM

D.1 Vehicles

The technology dimension exists of hardware and software components. The most prominent part of the technology is of course the vehicle. To execute this kind of operations, new vehicles are required, of which many are currently in development.

The design of the aircraft system is critical, and companies in this field are experimenting with several aerodynamic concepts. In general, five major aircraft systems can be distinguished (fig. 61). Each system has its own pros and cons when it comes to time to market, travel speed, ideal routes, efficiency, and potential market size (Porsche Consulting, 2018). Highly distributed propulsion concepts or multicopters are wingless aircraft concepts with room for two to four passengers in general. They have more than four fixed propellers, often arranged in a ring around or atop the cabin. Flight control is accomplished by varying the speed of the individual rotors. Multirotor systems have the twin advantage of being fairly simple and offering safety through redundancy. On the downside, they are hampered by lower travel speeds of 80 to 100 km/h. Initial multirotor systems, however, have a low risk profile and will help define future standards in a step-by-step process. Examples of this aircraft concept are camera drones or aircraft by the German startup Volocopter (Roland Berger, 2018; Porsche Consulting, 2018).

Quadcopters are wingless aircraft concepts with four fixed propellers, possibly arranged as four sets of push-pull propulsion groups. They can carry between two and six passenger at speeds of 120 to 150 km/h. Examples of these concepts are EHang 184, CityAirbus and Pop.Up Next (Roland Berger, 2018).

Hybrid concepts center around aircraft with fixed forward-facing propellers for forward movement and upward-facing/retractable propellers to generate lift during the take-off and landing phases. The hybrid model allows them to take advantage of the respective properties of fixed-wing and rotor aircraft. Wings give them longer range, while rotors enable them to vertically take off and land more efficiently and maintain a higher airspeed of 150 to 200 km/h. The basic technologies of both elements are already available, and the overall complexity of hybrid models is in the middle range, depending on a particular system's design. Next-generation hybrid drones can be considered the second phase in eVTOL aircraft development as they offer increased speed and efficiency. They provide more time savings and lower operational costs, two key drivers for commercial success in comparison to other modes of transportation Between two and four passengers can fly in these vehicles. Uber Air is an example of this approach (Roland Berger, 2018; Porsche Consulting, 2018).

Tilt-wing or convertible aircraft concepts cater to between two and four passengers. They have several propellers or ducted fans that can be tilted at different angles for fixed or tilting wings to achieve the different configurations needed for take-off, landing, flying and hovering. Since they have rotating components that need to reliably and safely handle the transition from the lift to the cruise phase, the complexity of tilt-x systems is significantly higher. By design, tilting wings, tilting rotors, or tilting ducts carry a higher risk of a single point of failure. As such, the underlying technology cannot currently be considered mature enough to handle passenger transport under critical weather conditions and requires further development to satisfy safety requirements. At the same time, Tilt-x aircraft can cover long distances at high speeds of of 180 to 250 km/h and therefore have clear potential for mobility services. Airbus's Vahana is one example (Roland Berger, 2018; Porsche Consulting, 2018).

Finally, fixed-wing vectored thrust concepts are equipped with variable-direction fans. They too can accommodate two to four passengers and can fly at 200 to 300 km/h. One of the best known examples of such a concept is the Lilium Jet (Roland Berger, 2018).

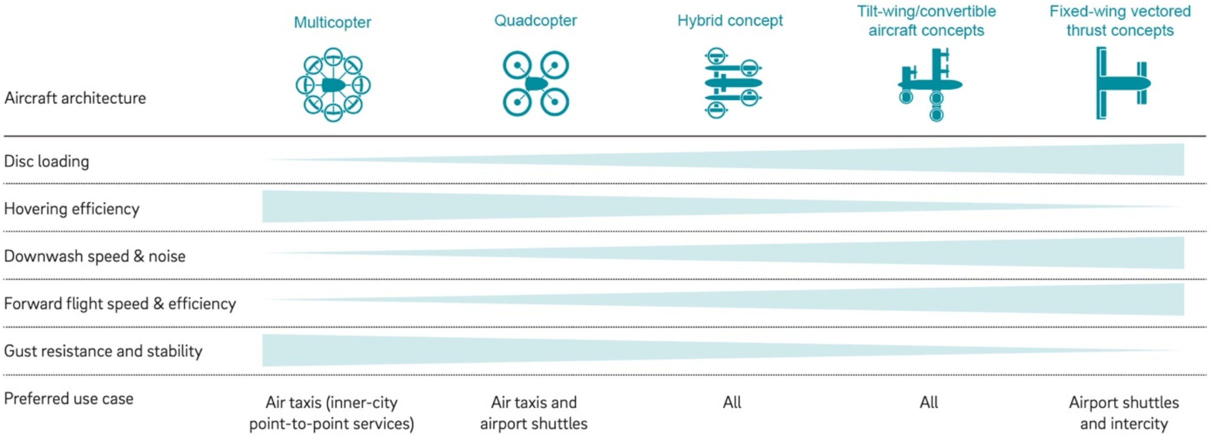


Figure 61 | Faster and further: the five basic aerodynamic concepts for drones, each with pros and cons (Roland Berger, 2018).

Regardless of the particular system, eVTOL aircraft will be an improvement. Even in this technological day and age, vertical mobility has remained the exclusive domain of the wealthy. Helicopters are not only expensive but also noisy and unsafe compared to other modes of transportation. It is also not available to the average consumer as an on-demand option. Compared to a traditional helicopter, an electric passenger drone is by orders of magnitude quieter, more reliable, safer, and less expensive. In the longer term, passenger drones should produce less than ~70 dB(A) of noise on a distance of 100 metres versus ~90 dB(A) of noise by a helicopter. Reliability should be 15 times higher, and eVTOL's should be two times safer. Also, the price level should become competitive to that of a traditional taxi (Roosien and Bussink, 2018; Crown Consulting, 2018; Porsche Consulting, 2018 and Uber Elevate, 2016).

These vehicles require all kinds of hardware and software components, presented in table 27, that are needed for the safe, autonomous, sustainable, responsible and efficient operations of the vehicles.

Necessary technologies for Urban Air Mobility	
Autonomy	**Safety**
Detect and avoid	Advanced vehicle safety systems
Vehicle autonomy and conflict resolution	Crashworthiness and survivability
System resiliency	**Pilot training**
Verification and validation methods	Pilot training methods
GPS-denied	Flight simulators
Highly automated architectures	**Certification**
Sensing	Airworthiness standards
Sensing system capabilities requirement	**Communications**
Lidar	Information Exchange, Data bandwith
Camera, image sensing	**Controls**
Flight and health management	Adaptive controls
Weather detection	Guidance and control software
Cybersecurity	Command, control and communications
Cybersecurity, cyber-physical detection	**Operations**
Propulsion	Ridesharing technologies
Electric propulsion	**Traffic management**
Hybrid-electric propulsion	Unmanned air traffic management
Energy storage	Navigation
High Specific Energy Batteries	**Infrastructure**
Emissions	Energy grid infrastructure
Active noise control	Vehicle charging infrastructure
Structures	Smart city
Multifunctional Structures	Vertiport technologies
Advanced materials	

Table 27 | Necessary technologies for UAM, identified by Crown Consulting (2018).

In this thesis, two parts of the technology of UAM are most relevant for further explanation: the vehicles and infrastructure. UAM vehicles are flying vehicles that transport either passengers or freight on specific and quick point-to-point routes within and between urban areas. Due to the constraints of buildings, plants, road traffic and crowds in cities, the ideal vehicle models need to be autonomous, small, efficient, nimble, manoeuvrable, sustainable and shared, with the ability to take off and land vertically (as opposed to with a runway) (EHang, 2020).

Different eVTOL vehicles are proposed by different companies. In figure 62, a selection of some of the better-known vehicles is given. Some information about these vehicles can be found in table 28.

Figure 62 | Different vehicles for Urban Air Mobility. Sources: Adams (2019), Hawkins (2020), "EHang" (n.d.), Bell Flight (n.d.), Kitty Hawk (n.d.), Palmer (2019), Lilium (n.d.), Airbus (n.d.), Volocopter (n.d.), Joby Aviation (n.d.) and EHang (2020).

Table 28 | Different vehicles for Urban Air Mobility. Sources: Adams (2019), Hawkins (2020), "EHang" (n.d.), Bell Flight (n.d.), Kitty Hawk (n.d.), Palmer (2019), Lilium (n.d.), Airbus (n.d.), Volocopter (n.d.), Joby Aviation (n.d.), EHang (2020), Polaczyk et al (2019), Bartini (n.d.), Opener, (n.d.), Uber Elevate (2016).

	Lilium	**Aurora**	**Kitty Hawk**
Aircraft design	Fixed-wing vectored thrust concept	Hybrid	Hybrid
Capacity	5 persons	2 persons	2 persons
Power type	Electric	Electric	Electric
Battery capacity	320 kWh		63 kWh
Max. payload		225 kg	181kg
Weight	2000 kg	800 kg	1,224 kg
Range	300km	80km	100km
Cruise speed	300km/h	180 km/h	180km/h
Flight time	60 min		
Altitude			
Size (HxLxW)			H x L x 11m
Noise*			"100 times quieter than a regular helicopter"
	Volocopter	**Bell Nexus**	**Uber Air | Hyundai**
Aircraft design	Multicopter	Tilt-wing	Hybrid
Capacity	2 persons	5 persons	5 persons
Power type	Electric/batteries	(Hybrid-)Electric	Electric
Battery capacity			
Max. payload	200kg		
Weight	900kg	2,750kg	
Range	35km	240km	100km
Cruise speed	110km/h	240km/h	290km/h
Flight time			
Altitude	2,000m		300-600m
Size (HxLxW)	2.15m x 3.2m x 9.15m		
Noise*	72-75 dB(A)		"less noise than a combustion engine helicopter"
	Airbus (Vahana)	**EHang**	**Joby Aviation**
Aircraft design	Tilt-wing	Quadcopter	
Capacity	1 person	1 person	5 persons
Power type	Electric	Electric	Electric
Battery capacity		14.4-17 kWh	
Max. payload	340kg	100 kg	
Weight	1,066kg	260 kg	
Range	50km	30-40km	240km
Cruise speed	220km/h	160km/h	320km/h
Flight time			
Altitude	3,000m	500m	
Size (HxLxW)	2.81 x 5.86 x 6.25m	1.76m x 5.61m x 5.5m	
Noise*	"Less noise than traditional helicopters"		"The aircraft is 100 times quieter than conventional aircraft during takeoff and landing, and near-silent when flying over."

Table 25 | (continued)

	Bartini Flying Car	**Davinci ZeroG**	**Opener Blackfly**
Aircraft design	Tilt-wing	Multicopter	Hybrid
Capacity	4 persons	1 person	1 person
Power type	Electric	Electric	Electric
Battery capacity	64 kWh	52.8 kWh	12 kWh
Max. payload	400 kg	150 kg	
Weight	1,100 kg	240 kg	142 kg
Range	150km		64 km
Cruise speed	300km/h	70km/h	128 km/h
Flight time	30 min	25 min	30 min
Altitude	1,000m		
Size (HxLxW)			
Noise*			
	Pop.up Next	CityAirbus	**Uber reference eVTOL**
Aircraft design	Quadcopter	Quadcopter	
Capacity	2 persons	4 persons	4 persons
Power type	Electric	Electric	Electric
Battery capacity	70 kWh	110 kWh	140 kWh
Max. payload			
Weight		2,200 kg	1,800 kg
Range	50 km	30 km	
Cruise speed	150 km/h	120 km/h	
Flight time		15 min	
Altitude			
Size (HxLxW)			
Noise*			
* As a reference: the Bell 407 helicopter produces 87 dB(A) on a 120m distance.			

D.2 Infrastructure

Infrastructure is needed to accommodate UAM. The development of infrastructure to support an urban VTOL network will likely have significant cost advantages over heavy-infrastructure approaches such as roads, rail, bridges and tunnels. As costs for traditional infrastructure options continue to increase, the lower cost and increased flexibility provided by these new approaches may provide compelling options for cities and states around the world (Uber Elevate, 2016).

For the operation of Urban Air Mobility, proper take-off and landing zones, battery charging stations and a sufficient energy network are the most critical infrastructure elements.

D.2.1 Landing infrastructure

The crucial component in the success of vertical mobility is the (ground) infrastructure that these vehicles need to take off, land, charge, and service a drone as well as park it in wait for passengers. From their location and number to their size, eVTOL landing sites, or vertiports, are a determining factor for the ecosystem. A city needs to have sufficient sites for take-off and landing as well as charging, in addition to the necessary resources to operationalize air traffic control. Finally, urban eVTOL infrastructure has to strike an acceptable balance between benefits and disturbances, such as defining and zoning the proper use of rooftops (Porsche Consulting, 2018). A wide network of landing infrastructure would require either new infrastructure or existing infrastructure, such as helipads, rooftops of large public buildings, and unused land, to be modified. Take-off and landing stations infrastructure—or "vertiplaces"—for both people and cargo are currently divided into three broad categories: vertihubs, vertiports and vertistops (fig. 63).

Vertihubs

Akin to small airports for eVTOLs, vertihubs—located on the periphery of urban or suburban areas—would likely be the biggest UAM ground infrastructure. In addition to being a pickup and drop-off site for people and cargo, a vertihub could serve as a central site for eVTOLs flying in a specific geographical area, with at least one vertihub in each city. Operators would need to outfit vertihubs with infrastructure for maintenance, repair, and overhaul (MRO) operations for the fleet, parking spaces for longer-haul eVTOLs, and a centralized citywide operations control system. Vertihubs could be designed to meet fleet service requirements—and for resilience, to ensure continuity of operations could be maintained during an unplanned disruption. Considerations would have to be made beyond fleet operations, such as providing office space for staffers as well as training and accommodations for pilots and service engineers (Lineberger et al., 2019).

Vertiports

Ideally, these take-off and landing pads would be constructed and/or placed in the heart of a city and serve as major sites for both cargo and passenger on-boarding and off-boarding and take-offs and landings. As such, operators would need to place them in and around primary destinations such as central business districts, shopping centers, and other transportation such as trains and subways, since the first and last part of the passenger journey and cargo delivery should be integrated with other modes of ground transportation. Vertiports will likely need to accommodate multiple eVTOL vehicles at any given time but could nevertheless require significantly less space than the vertihubs. Vertiports could be equipped with fast charging/refueling systems, have basic security checkpoints, and the capacity to carry out minor MRO operations, but they will likely not feature parking spaces for long-haul eVTOLs or full-fledged MRO stations. However, since vertiports would ideally handle comparatively large numbers of passengers, there could be a need for customer waiting lounges and ground staff to coordinate seamless boarding—and systems for fire safety, access control, and real-time surveillance (Lineberger et al., 2019).

Vertistops

Vertistops would be the smallest element of the network of vertiplaces, typically containing just one or two landing pads. Considering the smaller footprint, operators could build these relatively easily, perhaps using helipads already in use. As vertistops would be peripheral infrastructure, no primary charging or parking points would be needed at the site, though basic customer service capability—weather monitoring systems, waiting areas, security checkpoints, help desks, etc.—should be considered. As installation costs would be comparatively low, these facilities could extend operators' reach into suburban areas. Moreover, given the location and available facilities at each of these landing areas, cargo pickup and delivery services could be smoothly integrated with the existing infrastructure (Lineberger et al., 2019).

Deloitte's research findings suggest that neither government agencies nor private sector firms—in engineering, procurement, and construction—are widely discussing how to proceed with ground infrastructure. While build-out of this infrastructure poses a significant challenge due to space availability and cost, it potentially represents a significant new market opportunity. Public-private partnerships, along with utilizing a range of cost-sharing and revenue-sharing models, may help overcome cost barriers (Lineberger et al., 2019).

Taking urban transportation to the skies would require an integrated and robust city infrastructure

Source: Deloitte analysis.

Deloitte Insights | deloitte.com/insights

Figure 63 | Taking urban transportation to the skies would require an integrated and robust city infrastructure (Lineberger et al., 2019).

D.2.2 Charging infrastructure

As eVTOL vehicles need energy to carry out their services, charging infrastructure is needed to recharge the vehicles when they have run out of energy. Since most cases assume that these vehicles will be electrically driven, this research adopts the same assumption (although there are some initiatives that propose vehicles flying on hydrogen). Charging infrastructure will usually be integrated with the landing infrastructure. Currently, different charging options are considered, like direct charging from the grid with a mix of fast and conventional slow chargers, inductive charging or a battery swapping system. Because of the nature of the operations, the vehicles will need to be charged very quickly with high levels of power (Participant I, 2020).

D.2.3 Energy grid infrastructure

This requires upgrades to the existing energy grid (Participant I, 2020), that will guarantee a sufficiently working energy grid, and thereby the supply of electricity to enable Urban Air Mobility.

D.2.4 Other infrastructure

Besides, other infrastructure components are needed. To create a truly unified traffic management system, additional infrastructure may need to be installed along predefined flight corridors to aid high-speed data communications and geolocation (Crown Consulting, 2018; Lineberger et al., 2018; Roland Berger, 2018; Porsche Consulting, 2018). Also, service centres and docking stations will be needed for passenger drones (Crown Consulting, 2018). All these infrastructure changes must be implemented and will have an impact on the urban environment, asking for the collaboration of commercial stakeholders and the local urban planning authorities.

D.3 Markets, user practices

UAM will open up new markets in (urban) mobility. There is a large variety of applications to imagine. Depending on vehicle technology, operations, economics and market size, Urban air transportation could take many forms. There is a variety of segments and services of vertical mobility (fig. 64). As described in Table 29, Booz Allen Hammilton (2018) identified 36 potential UAM markets across 16 market categories. but in this thesis the focus is on passenger drones. Passenger drones satisfy intracity and longer city-to-city transportation needs. As the name implies, passenger drones are designed to transport one to five private passengers and offer mobility services to the broader public. Emergency services, airport shuttle, intra-city air taxi, and intercity air taxi are widely considered to become the most viable and largest use cases, carrying one to five passengers on trips between 20 to 80 kilometres (or more), and will likely be introduced in that order. Sometimes they will be on demand and point-to-point, while other times they can be scheduled with pre-determined routes (Roosien and Bussink, 2018; Crown Consulting, 2018; Booz Allen Hamiltion, 2018; Roland Berger, 2018; Porsche Consulting, 2018; KPMG, 2019; EHang, 2020; Volocopter, 2019 and Uber Elevate, 2016).

