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Analysis of Corridor Type Routing in Unmanned Air Traffic Management (UTM)

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This thesis is worth 30 study points

The undersigned have examined the thesis entitled ***Analysis of Corridor Type Routing in Unmanned Air Traffic Management (UTM)*** presented by *An Binh Nguyen*, a candidate for the degree of *Master in Systems Engineering with Embedded Systems* and hereby certify that it is worthy of acceptance.

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Abstract

The rise of using unmanned aerial vehicles (UAV) for commercial use has been increased lately, and it is estimated that within 2030 approximately 750 000 drones/UAVs will populate the European airspace. Which means the current air traffic will increase by 20 times. The growth of UAVs applications will mostly be in the logistics of goods and people, surveillance, inspection, rescue, and agriculture. As most of those applications will take place in densely populated areas, unmanned air traffic management (UTM) can manage those activities safely and securely while ensuring the quality of life for people and wildlife. At the moment, drone routing in airspace for UTM is centered around free-routing, which means the airspace is unstructured. This kind of free-routing is restricted or forbidden by having a vast volume of UAVs in the airspace. By utilizing structured airspace called corridor-routing, the airspace will be well defined for several types of operation. In this work, we evaluate current state-of-the-art in UAVs operation and integration of UTM.

This study aims to analyze the use of corridor type routing in UTM by going into four topics and proposes a framework that breaks down different aspects of a corridor-routing in UTM. First, the placement of a corridor is explored by defining very low-level (VLL) airspace as well as separation for the UAVs in the corridor and how the weather could impact the corridor and UAVs. Further on this section the thesis explores scenarios for placing a corridor in a rural area and in an urban area.

Secondly, two types of corridors characterized are analysis, static and dynamic corridors. The analysis looks into what's different between the two corridors and which risks are involved when switching between the two corridors. The main difference between static and dynamic is the dynamic corridor could reroute when a no-fly zone is established, and a dynamic corridor could temporarily increase the traffic by adding a new flight path in the corridor.

Thirdly, the comparison between the three types of the corridor is studied. The three corridors which are analyzed are specific, parallel, and switching. Between all three corridors, the specific and parallel share some common points, as both are a static type, the travel distance and travel time are known. In contrast, the switching corridors are a dynamic type, which is the most flexible corridor among the three. The capacity is limited for a specific corridor as it uses the same principle as a single railway line. For the other two corridors, the capacity is much higher as the parallel corridor utilizes multiple lanes, and the switching corridor uses a dynamic approach with multiple horizontal layers.

On the last topic, the liabilities and risks involved when transferring liabilities are looked into. The main three actors involved are pilots, supervisory control, and traffic management system. The supervisory control, in this case, is the one regulating the laws like the civil aviation authority in Norway and United Kingdom, and the traffic management system is the one who is responsible for traffic planning, monitoring, and communicating with every party that uses the corridor. A risk analysis is given for transferring liability and a mitigation plan for all the risks identified to reduce the impact of the risk.

Preface

This thesis is submitted to the University of South-Eastern Norway (USN), campus Kongsberg, Norway. This work has been performed in collaboration between the Department of Science and Industry Systems, Faculty of Technology, Natural Sciences and Maritime Sciences, USN and Indra Navia with Professor, José Manuel Martins Ferreira (Department of Science and Industry Systems, USN) and Ole Henrik Dahle (Indra Navia) as supervisors.

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List of Abbreviations

AGL Above Ground Level

AI Artificial Intelligence

BVLOS Beyond Visual Line of Sight

CAA Civil Aviation Authority

CORUS Concept of operations for European UTM Systems

ConOps Concept of Operations

DDAM Drone-delivery using Autonomous Mobility

EVLOS Extended Visual Line of Sight

FAA Federal Aviation Administration

GPS Global Positioning System

ICAO International Civil Aviation Organization

MDS Medical Drone Systems

NASA National Aeronautics and Space Administration

NUAIR Alliance Northeast UAV Airspace Integration Research Alliance

RPOS Remotely Piloted Aircraft Systems

SESAR Single European Sky ATM Research

UAS Unmanned Aircraft System

UAV Unmanned Aerial Vehicle

UTM Unmanned Air Traffic Management

VLL Very Low-Level

VLOS Visual Line of Sight

Chapter 1

Introduction

1.1 Background

As the unmanned aerial vehicles (UAV) or commonly known as drones market is rising, the demands for commercial drones have been increased. The military has been using drones since the 1900s to do tasks such as supporting ground units or survey places where humans can't. In the commercial, the use of drones has been bloomed lately because drones are a useful tool in many civilian applications ranging from agriculture, inspections, deliveries, surveillance, mapping to media [1] (figure 1.1) and the price of a good drone is cheaper than before.

Research done by Goldman Sachs [2] predicts that the drone market will be around $ 100 billion between 2016 and 2020. The military will take 70% of the market while the consumer market will take 17%, and commercial/business and civilian will take 13% of the market. According to Goldman Sachs, the fastest growth opportunity will come from business and civil governments, as they are just beginning to explore the possibilities. With the raising of drones in the sky, there will be a need to