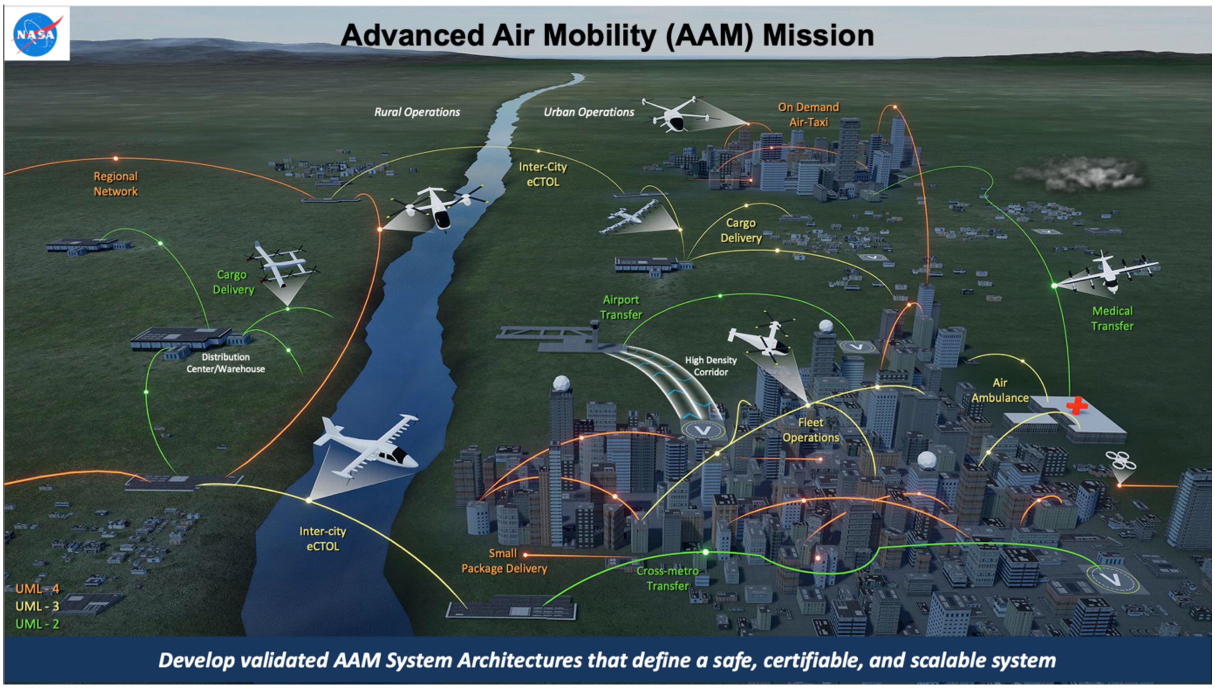


Figure 64 | Urban Air Mobility (or Advanced Air Mobility) can take many forms (NASA).

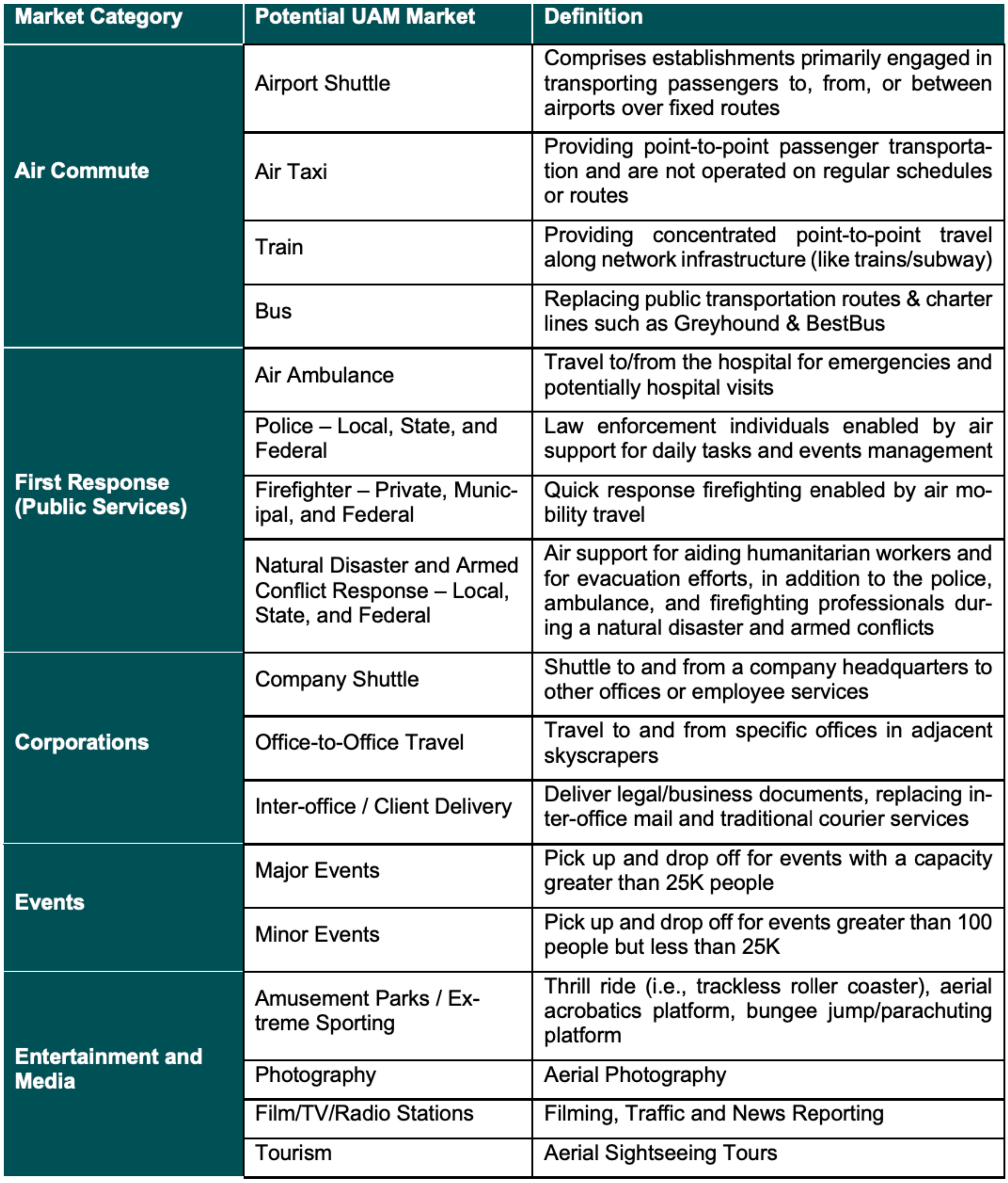
The first business model includes emergency response vehicles for the different emergency services. eVTOL vehicles could potentially offer similar capabilities as existing helicopters but with increased flexibility, lower operator requirements (due to automation), lower operating cost (due to mechanical simplicity) and a lower noise footprint. Together with air taxi services, this model is predicted to be the premier way to enter the UAM market. In comparison to air taxi services, the requirements regarding (operational) cost are higher, but public acceptance is likely to be easier (Roosien and Bussink, 2018). This is a complex market that includes travel to/from the hospital for emergencies and potentially hospital visits. The Air Ambulance market is concentrated; however, the services offer a high value. This market is driven by demographic trends, healthcare legislations, and changes in insurance policies.

‘Another one is the air taxi. So for example, you fly from one part of the city to another part of the city, where you would normally take a taxi ride. But this would be faster, because you skip all the traffic.’ (Participant B, 2020). Out of the 36 potential UAM markets, across 16 market categories, that Booz Allen Hamilton (2018) identified, they also selected the air taxi as one of the three use cases with the highest potential. Crown Consulting (2018) holds the same opinion, while the (intra-city) air taxi is also the use cases Volocopter (2019), one of the leading eVTOL manufacturers, focuses on. The air taxi use case is characterised by on-demand point-to-point non-stop service from one destination to another, generally within the same metropolitan area. It is optimally used on short distances between two landing sites (15 to 50 kilometres), with a fluctuating medium/high demand between the two landing sites. Disadvantages of this use case are, at first, that the schedule frequency depends on the number of air taxis. Secondly, a high number of routes and landing sites are needed to create a sufficient network that covers all points. Finally, sufficient airspace without any restrictions is required to to make use of direct point-to-point network. Advantages of this use case are the high network coverage and the fastest travel times between two points that it would deliver (Roland Berger, 2018).

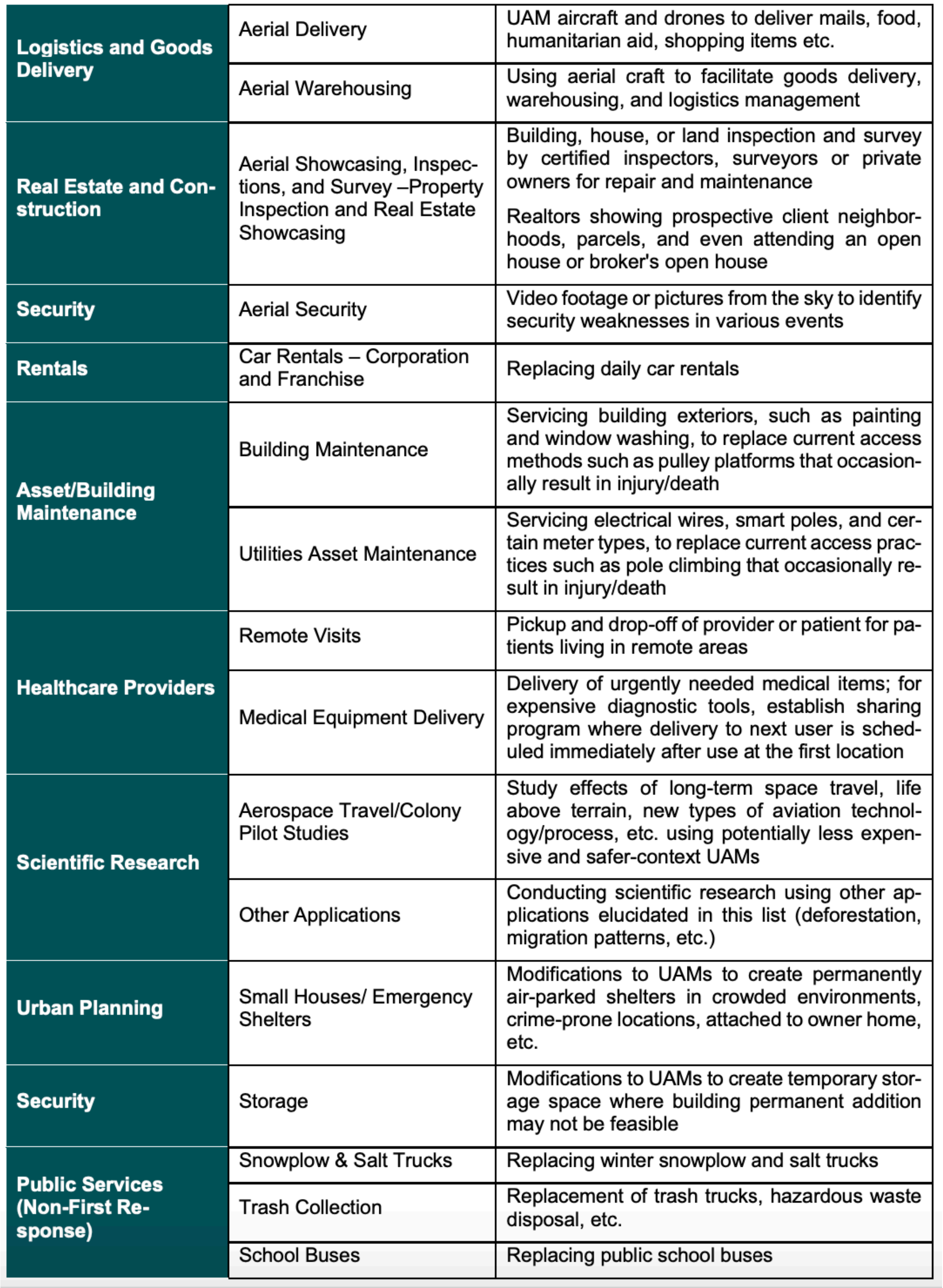
‘A third use case is the airport shuttle. Most of the cities have an airport between 20 to 40, 50 kilometres from the city centre, so that would be quite a nice use case, to take a drone from the airport to the city centre and the other way around to get quickly to and from the airport. This is especially attractive to business travellers.’ (Participant B, 2020). In fact, this use case is a very specific derivative of the air taxi use case. This is also stated by Volocopter (2019), who consider this as an interesting use case as well. It is also mentioned by Booz Allen Hamilton (2018) as a use case with a high potential. This use case would execute scheduled operations with fixed flight plans and pre-booked flights, where the flight schedule would be adjusted to arrival and departure times of the airport. An advantage of this use case is the fact that foundational infrastructure for takeoff/landing areas already exists on at least one side of the flight, strategically located very close to terminal and gates. As such, it will likely become the Fastest transportation option between airport and city. Besides, concentrating the demand at one end of the flight could reduce complexity of supply/demand matching and increase the operational efficiency. Disadvantages could be the problematic interference with commercial airline operations and scheduled operations (Roland Berger, 2018 and Booz Allen Hamilton, 2018). All in all, the research findings suggest that this airport shuttle use case will probably be the first UAM use case that will take off: ‘I do think the airport shuttle market will be the easiest market to start with.’ (Participant H, 2020).

‘And then the last use case is what we call intercity, for example when Urban Air Mobility would serve as a substitute for commuter. So, for example, you would travel from the city centre to some smaller cities or villages in the nearby metropolitan area. Which would be for example up to 80 kilometres away from the city centre.’ (Participant B, 2020). This use case is in fact an extended version of the air taxi and covers longer distances, like 50 to 250 kilometres, that are too short to be viable for regular aviation links. ‘On a certain moment, it won’t be strange any more to make a trip from Arnhem to Bremen, or from Rotterdam to Amsterdam, by a flying vehicle. Or you could live in Heerenveen and commute to Amsterdam’ (Participant G, 2020). This use case is, next to the airport shuttle, mentioned most often by the interviewees. It enables very fast connections between (sub)urban areas and on under-served routes, without the need of much infrastructure. ‘The interesting thing is now that these different polycentric parts of an urban area can suddenly become just as connected as the old city centre, because with UAM you can connect any point to any point.‘ (Participant J, 2020). Scheduled operations with predictable demand can be seen as another advantage. Possible disadvantages are the alternate landing sites that will be required along the way in case of emergency and the fact that the long flight times pose challenges to the current technology (Roland Berger, 2018 and Uber Elevate, 2016).

Table 29 | Potential UAM markets (Booz Allen Hammilton, 2018).



Market Category	Potential UAM Market	Definition
Air Commute	Airport Shuttle	Comprises establishments primarily engaged in transporting passengers to, from, or between airports over fixed routes
	Air Taxi	Providing point-to-point passenger transportation and are not operated on regular schedules or routes
	Train	Providing concentrated point-to-point travel along network infrastructure (like trains/subway)
	Bus	Replacing public transportation routes & charter lines such as Greyhound & BestBus
First Response (Public Services)	Air Ambulance	Travel to/from the hospital for emergencies and potentially hospital visits
	Police – Local, State, and Federal	Law enforcement individuals enabled by air support for daily tasks and events management
	Firefighter – Private, Municipal, and Federal	Quick response firefighting enabled by air mobility travel
	Natural Disaster and Armed Conflict Response – Local, State, and Federal	Air support for aiding humanitarian workers and for evacuation efforts, in addition to the police, ambulance, and firefighting professionals during a natural disaster and armed conflicts
Corporations	Company Shuttle	Shuttle to and from a company headquarters to other offices or employee services
	Office-to-Office Travel	Travel to and from specific offices in adjacent skyscrapers
	Inter-office / Client Delivery	Deliver legal/business documents, replacing inter-office mail and traditional courier services
Events	Major Events	Pick up and drop off for events with a capacity greater than 25K people
	Minor Events	Pick up and drop off for events greater than 100 people but less than 25K
Entertainment and Media	Amusement Parks / Extreme Sporting	Thrill ride (i.e., trackless roller coaster), aerial acrobatics platform, bungee jump/parachuting platform
	Photography	Aerial Photography
	Film/TV/Radio Stations	Filming, Traffic and News Reporting
	Tourism	Aerial Sightseeing Tours



Logistics and Goods Delivery	Aerial Delivery	UAM aircraft and drones to deliver mails, food, humanitarian aid, shopping items etc.
	Aerial Warehousing	Using aerial craft to facilitate goods delivery, warehousing, and logistics management
Real Estate and Construction	Aerial Showcasing, Inspections, and Survey –Property Inspection and Real Estate Showcasing	Building, house, or land inspection and survey by certified inspectors, surveyors or private owners for repair and maintenance Realtors showing prospective client neighborhoods, parcels, and even attending an open house or broker's open house
Security	Aerial Security	Video footage or pictures from the sky to identify security weaknesses in various events
Rentals	Car Rentals – Corporation and Franchise	Replacing daily car rentals
Asset/Building Maintenance	Building Maintenance	Servicing building exteriors, such as painting and window washing, to replace current access methods such as pulley platforms that occasionally result in injury/death
	Utilities Asset Maintenance	Servicing electrical wires, smart poles, and certain meter types, to replace current access practices such as pole climbing that occasionally result in injury/death
Healthcare Providers	Remote Visits	Pickup and drop-off of provider or patient for patients living in remote areas
	Medical Equipment Delivery	Delivery of urgently needed medical items; for expensive diagnostic tools, establish sharing program where delivery to next user is scheduled immediately after use at the first location
Scientific Research	Aerospace Travel/Colony Pilot Studies	Study effects of long-term space travel, life above terrain, new types of aviation technology/process, etc. using potentially less expensive and safer-context UAMs
	Other Applications	Conducting scientific research using other applications elucidated in this list (deforestation, migration patterns, etc.)
Urban Planning	Small Houses/ Emergency Shelters	Modifications to UAMs to create permanently air-parked shelters in crowded environments, crime-prone locations, attached to owner home, etc.
Security	Storage	Modifications to UAMs to create temporary storage space where building permanent addition may not be feasible
Public Services (Non-First Response)	Snowplow & Salt Trucks	Replacing winter snowplow and salt trucks
	Trash Collection	Replacement of trash trucks, hazardous waste disposal, etc.
	School Buses	Replacing public school buses

Agriculture	Flock Tending	Reaching remote flocks for herding, medical care
	Harvesting	Reaching less-accessible farmland for planting, harvesting, potable water
	Landscaping	Replacing ladders and tree-climbing assists with UAMs for tree limb removal

D.4 Culture, symbolic meaning

The public's perceptions and opinions about vertical mobility vary from continent to continent, from country to country, and from city to city, covering everything from fear and scepticism to outright enthusiasm (Porsche Consulting, 2018). Therefore, it turns out that the symbolic meaning that UAM will have for people can be twofold, partly positive and partly negative. In the vision of the future, the positive meaning must prevail if UAM is to be socially accepted. Sectoral policy and stakeholder engagement can play an important role in this during the process. So, it's up to the cities and regions that are planning to implement the technology to start educating their populous and engage their populous on the technology, so they see it as a positive and not a negative thing (Participant E, H, 2020).

On the plus side, UAM mainly represents speed and connectivity. It is a form of urban mobility that will be faster than the alternatives (Crown Consulting, 2018). Given the cultural preference for speed and time savings, this can be of great significance for people (Geels, 2012). UAM will ensure that people can save travel time and cover longer distances in the same time, which can give them additional opportunities. It allows to make quick connections from almost every location to every location, and amenities can come more within reach (Participant B, E, F, G, J, 2020).

On the negative side, however, drones are often thought of as nuisances. This has to do with aspects such as security, privacy, noise nuisance and horizon pollution, but also social tension. If you imagine now there will be drones on a very low flight level in the city, most people will be annoyed because of the noise pollution, especially during take-off and landing. Therefore, there might be a concern from private citizens, especially very early on about having vertiports near their residential areas (Participant B, C, G, H, I, 2020; Crown Consulting, 2018; Porsche Consulting, 2018). Also, where currently hardly any vehicles fly through the urban skies, this will change considerably when UAM becomes a reality. Most inhabitants of a city simply may not want to imagine a sky where maybe hundreds of (unfamiliar) drones will be flying (Participant B, G, H, L, 2020; Crown Consulting, 2018; Porsche Consulting, 2018 and Cremer et al., 2020). Then there is the safety aspect. Typically, the drone related advertising people see is negative. They often see reckless drone flights, which does not contribute to the idea of safe air transportation. Also, when you imagine that an incident, like a crash, happens, the interest by people will likely decrease and they will say it is too dangerous and do not want to fly on a drone flight over populated areas (Participant B, C, D, E, 2020; Crown Consulting, 2018; Porsche Consulting, 2018; Booz Allen Hammilton, 2018 and Cremer et al., 2020). Another aspect is the privacy issue. People often associate a drone with infringement of their privacy (Participant H, 2020; Crown Consulting, 2018). Finally, passenger drones will not sell for five dollars a ride. Especially in the beginning, it will be quite more expensive than any cab ride, and especially more expensive than public transportation. In the long-term, it is doubtful if the price will become below the price level of a taxi. Therefore, the people who actually can afford it may be limited, and then of course it becomes a luxury good. There is a risk that it will become a symbol for the wealthy (Porsche Consulting, 2018), and a sort of a class distinction arises where upper class higher income individuals are avoiding traffic and they are flying, while middle class and lower class people are being stuck in traffic. This could cause social tension (Participant B, H, I, J, 2020).

To conclude this, passenger drones will mean speed, connectivity and convenience, but also nuisance. Care must be taken not to let the negative properties get the upper hand. How this will develop with regard to the symbolic meaning, will depend on how the use of drones is framed over the upcoming years.

D.5 Industrial networks, strategic games

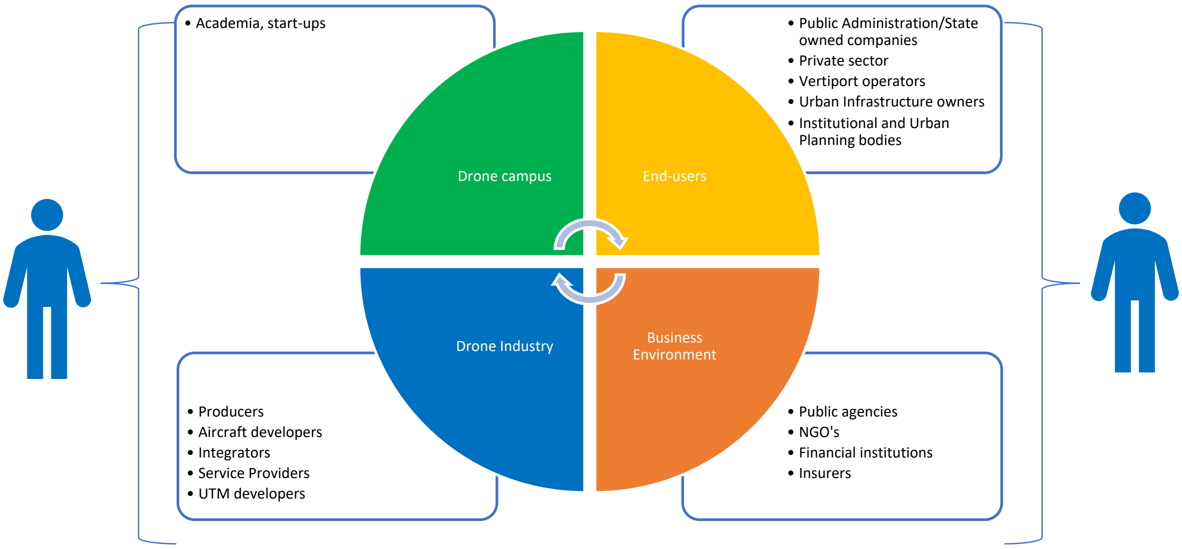


Figure 65 | Actor network of Urban Air Mobility.

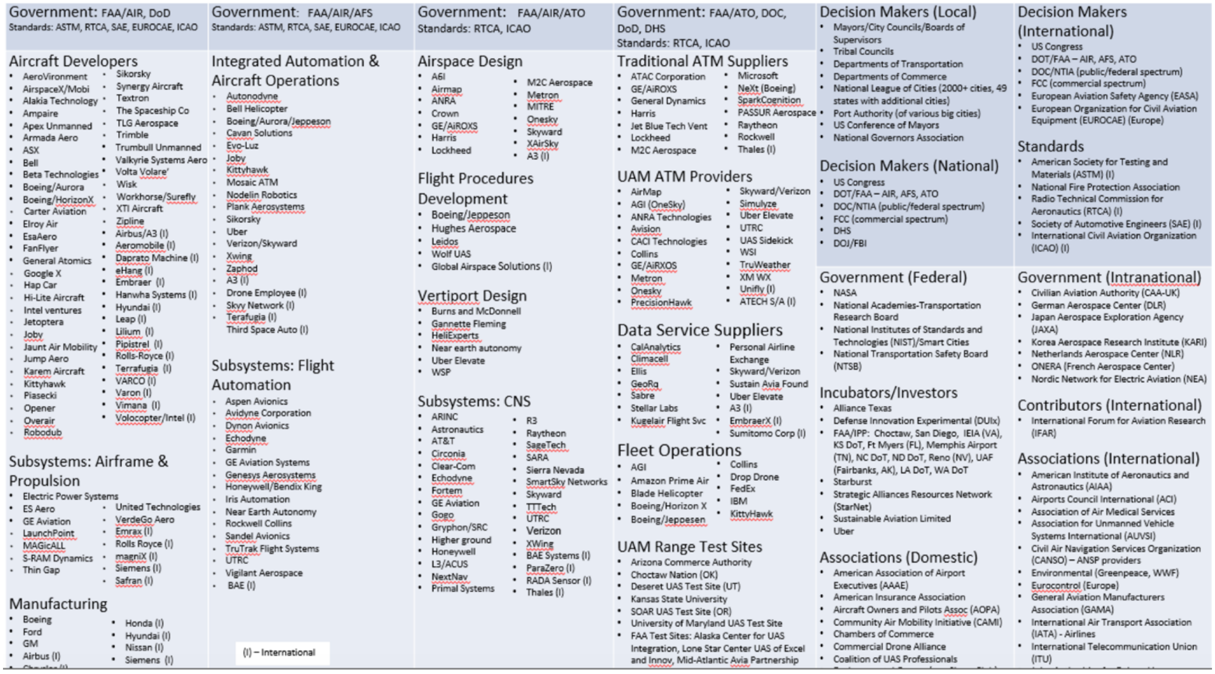
Based on the ADVANCED AIR MOBILITY (AAM) ECOSYSTEM WORKING GROUPS, organised by NASA, and the Amsterdam Drone Week, insight in the stakeholder network of Urban Air Mobility was obtained. It turns out that a wide range of actors must be involved, which can be divided over the five different pillars that are distinguished by NASA. It was decided to use this framework to describe the stakeholder network of UAM. Among the actors are new players that did not exist before, players that are new in the particular field of urban mobility and (traditional) players that were already present in this field. Within the pillar of Vehicle Development and Production, there are existing aircraft developers, such as major players like Airbus, Boeing, and Bell Flight, but also new aircraft developers such as EHang, Joby Aviation and Volocopter. Nor should we be surprised if traditional car manufacturers join this group, such as Hyundai, which has partnered with Uber.

The aircraft developers (and producers) are supported by parties that are responsible for, among other things, electric propulsion technologies. Among them are companies such as Rolls Royce and Siemens. In the pillar of Individual Vehicle Management and Operations, they are supported by stakeholders that work on making automated flight a reality.

In the pillars of Airspace System Design and Implementation and Airspace and Fleet Operations Management, parties are involved that are responsible for the design of the airspace, flight procedures that must be followed and the design of the vertiport infrastructure, like Uber Elevate and Skyports. Also, actors that work on the realisation of a new air traffic management system are involved, both new and traditional.

Finally, in the pillar of Community Integration, which is most relevant in this research, mainly existing actors from the community are involved. These include governmental bodies, varying from local to international, a variety of associations from different fields that serve the interests of the community and bring in their expertise for responsible community integration of UAM, investors, and so on.

The overview shows that a large number and large variety of parties is required for the realization of UAM. Looking at fig. 60, in appendix C.5, changes in the urban mobility actor network will mostly take place in the producer and supplier network. The biggest change from the current regime is that new stakeholder relationships will (should) arise that were not there before. These new relationships arise mainly between actors from the first four pillars and the last pillars: local authorities suddenly have to deal with actors (producers) from the aviation industry, and vice versa. For instance, actors like Airbus that are used to talk to the big players, national governments, national authorities, big aircraft operators, now suddenly have to dive into the complicated headache world of local politics and stakeholders where everything and everywhere is different. Whereas the city stakeholders were not really a priority before, with UAM now the stakeholders are much more different for traditional aircraft developers. They are very politically driven and very different from one place to another one. Dealing with this can be a complex process (Participant J, K, 2020). With every stakeholder having their own opinion, stakeholder engagement is therefore an important piece of the UAM puzzle, in order to get everyone aligned with each other (Participant H, J, K, 2020). To solve this puzzle, partnerships can be established. Local governments partnering with the local airport could be a logical first step in this (Participant F, H, J, K, 2020).



Government: FAA/AIR, DoD
Standards: ASTM, RTCA, SAE, EUROCAE, ICAO

Aircraft Developers
- AeroVironment
- AirspaceX/Mobi
- Alakia Technology
- Ampaire
- Apex Unmanned
- Armada Aero
- ASX
- Bell
- Beta Technologies
- Boeing/Aurora
- Boeing/HorizonX
- Carter Aviation
- Elroy Air
- EsaAero
- FanFlyer
- General Atomics
- Google X
- Hap Car
- Hi-Lite Aircraft
- Intel ventures
- Jetoptera
- Joby
- Jaunt Air Mobility
- Jump Aero
- Karem Aircraft
- Kittyhawk
- Piasecki
- Opener
- Overair
- Robodub
- Sikorsky
- Synergy Aircraft
- Textron
- The Spaceship Co
- TLG Aerospace
- Trimble
- Trumbull Unmanned
- Valkyrie Systems Aero
- Volta Volare'
- Wisk
- Workhorse/Surefly
- XTI Aircraft
- Zipline
- Airbus/A3 (I)
- Aeromobile (I)
- Daprato Machine (I)
- eHang (I)
- Embraer (I)
- Hanwha Systems (I)
- Hyundai (I)
- Leap (I)
- Lilium (I)
- Pipistrel (I)
- Rolls-Royce (I)
- Terrafugia (I)
- VARCO (I)
- Varon (I)
- Vimana (I)
- Volocopter/Intel (I)

Subsystems: Airframe & Propulsion
- Electric Power Systems
- ES Aero
- GE Aviation
- LaunchPoint
- MAGicALL
- S-RAM Dynamics
- Thin Gap
- United Technologies
- VerdeGo Aero
- Emrax (I)
- Rolls Royce (I)
- magniX (I)
- Siemens (I)
- Safran (I)

Manufacturing
- Boeing
- Ford
- GM
- Airbus (I)
- Honda (I)
- Hyundai (I)
- Nissan (I)
- Siemens (I)

Government: FAA/AIR/AFS
Standards: ASTM, RTCA, SAE, EUROCAE, ICAO

Integrated Automation & Aircraft Operations
- Autonodyne
- Bell Helicopter
- Boeing/Aurora/Jeppeson
- Cavan Solutions
- Evo-Luz
- Joby
- Kittyhawk
- Mosaic ATM
- Nodelin Robotics
- Plank Aerosystems
- Sikorsky
- Uber
- Verizon/Skyward
- Xwing
- Zaphod
- A3 (I)
- Drone Employee (I)
- Skyy Network (I)
- Terafugia (I)
Third Space Auto (I)

Subsystems: Flight Automation
- Aspen Avionics
- Avidyne Corporation
- Dynon Avionics
- Echodyne
- Garmin
- GE Aviation Systems
- Genesys Aerosystems
- Honeywell/Bendix King
- Iris Automation
- Near Earth Autonomy
- Rockwell Collins
- Sandel Avionics
- TruTrak Flight Systems
- UTRC
- Vigilant Aerospace
- BAE (I)

(I) – International

Government: FAA/AIR/ATO
Standards: RTCA, ICAO

Airspace Design
- A6I
- Airmap
- ANRA
- Crown
- GE/AiROXS
- Harris
- Lockheed
- M2C Aerospace
- Metron
- MITRE
- Onesky
- Skyward
- XAirSky
- A3 (I)

Flight Procedures Development
- Boeing/Jeppeson
- Hughes Aerospace
- Leidos
- Wolf UAS
- Global Airspace Solutions (I)

Vertiport Design
- Burns and McDonnell
- Gannette Fleming
- HeliExperts
- Near earth autonomy
- Uber Elevate
- WSP

Subsystems: CNS
- ARINC
- Astronautics
- AT&T
- Circonia
- Clear-Com
- Echodyne
- Fortem
- GE Aviation
- Gogo
- Gryphon/SRC
- Higher ground
- Honeywell
- L3/ACUS
- NextNav
- Primal Systems
- R3
- Raytheon
- SageTech
- SARA
- Sierra Nevada
- SmartSky Networks
- Skyward
- TTTech
- UTRC
- Verizon
- XWing
- BAE Systems (I)
- ParaZero (I)
- RADA Sensor (I)
- Thales (I)

Government: FAA/ATO, DOC, DoD, DHS
Standards: RTCA, ICAO

Traditional ATM Suppliers
- ATAC Corporation
- GE/AiROXS
- General Dynamics
- Harris
- Jet Blue Tech Vent
- Lockheed
- M2C Aerospace
- Microsoft
- NeXt (Boeing)
- SparkCognition
- PASSUR Aerospace
- Raytheon
- Rockwell
- Thales (I)

UAM ATM Providers
- AirMap
- AGI (OneSky)
- ANRA Technologies
- Avision
- CACI Technologies
- Collins
- GE/AiRXOS
- Metron
- Onesky
- PrecisionHawk
- Skyward/Verizon
- Simulyze
- Uber Elevate
- UTRC
- UAS Sidekick
- WSI
- TruWeather
- XM WX
- Unifly (I)
- ATECH S/A (I)

Data Service Suppliers
- CalAnalytics
- Climacell
- Ellis
- GeoRq
- Sabre
- Stellar Labs
- Kugelair Flight Svc
- Personal Airline Exchange
- Skyward/Verizon
- Sustain Avia Found
- Uber Elevate
- A3 (I)
- EmbraerX (I)
- Sumitomo Corp (I)

Fleet Operations
- AGI
- Amazon Prime Air
- Blade Helicopter
- Boeing/Horizon X
- Boeing/Jeppesen
- Collins
- Drop Drone
- FedEx
- IBM
- KittyHawk

UAM Range Test Sites
- Arizona Commerce Authority
- Choctaw Nation (OK)
- Deseret UAS Test Site (UT)
- Kansas State University
- SOAR UAS Test Site (OR)
- University of Maryland UAS Test Site
- FAA Test Sites: Alaska Center for UAS Integration, Lone Star Center UAS of Excel and Innov, Mid-Atlantic Avia Partnership

Decision Makers (Local)
- Mayors/City Councils/Boards of Supervisors
- Tribal Councils
- Departments of Transportation
- Departments of Commerce
- National League of Cities (2000+ cities, 49 states with additional cities)
- Port Authority (of various big cities)
- US Conference of Mayors
- National Governors Association

Decision Makers (National)
- US Congress
- DOT/FAA – AIR, AFS, ATO
- DOC/NTIA (public/federal spectrum)
- FCC (commercial spectrum)
- DHS
- DOJ/FBI

Government (Federal)
- NASA
- National Academies-Transportation Research Board
- National Institutes of Standards and Technologies (NIST)/Smart Cities
- National Transportation Safety Board (NTSB)

Incubators/Investors
- Alliance Texas
- Defense Innovation Experimental (DUIx)
- FAA/IPP: Choctaw, San Diego, IEIA (VA), KS DoT, Ft Myers (FL), Memphis Airport (TN), NC DoT, ND DoT, Reno (NV), UAF (Fairbanks, AK), LA DoT, WA DoT
- Starburst
- Strategic Alliances Resources Network (StarNet)
- Sustainable Aviation Limited
- Uber

Associations (Domestic)
- American Association of Airport Executives (AAAE)
- American Insurance Association
- Aircraft Owners and Pilots Assoc (AOPA)
- Community Air Mobility Initiative (CAMI)
- Chambers of Commerce
- Commercial Drone Alliance
- Coalition of UAS Professionals

Decision Makers (International)
- US Congress
- DOT/FAA – AIR, AFS, ATO
- DOC/NTIA (public/federal spectrum)
- FCC (commercial spectrum)
- European Aviation Safety Agency (EASA)
- European Organization for Civil Aviation Equipment (EUROCAE) (Europe)

Standards
- American Society for Testing and Materials (ASTM) (I)
- National Fire Protection Association
- Radio Technical Commission for Aeronautics (RTCA) (I)
- Society of Automotive Engineers (SAE) (I)
- International Civil Aviation Organization (ICAO) (I)

Government (Intranational)
- Civilian Aviation Authority (CAA-UK)
- German Aerospace Center (DLR)
- Japan Aerospace Exploration Agency (JAXA)
- Korea Aerospace Research Institute (KARI)
- Netherlands Aerospace Center (NLR)
- ONERA (French Aerospace Center)
- Nordic Network for Electric Aviation (NEA)

Contributors (International)
- International Forum for Aviation Research (IFAR)

Associations (International)
- American Institute of Aeronautics and Astronautics (AIAA)
- Airports Council International (ACI)
- Association of Air Medical Services
- Association for Unmanned Vehicle Systems International (AUVSI)
- Civil Air Navigation Services Organization (CANSO) – ANSP providers
- Environmental (Greenpeace, WWF)
- Eurocontrol (Europe)
- General Aviation Manufacturers Association (GAMA)
- International Air Transport Association (IATA) - Airlines
- International Telecommunication Union (ITU)

Figure 66 | Actor network of Urban Air Mobility as identified by NASA.

D.6 Sectoral policy

While they represent a good starting point, existing regulatory frameworks may be insufficient to deal with the complex and specific challenges raised by commercial drones, and further technological developments such as collision avoidance systems could soon render them obsolete. There are parallels here with the need to update regulatory frameworks ahead of the introduction of automated vehicles such as driverless trucks on public roads (International Transport Forum, 2018).

The final picture must involve policy that has both a stimulating and regulating function for the passenger drone market, so it can flourish while at the same time potentially adverse economic and societal impacts that arise from disruptions are mitigated. It must support economically viable drone operations in urban environments (Participant B, 2020), which means that the sectoral policy must not restrict commercial service to certain parameters that are not conducive to make money (Participant E, 2020). It should mainly change in favour of drone operations. This means that drones must get more freedom of movement. This also entails that governments need to embrace UAM in order to make it reality (Participant H, 2020). Whatever concept of operations we have, we need a regulatory framework that allows to take off, depart terminal areas, fly, interact with other aircraft, approach, and land. This implies that regulations with regard to VLOS, flying over populated areas, maximum altitudes and the like will need to change in order to make (autonomous) commercial drone services in urban areas possible. Also, governments could play a stimulating role in terms of financial incentives, especially in the early stages of the development. This can be done with targeted financial support for technological research to improve either vehicle or infrastructure technologies and financial support for drone operations to make them price competitive with their alternatives. It is good to imagine that this would be a defensible policy in the context of the longer-term goal of making general aviation more sustainable (Participant E, I, 2020).

At the same time, the sectoral policy should have a regulating function. Nuisance of this new urban transportation mode to the general public must be avoided as much as possible. This requires regulations that provide guidelines with regard to where, when and by who those passenger drones are operated. As such, issues with regard to safety, privacy, noise, visual pollution and the like can be limited (Participant G, 2020). For example, if windows, rooftops, yards or public space like sidewalks all become potential droneports, zoning, construction, building regulations, property law (including air rights), private contract law regarding the use of shared spaces of collective dwellings, and laws regarding noise and visual amenity will all come under pressure. The risk of unwanted outcomes through poor, or inexistent, coordination across these regulatory spheres is high, and must be taken into account thoroughly (International Transport Forum, 2018).

In addition, when the existing regulatory frameworks are updated for drone operations, the rules must be enforced as well. This requires some new sort of organisation or system, counter UAS measures. That is the type of technology that is needed to keep an incident, a national security incident or a safety incident from happening. Inevitably, if something like that would happen, it would stifle or destroy the industry. It is the task of the government to come up with such kind of technology (Participant E, 2020).

Besides a regulatory framework for the operations, it is of similar importance to come with certification standards for both the infrastructure and vehicles that will be introduced in cities. This must ensure a standardised and high level of technology and reduce risks, but also smooth operations around the world, meaning that, for instance, every vehicle will be able to use every vertiport around the world without exceptions (Participant H, I, 2020; Porsche Consulting, 2018).

It is furthermore important to create a clear and standardised framework and avoid a patchwork of different policies. Therefore, the regulatory framework should be created at an international level (Participant E, G, M, 2020), in order to keep the industry operable (EH, 2020). This should be done by organisations like EASA, FAA and Jarus. The benefits of an international regulatory approach to commercial drones may not be as clear as for the manned aviation sector (since commercial drone operations are not yet international in nature) but there are multiple benefits of international regulatory cooperation in this field too, not least the ability to update safety standards at the global level based on the most recent evidence. This helps to enable such a global industry to operate in a very similar fashion around the world. First examples of governmental international co-operation for cross-border drone operations in Europe are trials by the European Maritime Safety Agency (EMSA) and FRONTEX, the European Border and Coast Guard Agency to surveil maritime borders. Moreover, with introduction of large, long haul freight drones the need for internationally harmonised regulation will become even more apparent (International Transport Forum, 2018). Governments also have an important role to play in bringing market parties together for consultation, so that their activities are coordinated as well as possible.

Flexibility is also an important characteristic of emerging drone regulation, in two ways. First, requirements across administrative, operational and airspace rules are modulated based on the different characteristics of commercial drones. These encompass size (weight), flight altitude, the role of the pilot (if any), the degree of autonomy and the purpose of the drone operation (International Transport Forum, 2018).

D.7 Techno-scientific knowledge

UAM requires a broad field of knowledge, which is in line with the five pillars formulated by NASA: (1) Vehicle Development and Production, (2) Individual Vehicle Management and Operations, (3) Airspace System Design and Implementation, (4) Airspace and Fleet Operations Management and (5) Community Integration. Specifically the Community Integration, which this thesis focuses on, requires knowledge with regard to public acceptance, infrastructure, integration with ground transportation and sectoral policy, among other things.

Appendix E: The Randstad versus the Munich Metropolitan Area

E.1 Demographics

Population size and growth

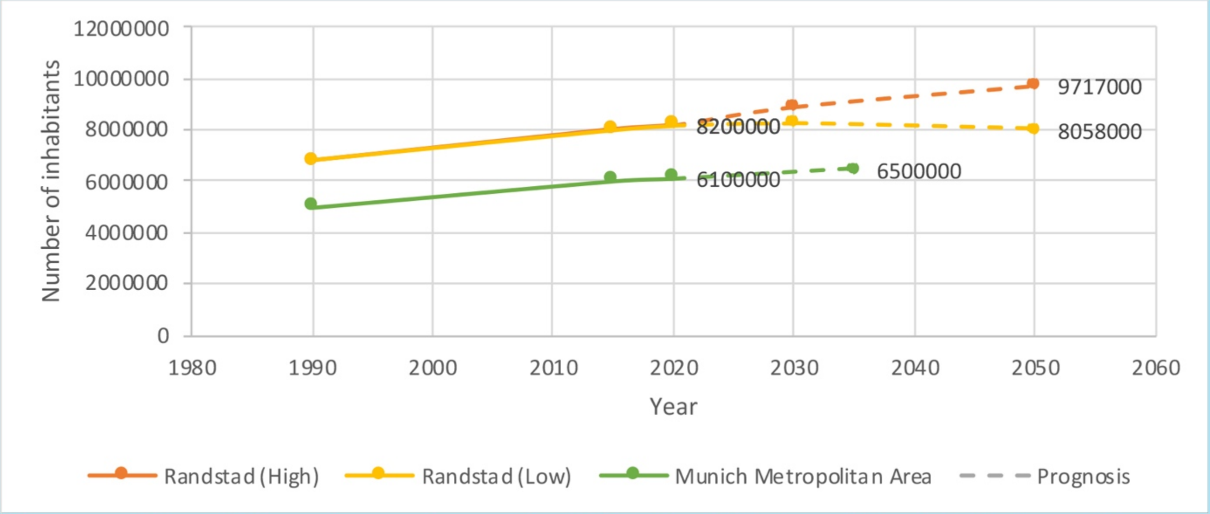


Figure … | Population size and growth of the Randstad and Munich Metropolitan Area. Sources: Regio Randstad (2019), NIDI (2018), Metropolregion München (n.d.).

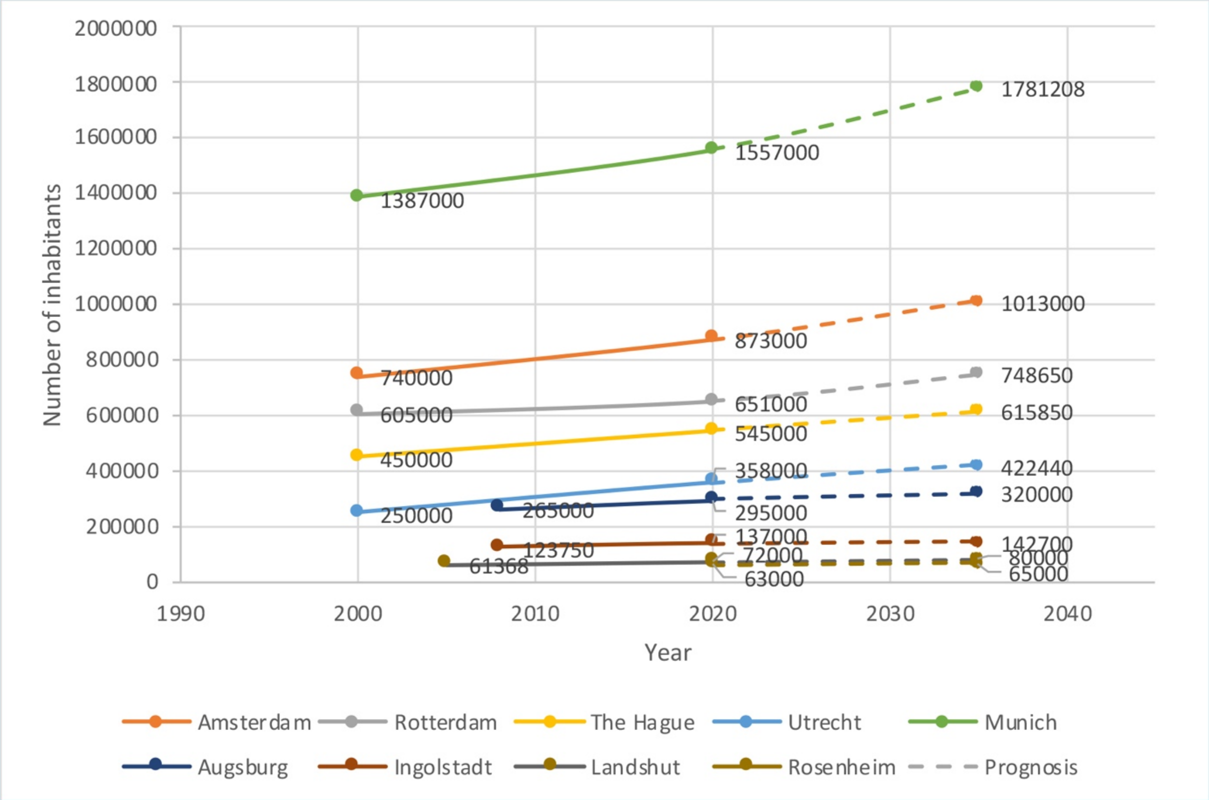


Figure … | Population size and growth of the four largest cities in the Randstad and five largest cities in the Munich Metropolitan Area. Sources: AlleCijfers.nl (2020), Planbureau voor de Leefomgeving (2019), Bayerische Landesamt für Statistik (2019), Stadt Augsburg (2019), Stadt Ingolstadt (2018), Landeshauptstadt München (2019).

The population of the entire Randstad is, with 8.2 million people, bigger than that of the Munich Metropolitan Area (6.1 million people). Population growth in both regions is more or less equal. The Munich Metropolitan Area exists of one large city and many smaller cities, making this large city the 'Point of Interest' in the region. Compared to the Munich Metropolitan Area, the Randstad exists of four medium-large sized cities and many smaller cities, resulting in more (but possibly smaller) 'Points of Interest'. As a result, the single 'Point of Interest' in the Munich Metropolitan Area may attract more people from outside and thus over larger distances than the multiple 'Points of Interest' do in the Randstad.

With regard to population density, the Randstad is much denser populated than the Munich Metropolitan Area.

Population density

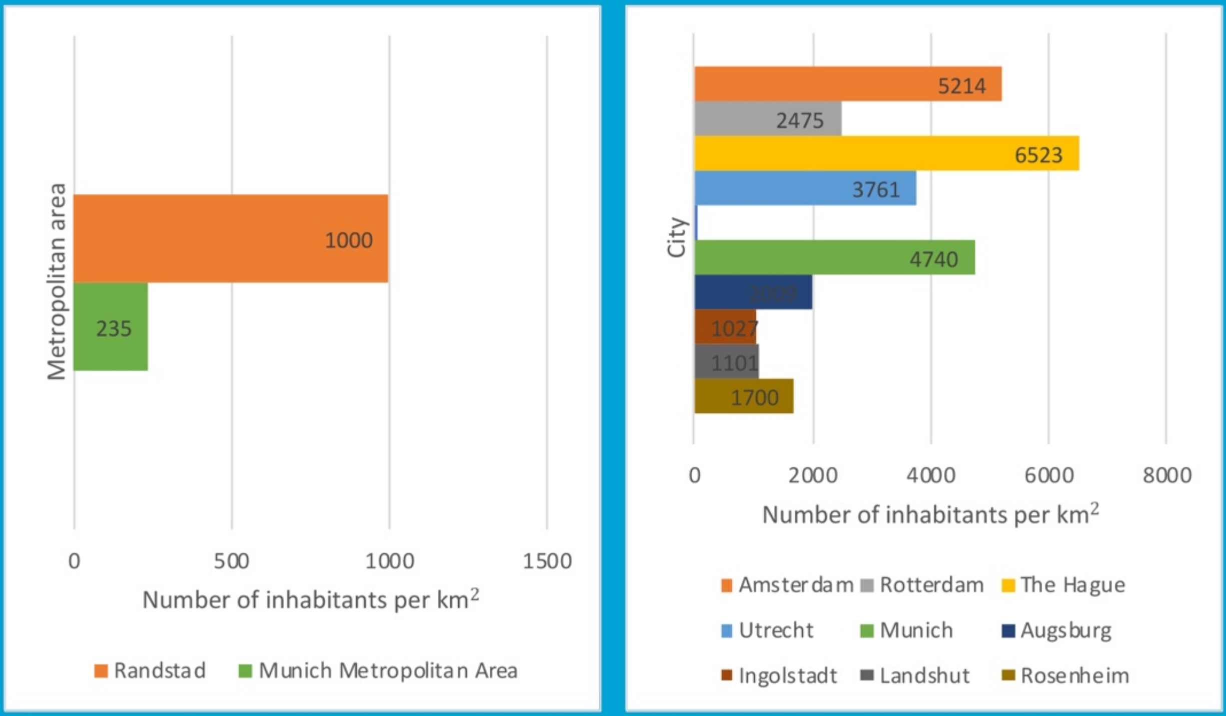


Figure ... and ... | Polulation densities in the Randstad, Munich Metropolitan Area and their largest cities. Sources: Regio Randstad (2019), Metropolregion München (n.d.), AlleCijfers.nl (2020), Planbureau voor de Leefomgeving (2019), Bayerische Landesamt für Statistik (2019), Stadt Augsburg (2019), Stadt Ingolstadt (2018), Landeshauptstadt München (2019).

GDP per capita

In general, GDP per capita in the Munich Metropolitan Area is slightly higher than in the Randstad. However, in recent years, economic growth in the Randstad has been slightly higher than in the Munich Metropolitan Area.

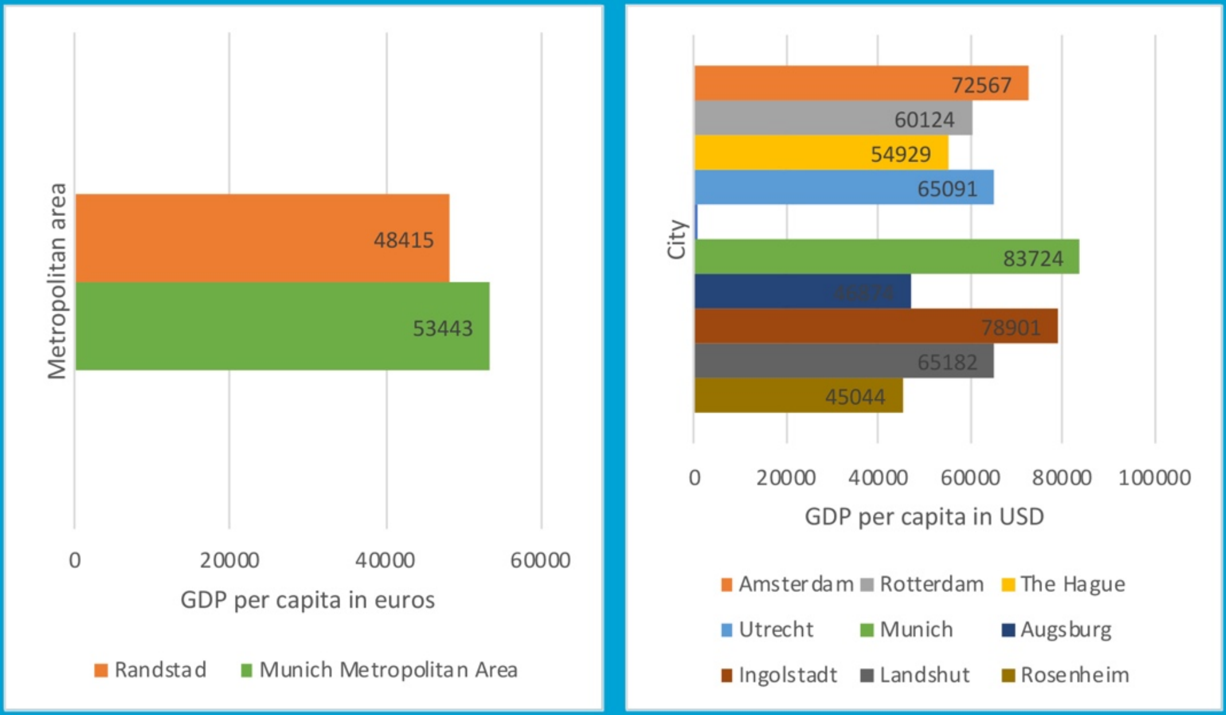


Figure ... and ... | GDP per capita in the Randstad, Munich Metropolitan Area and their largest cities. Sources: Regio Randstad (2019), Metropolregion München (n.d.), Statista (2020), OECD (n.d.).

E.2 Business Climate

Regional Competitiveness Index 2019

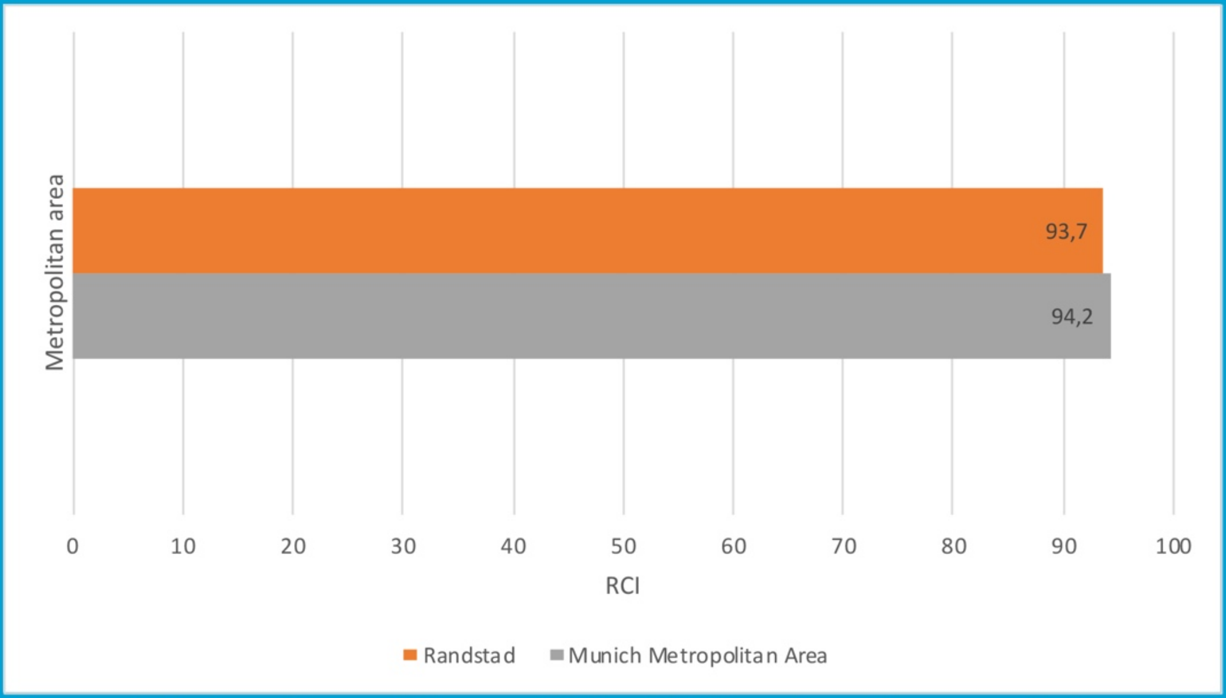


Figure ... | Regional Competitiveness Index of both regions. Sources: Regio Randstad (2019), European Commission (2019).

The business environment of the Netherlands is classified as friendly. The country ranked sixth in the Global Competitiveness Index of 2018, a publication by the World Economic Forum. In the EU, only Germany scored better in this index that focusses on drivers for competitiveness. The Netherlands is a topscorer in infrastructure, innovation and business sophistication and it is one of the best performers in the area of connectivity (Regio Randstad, 2019).

In the European Commission's Regional Competitiveness Index 2019, the Randstad scores around 93.7, while the Oberbayern region - which is not entirely but almost the same as the Munich Metropolitan Area - scores 94.2 (European Commission, 2019). This index is based on a broad range of indicators related to innovation, governance, transport and human capital. Taken together, these indicators characterise a region's ability to offer an attractive and sustainable environment for firms and residents to live and work. As such, both regions are almost equally attractive (Regio Randstad, 2019).

Furthermore, the Randstad is considered attractive to very attractive for businesses. After London and Paris, the Randstad ranks as the most important location for multinationals in Fortune's Global 500. Besides, after Paris, London and the Ruhr area, it is the largest economic urban region in Europe (Regio Randstad, 2017).

The Randstad is also strong on tourism, now ranking fourth after Paris, Barcelona and Hamburg, thanks to above-average growth in recent years. The Randstad holds first place when it comes to the number of international conferences (Regio Randstad, 2017).

Mainports

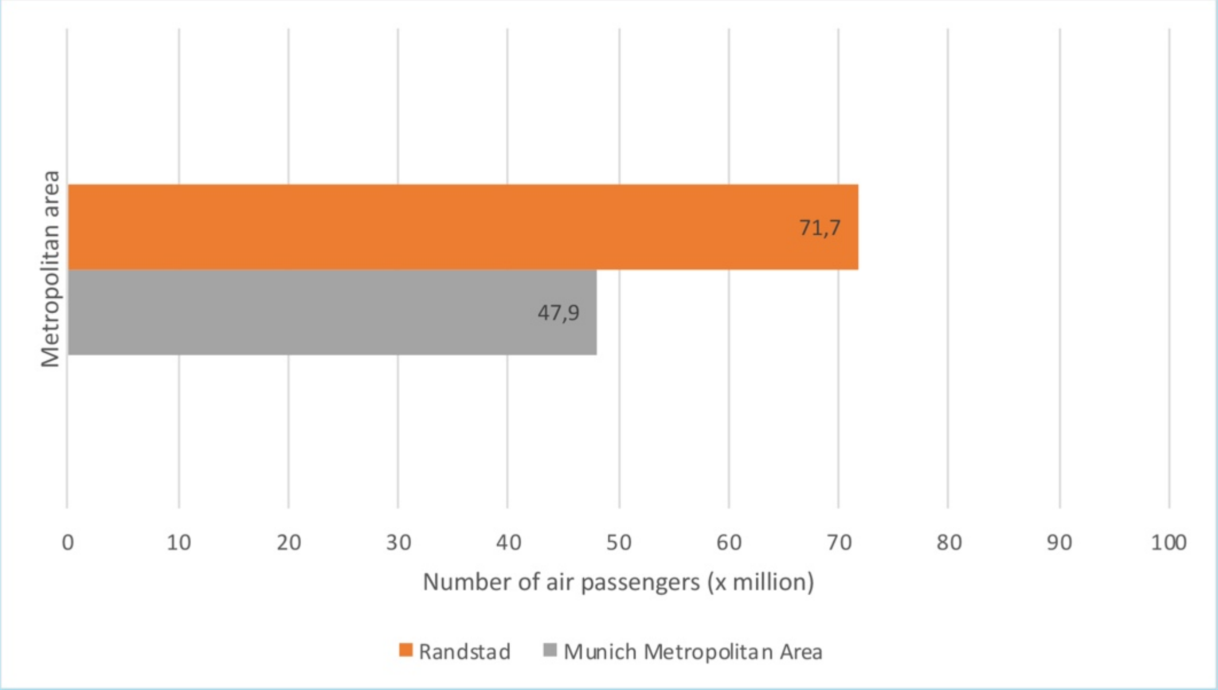


Figure ... | Number of passengers on Amsterdam Schiphol Airport and Munich Airport, in 2019. Sources: Royal Schiphol Group (2020), Munich Airport (2020).

The Randstad and Munich Metropolitan Area both feature at least one mainport, which is a hub of important transport routes and often provides large economic value to a region. In the Munich Metropolitan Area, it is Munich Airport that can be called a mainport. With almost 48 million air passengers in 2019, it is one of the busiest airports in Europe. But not as busy as Amsterdam Schiphol Airport, which processed more than 70 million passengers in 2019 and ranks 12th worldwide and third in Europe (Airports Council International, 2020).

But the Randstad contains more than one mainport. With the port of Rotterdam, the largest seaport in Europe, and the port of Amsterdam which ranks fourth, the Randstad leads the rankings of maritime transport by far (Regio Randstad, 2019).

E.3 Mobility

Number of trips

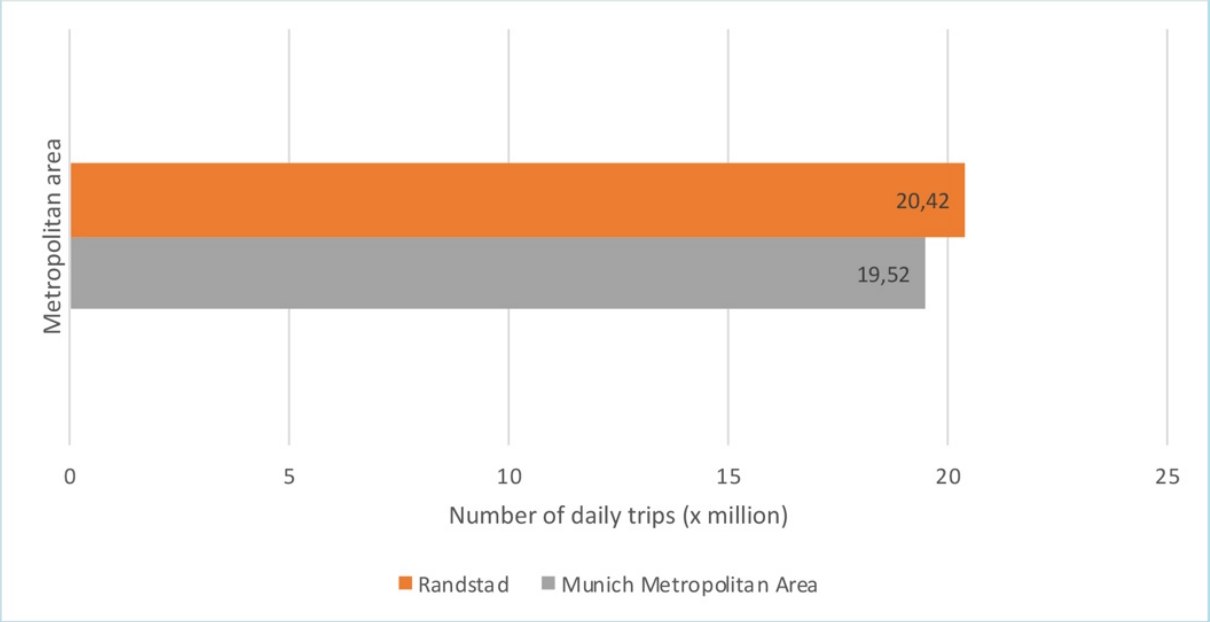


Figure ... | Number of total daily trips in the Randstad and Munich Metropolitan Area. Sources: Gemeente Rotterdam (2018), Bundesministerium für Verkehr und digitale Infrastruktur (2019).

The number of daily trips is almost equal for both regions, but the number of trips per person is quite larger in the Munich Metropolitan Area than in the Randstad. Also, the number of daily trips is at least two times higher in Munich than in any other city considered.

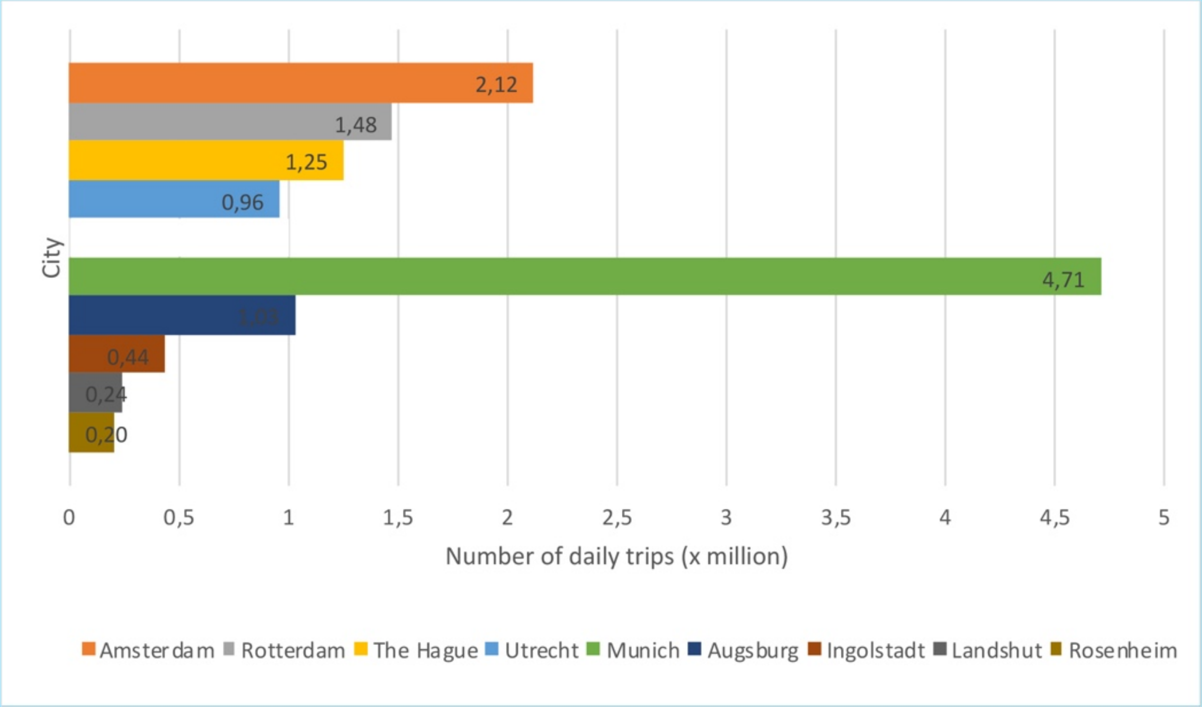


Figure ... | Number of total daily trips in all cities considered. Sources: Gemeente Rotterdam (2018), Bundesministerium für Verkehr und digitale Infrastruktur (2019), Stadt Augsburg (n.d.), Stadt Ingolstadt (2017), Büro Stadtverkehr (2019).

Passenger Kilometers Traveled (PKT)

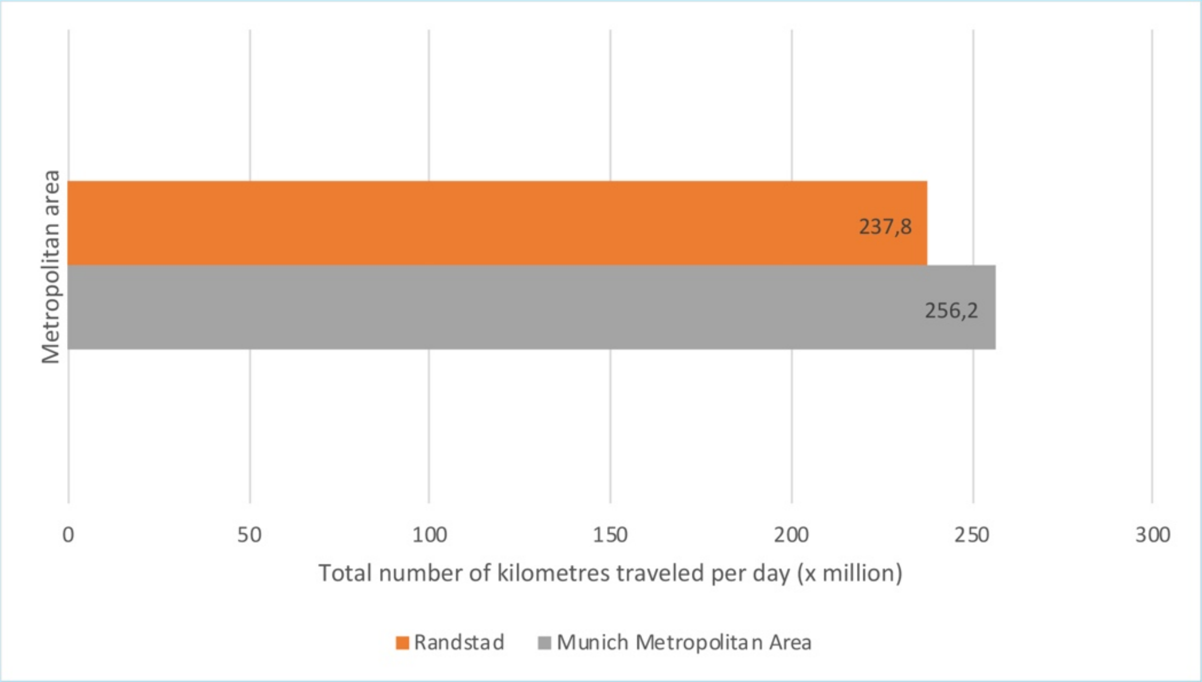


Figure ... | Total number of passenger kilometers traveled per day in the Randstad and Munich Metropolitan Area. Sources: Gemeente Rotterdam (2018), Bundesministerium für Verkehr und digitale Infrastruktur (2019).

About 20% of all trips in the Randstad are above 15 km, of which about half is above 30 km. For the Munich Metropolitan Area, these shares may be higher.

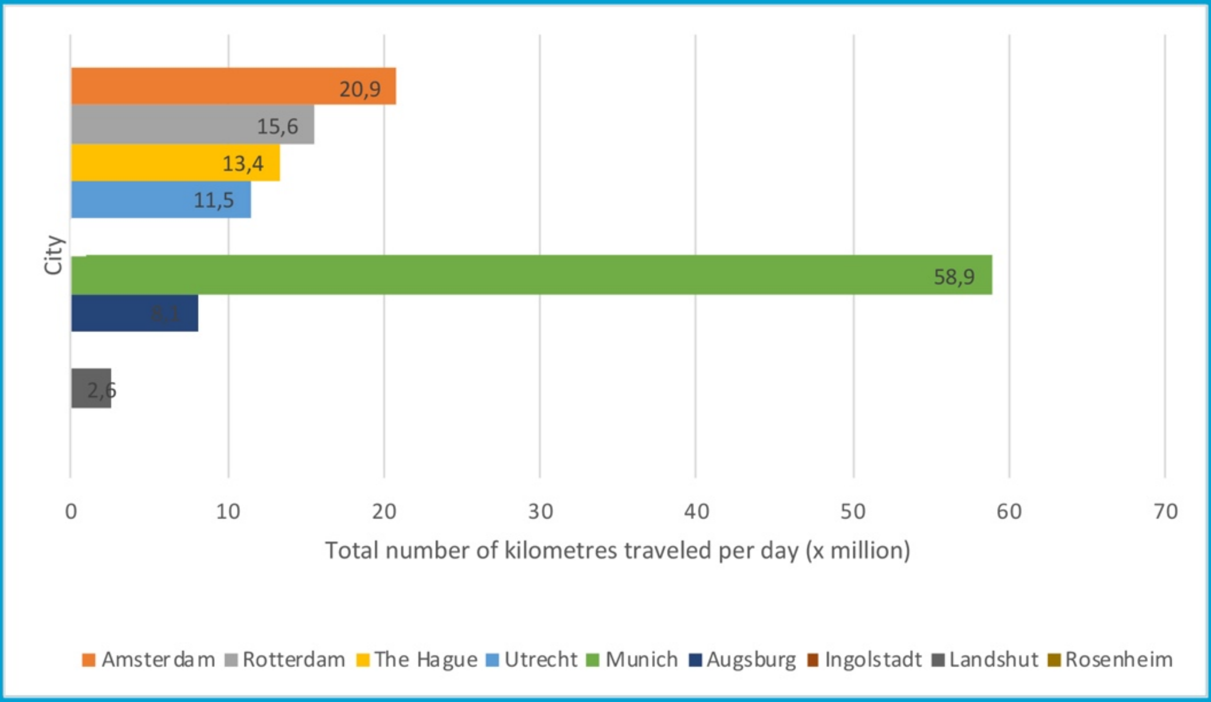


Figure ... | Total number of passenger kilometers traveled per day in all cities considered, for which data was found. Sources: Gemeente Rotterdam (2018), Bundesministerium für Verkehr und digitale Infrastruktur (2019), Stadt Augsburg (n.d.), Büro Stadtverkehr (2019).

On a daily basis, more kilometers are traveled in the Munich Metropolitan Area than in the Randstad. With a smaller population, this means that people in the Munich Metropolitan Area travel longer distances than people in the Randstad.

Daily commutes

				Daily commutes [#]			
				INBOUND			
		Amsterdam	Rotterdam	Den Haag	Utrecht		
OUTBOUND	Amsterdam		4,300	4,700	12,400		21,400
	Rotterdam	6,400		15,200	6,400		28,000
	Den Haag	8,500	12,000		10,600		31,100
	Utrecht	21,500	2,700	4,500			28,700
							109,200
		36,400	19,000	24,400	29,400	109,200	218,400

Table... | Total number of daily commutes between the four largest cities in the Randstad. Source: CBS (2020).

Overall, more trips per person and longer distances are made in the Munich Metropolitan Area. However, many more commuters travel on a daily basis within the Randstad between the four big cities than people do between the five cities in the Munich Metropolitan Area. In fact only the city of Munich can compete with the Randstad cities in this sense. Total daily commuter demand in the Randstad equals 218,400, while in the Munich Metropolitan Area this number equals 59,400.

Daily commutes [#]

		INBOUND						
		Munich	Augsburg	Ingolstadt	Landshut	Rosenheim		
OUTBOUND	Munich		1,863	1,640	493	1,583		5,579
	Augsburg	9,459		220	16	37		9,732
	Ingolstadt	2,616	197		58	16		2,887
	Landshut	2,343	20	58		23		2,444
	Rosenheim	8,854	85	57	62			9,058
								29,700
		23,272	2,165	1,975	629	1,659	29,700	59,400

Table... | Total number of daily commutes between the five largest cities in the Munich Metropolitan Area. Source: Bundesagentur für Arbeit (2019).

On the other hand, the commuter distances are longer in the Munich Metropolitan Area than in the Randstad.

N.B. Only the commutes between these cities were considered.

Commuting distances [km]

		INBOUND				
		Amsterdam	Rotterdam	Den Haag	Utrecht	
OUTBOUND	Amsterdam		78	64	50	59
	Rotterdam	78		25	66	46
	Den Haag	64	25		73	52
	Utrecht	50	66	73		55
		58	43	41	62	53

Table... | The distance by car between the four largest cities in the Randstad, and the weighted average distances for commutes in and out of each city.. Source: Google Maps.

Commuting distances [km]

		INBOUND					
		Munich	Augsburg	Ingolstadt	Landshut	Rosenheim	
OUTBOUND	Munich		80	80	73	67	76
	Augsburg	80		78	123	148	80
	Ingolstadt	80	78		76	150	80
	Landshut	73	123	76		91	74
	Rosenheim	67	148	150	91		68
		74	83	82	76	70	75

Table... | The distance by car between the five largest cities in the Munich Metropolitan Area, and the weighted average distances for commutes in and out of each city.. Source: Google Maps.

Multiplying the first two matrices of both regions results in the matrices below, which present the total daily PKT by commuters between these cities. The total PKT is much higher in the Randstad, but - again - the distance per commute is larger in the Munich Metropolitan Area.

Total commuting distances traveled [km]

		INBOUND					
		Amsterdam	Rotterdam	Den Haag	Utrecht		
OUTBOUND	Amsterdam		335,400	300,800	620,000		1,256,200
	Rotterdam	499,200		380,000	422,400		1,301,600
	Den Haag	544,000	300,000		773,800		1,617,800
	Utrecht	1,075,000	178,200	328,500			1,581,700
							5,757,300
		2,118,200	813,600	1,009,300	1,816,200	5,757,300	11,514,600

Table... | Total distances that commuters travel on a day between the four largest cities in the Randstad.

Total commuting distances traveled [km]

		INBOUND						
		Munich	Augsburg	Ingolstadt	Landshut	Rosenheim		
OUTBOUND	Munich		149,040	131,200	35,989	106,061		422,290
	Augsburg	756,720		17,160	1,968	5,476		781,324
	Ingolstadt	209,280	15,366		4,408	2,400		231,454
	Landshut	171,039	2,460	4,408		2,093		180,000
	Rosenheim	593,218	12,580	8,550	5,642			619,990
								2,235,058
		1,730,257	179,446	161,318	48,007	116,030	2,235,058	4,470,116

Table... | Total distances that commuters travel on a day between the five largest cities in the Munich Metropolitan Area.

Air travelers

Besides commutes, also many daily trips are made by air travelers to the regions main airport. The numbers represent the potential demand between the cities and the airport (left) and the distance (right). Both numbers and distances are larger in the Munich Metropolitan Area than in the Randstad. Exact numbers for the Randstad could not be found. They are assumptions based on the ratio between the total number of passengers at Schiphol Airport and the population size of the cities, and an e-mail conversation with Zijlstra (2020), and are taken together under the name G4.

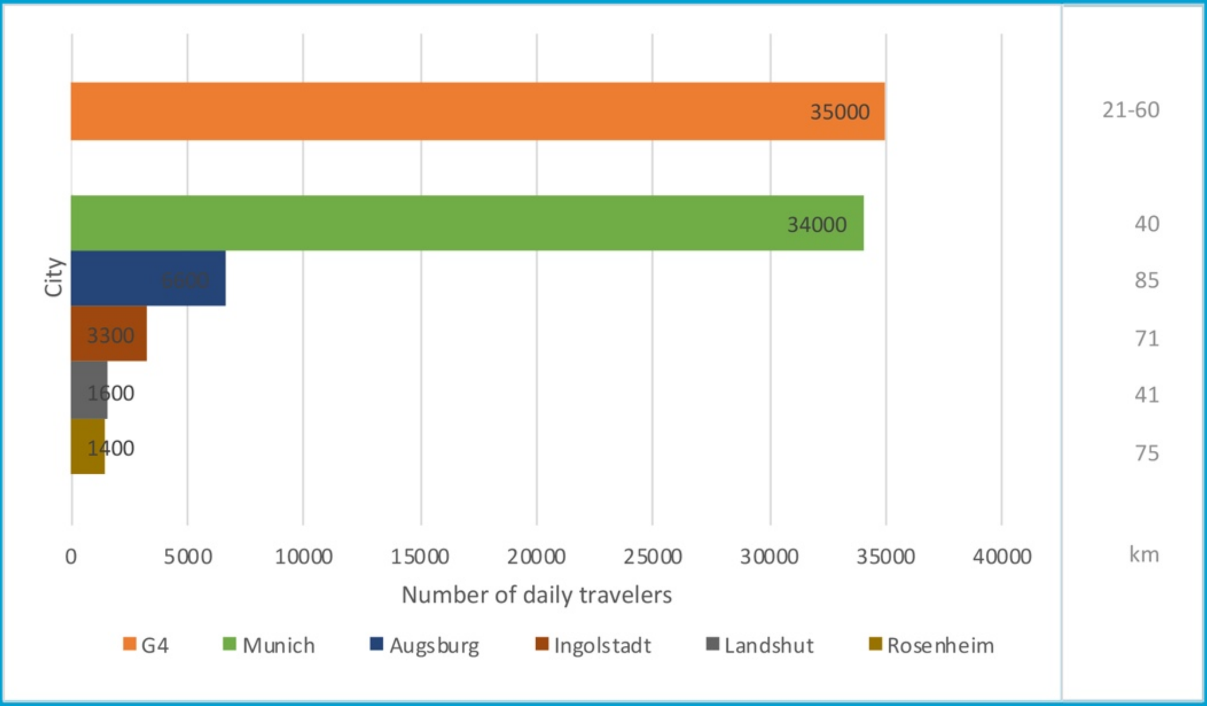


Figure ... | Number of daily travelers and distances between the cities and the largest/dominant airport of the region. Sources: AlleCijfers.nl, Royal Schiphol Group (2020), Zijlstra (2020), Bayerische Landesamt für Statistik (2019), Stadt Augsburg (2019), Stadt Ingolstadt (2018), Landeshauptstadt München (2019), Munich Airport (2020), Roland Berger (2018), Google Maps.

Modal Split

The diagram shows the overall modal split of inhabitants of the nine cities, which includes trips both within the city and to and from the city. In general, car usage in the Munich Metropolitan Area is slightly higher than in the Randstad. It must be mentioned that the shares of the car and public transport are lower for trips within the city - in favor of other transportation modes, mainly cycling and walking - and higher for trips to and from the city - at the expense of other transportation modes, mainly cycling and walking.

The same holds for longer distances: the shares of both the car and public transport increase with longer distances. However, the car is by far the dominant transportation mode on these distances, with up to 70% of all trips above 15 km made by car in the Randstad. In the Munich Metropolitan Area, this percentage is even higher.

N.B. When we would look at the modal split in terms of passenger kilometers traveled - instead of trips - the share of the car would be much higher.

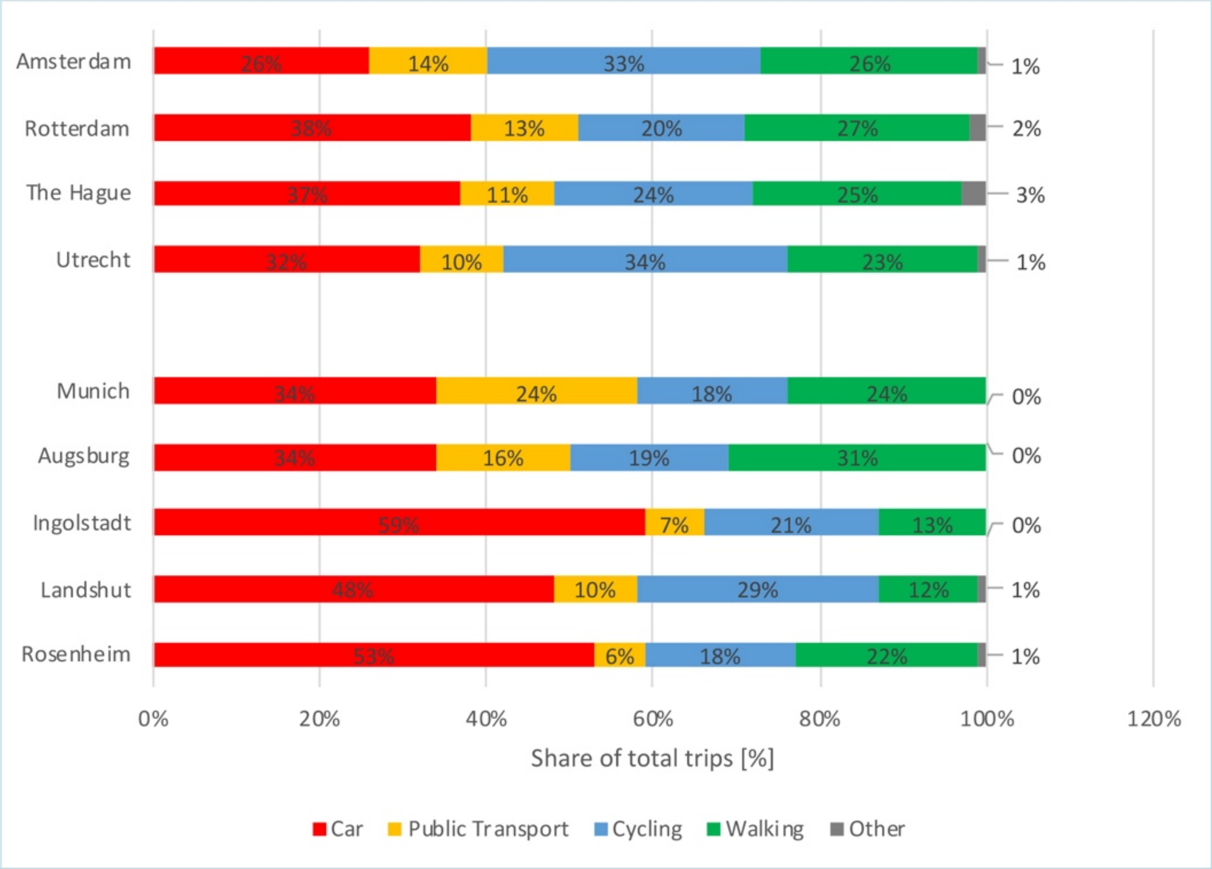


Figure ... | Modal spilts in the different cities of both regions. Sources: Gemeente Rotterdam (2018), Stadt Augsburg (n.d.), Stadt Ingolstadt (2017), Büro Stadtverkehr (2019), Deutscher Bundestag (2017), Bundesministerium für Verkehr und digitale Infrastruktur (2019).

Travel times, travel speed and congestion

Commuter travel times [minutes]

		INBOUND											
		Amsterdam		Rotterdam		Den Haag		Utrecht				Average	
OUTBOUND	Amsterdam			55	80	50	85	40	60			45	70
	Rotterdam	55	85			30	65	45	75			39	72
	Den Haag	50	80	26	55			55	80			42	70
	Utrecht	40	60	45	70	55	85					43	65
												42	69
	Average	45	69	35	63	38	73	46	70	42	69	42	69

Table... | The travel times of commutes between the four largest cities in the Randstad, with lower and upper limits. Source: Google Maps.

Commuter travel times [minutes]

		INBOUND													
		Munich		Augsburg		Ingolstadt		Landshut		Rosenheim				Average	
OUTBOUND	Munich			60	100	65	110	50	80	50	85			58	97
	Augsburg	55	100			60	100	70	110	85	130			55	100
	Ingolstadt	55	100	60	100			60	90	90	130			56	99
	Landshut	50	85	70	110	65	100			80	120			51	86
	Rosenheim	50	85	90	140	90	140	80	120					51	86
														54	94
	Average	53	93	61	102	65	109	54	86	52	87	54	94	54	94

Table... | The travel times of commutes between the five largest cities in the Munich Metropolitan Area, with lower and upper limits. Source: Google Maps.

Travel times are shorter in the Randstad than in the Munich Metropolitan Area, which seems to be mostly due to longer travel distances in the latter region. For the commutes between the different cities, travel times are on average between 42 minutes and 69 minutes in the Randstad, which is in agreement with the national average of 58 minutes of travel time per day (CBS, n.d.). In the Munich Metropolitan Area, the average is between 54 and 94 minutes, also in agreement with the national average of 79 minutes of travel time per day (Bundesministerium für Verkehr und digitale Infrastruktur, 2019). The upper limit concerns travel times during peak hours, while the lower limit concerns travel times during more quiet moments of the day.

Average travel speed [km/h]

		INBOUND											
		Amsterdam		Rotterdam		Den Haag		Utrecht				Average	
OUTBOUND	Amsterdam			85	59	77	45	75	50			77	51
	Rotterdam	85	55			50	23	88	53			67	37
	Den Haag	77	48	58	27			80	55			70	42
	Utrecht	75	50	88	57	80	52					77	51
												73	45
	Average	77	50	68	39	61	33	80	52	73	45	73	45

Table... | The travel speeds of commutes between the four largest cities in the Randstad, with lower and upper limits.

The average travel speed in km/h is a variable that can say something about the heaviness of traffic. The average travel speed of the commutes was obtained by dividing the distance of the commute by the travel time of the commute, times 60 minutes. In the Randstad, the average travel speed is a bit lower than in the Munich Metropolitan Area, but this is probably partly due to the shorter distances and smaller highway share in the Randstad commutes. Taking this into account, average travel speeds seem to be quite similar in both regions, with 45 to 73 km/h in the Randstad and 48 to 84 km/h in the Munich Metropolitan Area.

Average commuter travel speed [km/h]															
		INBOUND													
		Munich		**Augsburg**		**Ingolstadt**		**Landshut**		**Rosenheim**				**Average**	
	Munich			80	48	74	44	88	55	80	47			79	47
	Augsburg	87	48			78	47	105	67	104	68			87	48
OUTBOUND	**Ingolstadt**	87	48	78	47			76	51	100	69			86	48
	Landshut	88	52	105	67	70	46			68	46			87	51
	Rosenheim	80	47	99	63	100	64	68	46					81	48
														84	48
	Average	85	48	81	49	75	45	85	54	81	48	84	48	84	48

Table... | The travel speeds of commutes between the five largest cities in the Munich Metropolitan Area, with lower and upper limits.

Congestion in both the Randstad and Munich Metropolitan Area seem to be quite comparable and average on a global scale, although it might be slightly worse in the latter region - mostly concentrated around the largest city: Munich. In the near future, congestion levels might worsen (Mobiliteitsalliantie, n.d.).

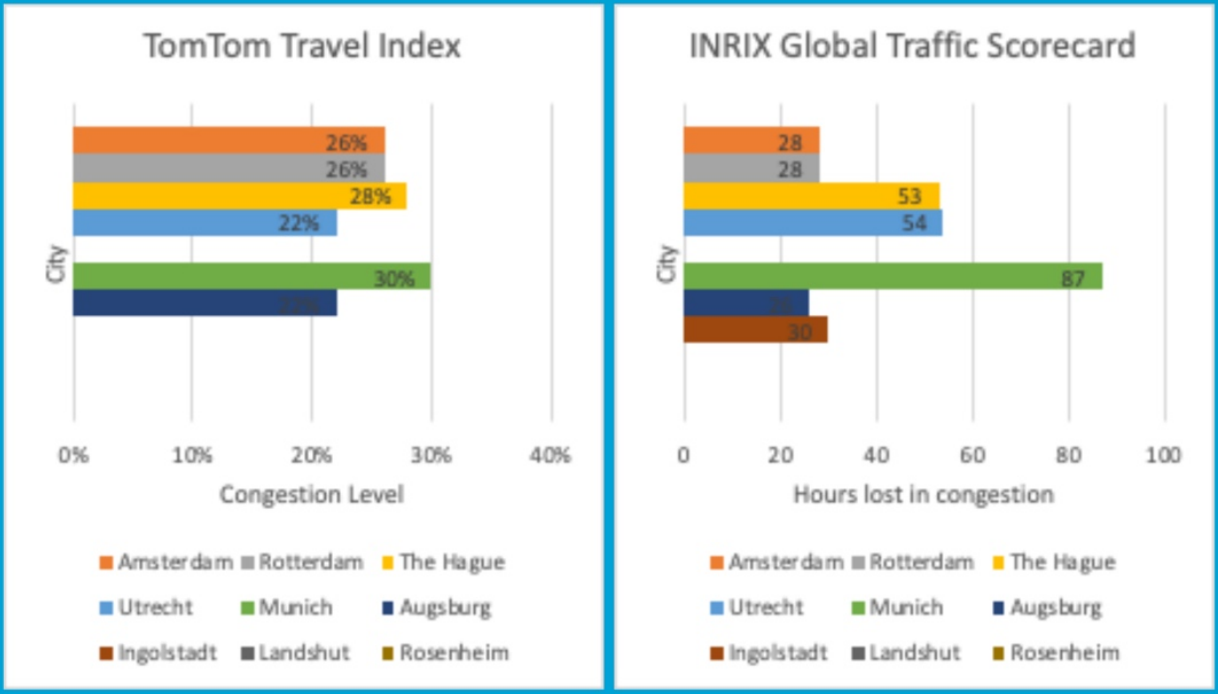


Figure ... and ... | Congestion in the cities of both regions. Sources: TomTom (n.d.), INRIX (n.d.).

E.4 Summary and conclusion

The regions of the Randstad and Munich Metropolitan Area have been compared on different aspects that are considered as important to assess the potential for a UAM market. These mainly relate to demographic factors, business climate and the state of the existing mobility system (KPMG, 2019; Roland Berger, 2018). The Randstad has been found to be very similar to the Munich Metropolitan Area, one of the areas where UAM is expected to play a role in the future (KPMG, 2019; Porsche Consulting, 2018; Roland Berger, 2018). Here the findings are summarized and conclusions drawn.

Demographics

- Population size and growth (+)

The population of the Randstad comprises 8.2 million inhabitants, compared to 6.1 million inhabitants in the Munich Metropolitan Area. The city of Munich has a much bigger population than any other city considered, but every other city in the Munich Metropolitan Area is smaller than the cities in the Randstad. The growth over the past 30 years has been comparable in both regions and is expected to be the same in the next 15 years.

Conclusion: the larger population of the Randstad (+ 2.1 million people) makes this region relatively more attractive for UAM.

- Population density (+)

Population density is much higher in the Randstad than in the Munich Metropolitan Area, since more people live on a much smaller area: ~ 1000 inhabitants/km2 versus ~ 250 inhabitants/km2. Of the cities, only the population density of Munich is comparable to that of the cities in the Randstad.

Conclusion: the higher population density makes the Randstad relatively more attractive for UAM.

- GDP per capita (-)

The Randstad is slightly less wealthy than the Munich Metropolitan Area, with € 48,415 per capita versus € 53,443 per capita. In the Randstad cities, GDP per capita is between $ 54,929 and $ 72,567 and in the cities of the Munich Metropolitan Area, GDP per capita is between $ 45,044 and $ 83,724. However, economic growth in the Randstad has been slightly higher than in the Munich Metropolitan Area in recent years.

Conclusie: a GDP per capita that is approximately 10% lower, makes the Randstad relatively less attractive for UAM.

Business climate

- Regional Competitiveness Index (0)

This index characterizes a region’s ability to offer an attractive and sustainable environment for firms and residents to live and work. In the European Commission’s Regional Competitiveness Index 2019, the Randstad scores around 93.7, while the Oberbayern region - which is not entirely but almost the same as the Munich Metropolitan Area - scores 94.2.

Conclusion: in this context, both regions are almost equally attractive for UAM.

• Mainports (+)
With the Port of Rotterdam, the Port of Amsterdam and Amsterdam Airport Schiphol, the Randstad contains at least three mainports. The Munich Metropolitan Area contains (at least) one mainport: Munich Airport.

Conclusion: the Randstad has more mainports / international hubs to offer, making it more attractive for UAM in this context.

Mobility

• Number of trips (+)
The number of daily trips is almost equal in both regions, with 20.4 million daily trips in the Randstad and 19.5 million daily trips in de Munich Metropolitan Area. On the other hand, the number of daily trips is at least two times higher in Munich than in any other city considered.

Some categories of trips are considered more promising for UAM applications than others. One of these are commutes (Roland Berger, 2018). An analysis of the number of daily commutes between the different cities in both regions shows that many more commutes are made in the Randstad than in the Munich Metropolitan Area, with 218,400 versus 59,400 (round trip). In the Randstad, serious numbers of commutes exist between all four cities. In the Munich Metropolitan Area, only the connections to and from Munich and between Augsburg and Ingolstadt contain large numbers of commutes.

Another promising category are trips to and from airports (Roland Berger, 2018). Based on the available data, it seems that fewer of these trips take place between Amsterdam Schiphol Airport and the four largest cities in the Randstad than between the cities in the Munich Metropolitan Area and Munich Airport. However, the difference may not be very big, with an estimated 35,000 daily travelers versus 46,900 daily travelers.

Conclusion: both regions deal with similar numbers of daily trips, although at least twice as many take place in Munich than in any other city considered. A part of these trips are commutes and many more of these trips take place in the Randstad than in the Munich Metropolitan Area. On the other hand, the number of travelers between the concerning cities and the airport is smaller in the Randstad than in the Munich Metropolitan Area. However, the difference in (air) travelers is smaller than the difference in commuters, while both are considered promising categories for UAM applications. Given these figures, the Randstad is therefore generally assumed to be more attractive for UAM than the Munich Metropolitan Area.

• Passenger Kilometers Traveled (PKT) (-)
The total number of passenger kilometers traveled per day is smaller in the Randstad than in the Munich Metropolitan Area, with 237.8 million km versus 256.2 million km. With a bigger population, this also means that people in the former region travel shorter distances a day than people in the latter area (29 km versus 42 km). Besides, the total number of passenger kilometers traveled per day is three times higher in Munich than in any other city.

Furthermore, about 20% of all trips in the Randstad are above 15 km, of which about half is above 30 km. For the Munich Metropolitan Area, these shares may be higher, given the longer distances traveled in that region.

Moreover, commuter data suggests that the total distance traveled by commuters is larger in the Randstad than in the Munich Metropolitan Area: 11.5 million km versus 4.5 million km. However, each single commute is shorter in the Randstad than in the Munich Metropolitan Area (53 km versus 75 km). The distances between the cities and the airport are also smaller in the Randstad (21 to 60 km) than in the Munich Metropolitan Area (40 to 85 km).

Conclusion: overall, shorter distances are traveled in the Randstad than in the Munich Metropolitan Area. Since UAM is especially attractive for journeys over longer distances, the Randstad is considered less attractive for UAM than the Munich Metropolitan Area.

- Modal Split (-)

The share of the car is overall lower in the Randstad than in the Munich Metropolitan Area, while the share of public transport is quite similar in both regions. The share of active transport (walking and cycling) is a bit higher in the Randstad than in the Munich Metropolitan Area. In both regions, the car is by far the dominant transportation mode on longer distances, with up to 70% of all trips above 15 km made by car in the Randstad. In the Munich Metropolitan Area, this percentage is even higher.

Conclusion: given the idea that passenger drones will primarily compete with the car – on distances starting between 15 km and 30 km –, it is assumed that the Randstad is less attractive for UAM than the Munich Metropolitan Area in the context of the existing modal split.

- Travel times, travel speed and congestion (-)

Travel times per day are shorter in the Randstad than in the Munich Metropolitan Area, which seems to be mostly due to longer travel distances in the latter region. The national averages are 58 minutes versus 79 minutes. For the commutes between the cities concerned, average travel times by car are between 42 and 69 minutes in the Randstad and between 54 and 94 minutes in the Munich Metropolitan Area. Travel times between the cities and the airport are also shorter in the Randstad than in the Munich Metropolitan Area.

Travel speeds for commutes (by car) are slightly lower in the Randstad than in the Munich Metropolitan Area, but this may partially be declared by the higher maximum speed in Germany and the longer distances traveled in the Munich Metropolitan Area (and so a higher share of highways). Average travel speeds for commutes are between 45 and 73 km/h in the Randstad and between 48 and 84 km/h in the Munich Metropolitan Area, depending on the traffic situation at the time of day.

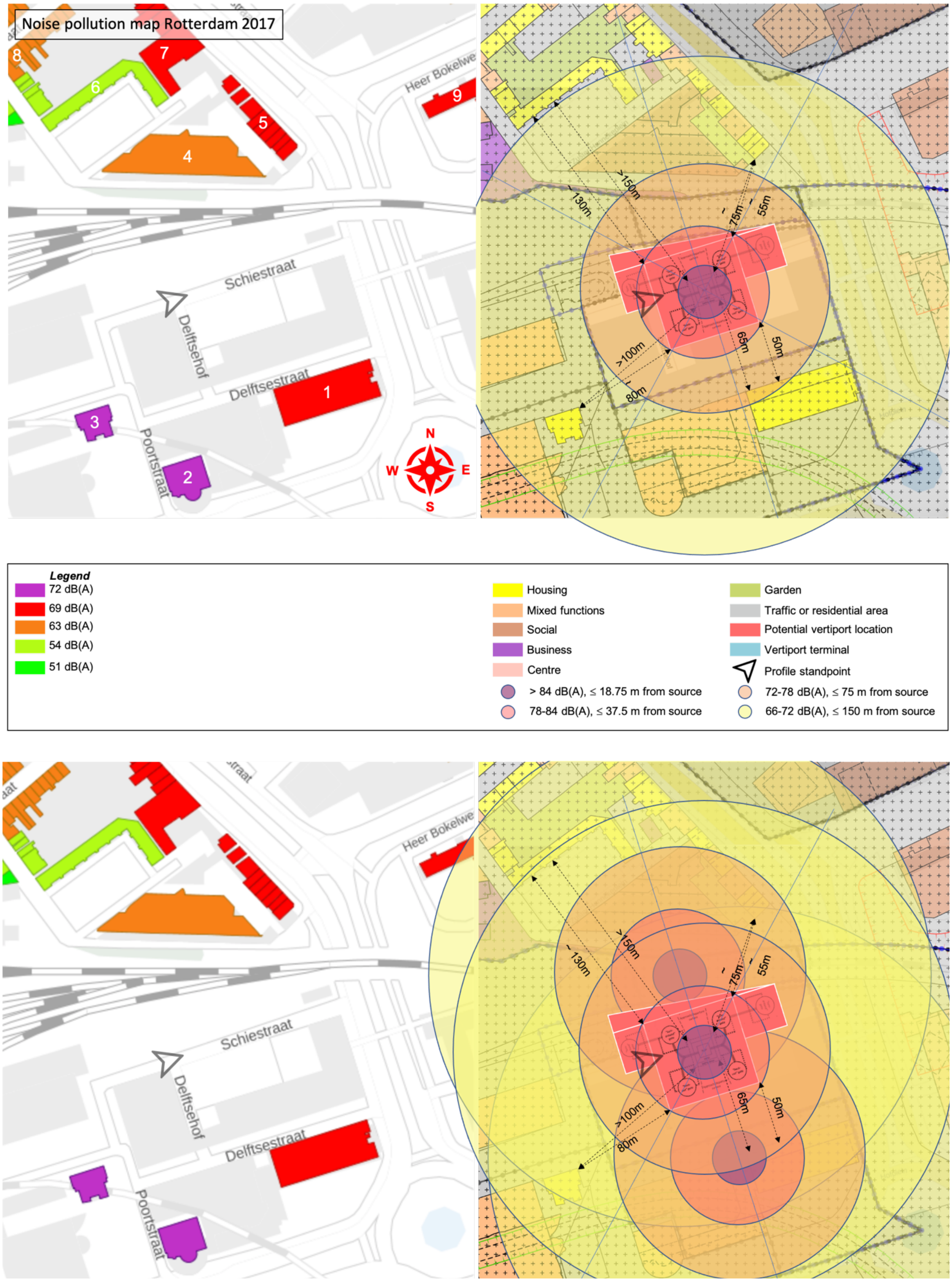
Although not complete, the available data suggests that congestion in both regions is quite similar. TomTom congestion levels in cities of both regions vary between 22% and 30%. However, according to the INRIX Global Traffic Scorecard, the average number of hours lost in congestion in a year is much higher in Munich than in other cities: 87 hours in Munich and below 55 hours in any other city considered.

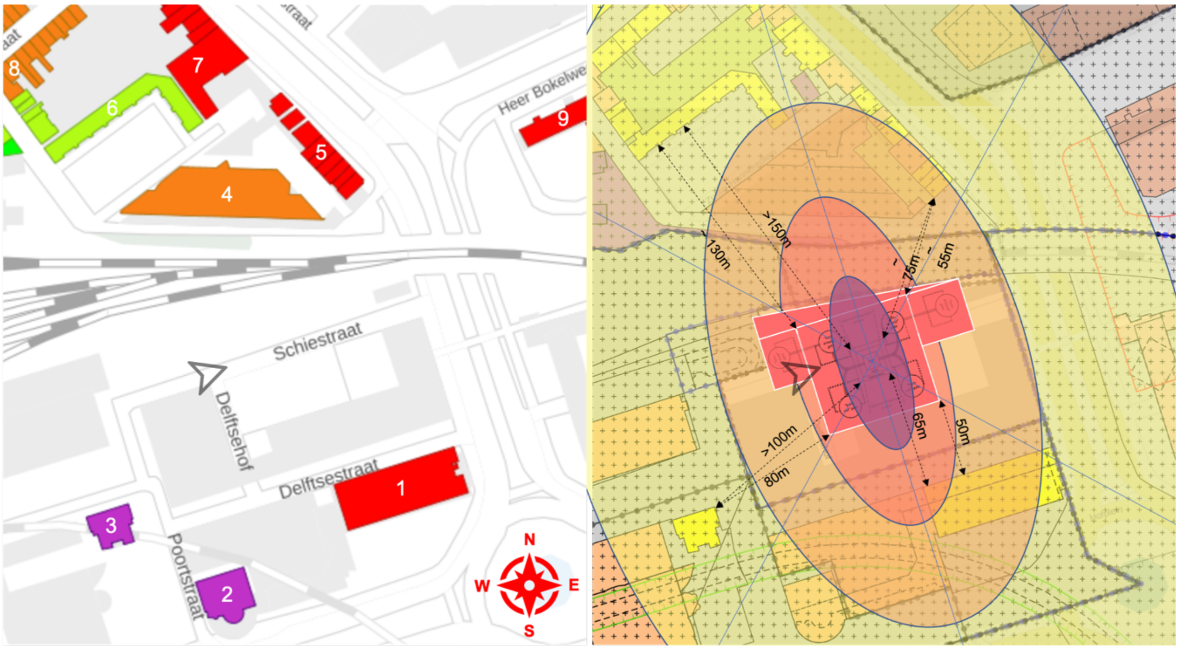
Conclusion: travel times are shorter and congestion levels might be slightly lower in the Randstad, making the region less attractive for UAM.

In conclusion, the Randstad is comparable in this sense to the Munich Metropolitan Area. Both regions score better than the other on a number of points and almost the same on other points. This is explained - in a very straightforward way - in table... on the basis of the available and used criteria and assigned weightings. Besides, both metropolitan areas can be categorized as a mix of the urban archetypes 'Prosperous Community' and 'Sprawling Metropolis', or simply as a large 'Prosperous Community' (4.3.5), given the large total populations, high GDP and medium population density, state of the mobility system and business climate. It is assumed that the Randstad scores slightly lower than the Munich Metropolitan Area when it comes to the market potential for UAM.

Criteria	Weight	Randstad	Munich Metropolitan Area
Population size and growth	5	+	-
Population density	3	+	-
GDP per capita	5	-	+
RCI	2	0	0
Mainports	1	+	-
PKT	5	-	+
Number of trips	5	+	-
Modal Split	3	-	+
Congestion	5	-	+
Score		-4	+4

Appendix F: Noise production of passenger drones around landing infrastructure

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Schiestraat
Delftsehof
Delftsestraat
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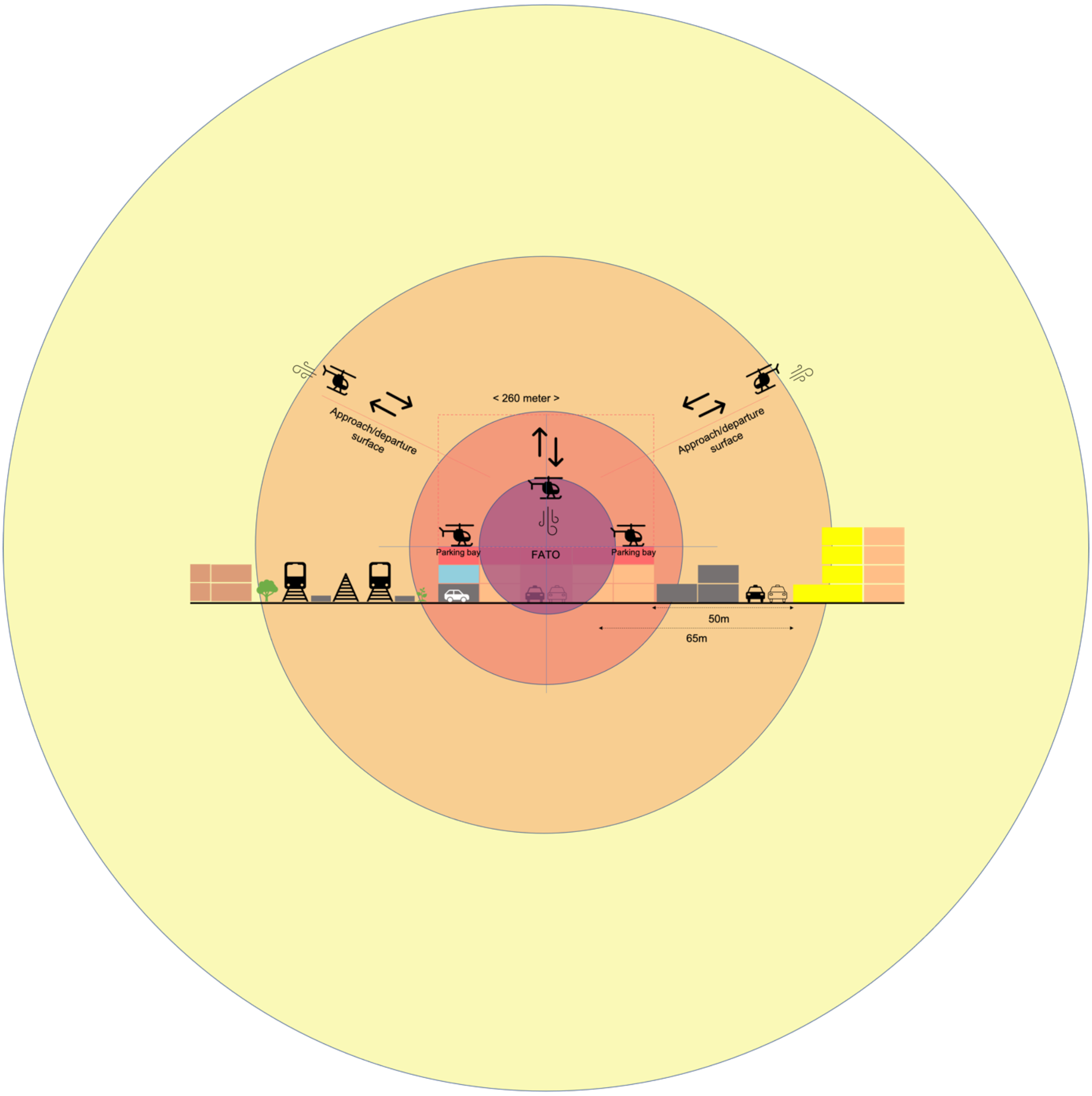

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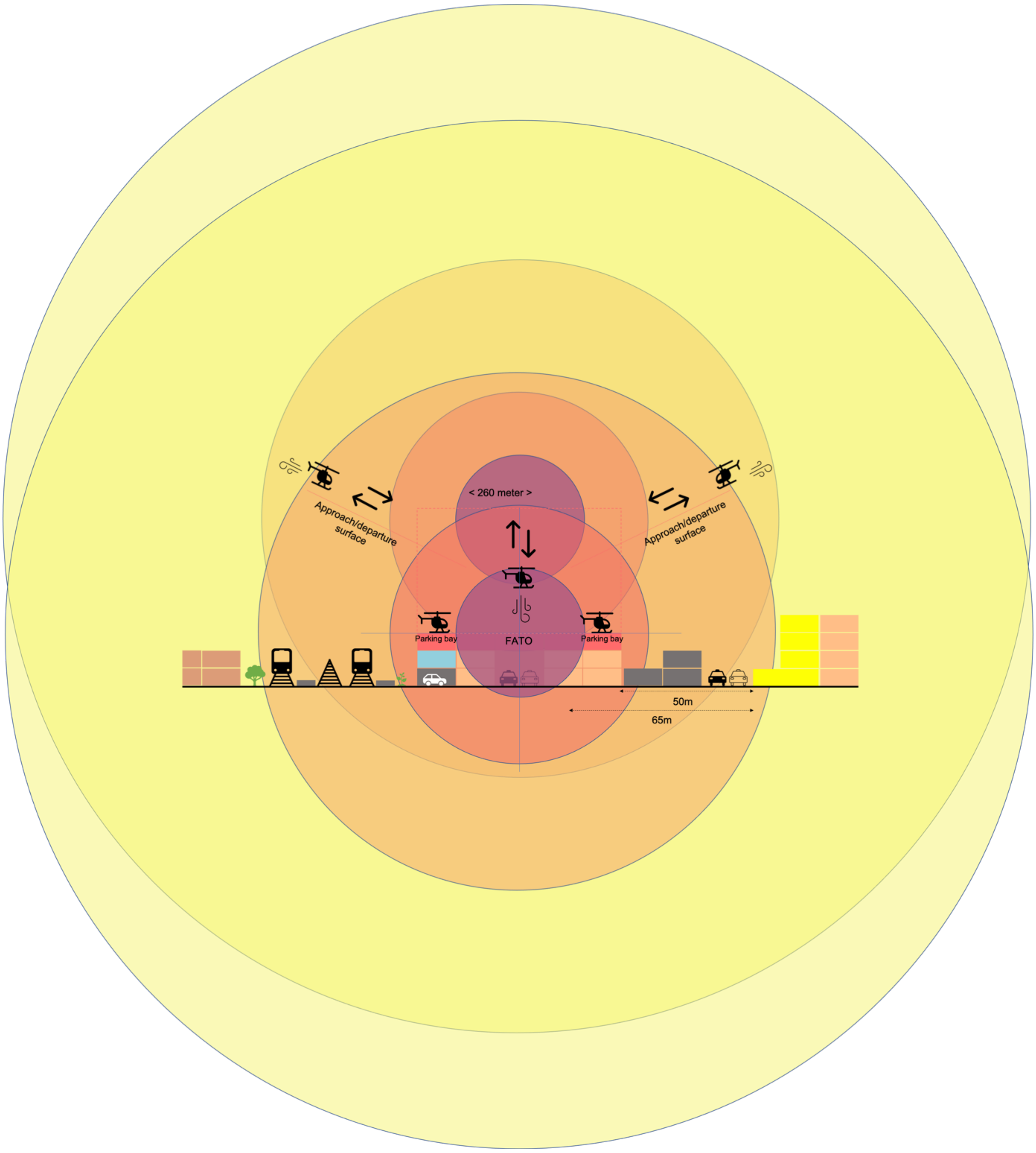
Approach/departure surface
Approach/departure surface
Parking bay
FATO
Parking bay
50m
65m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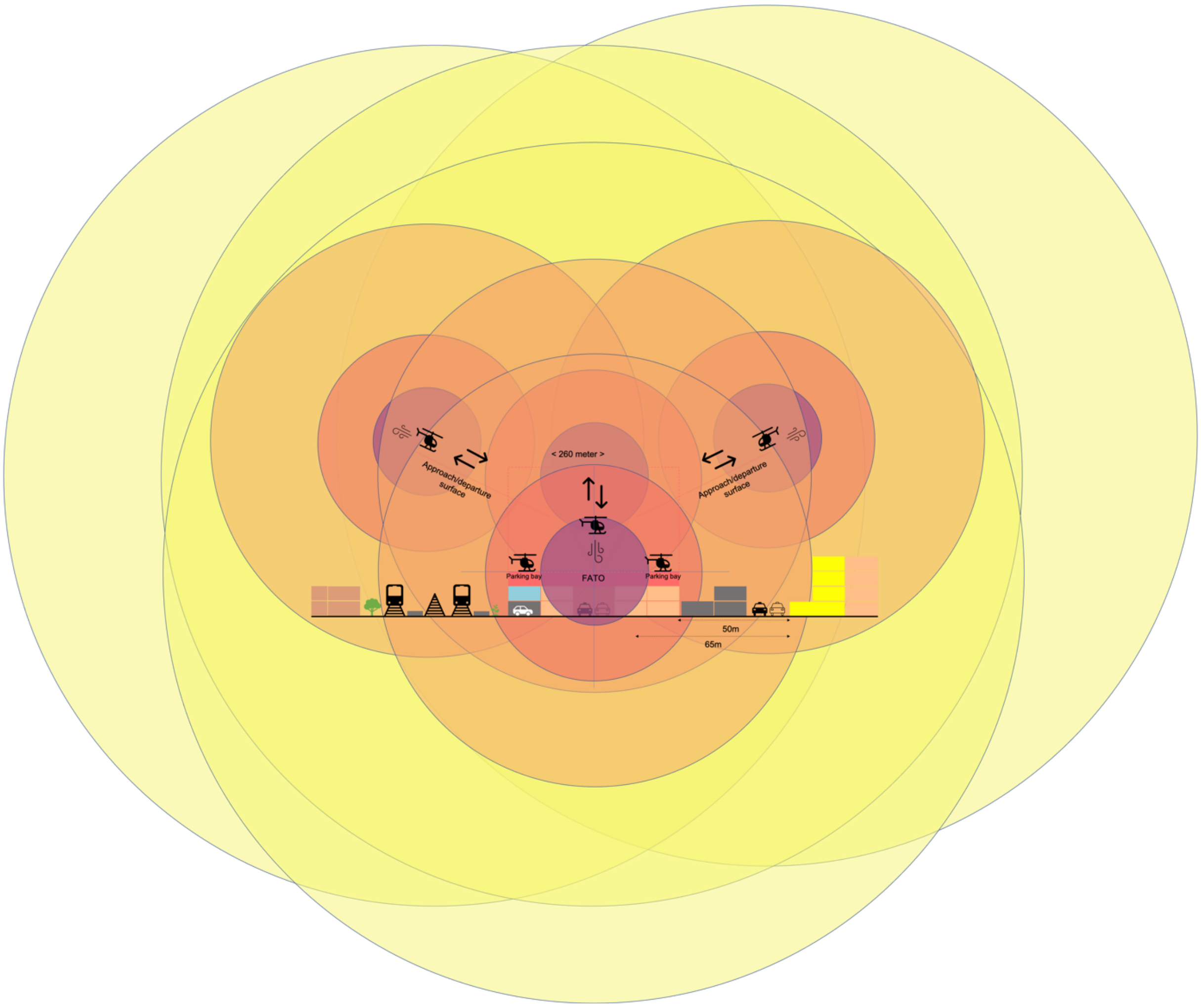
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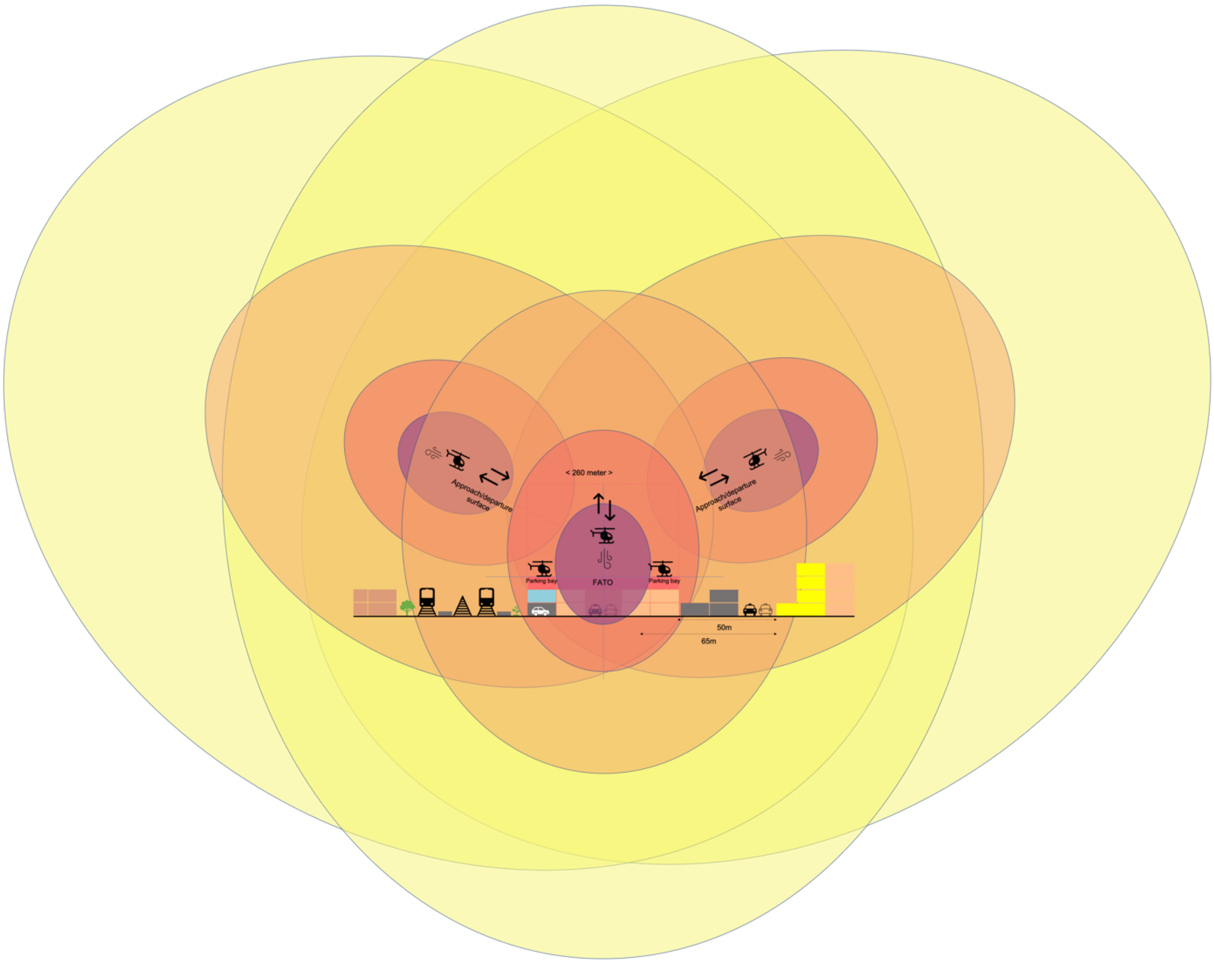
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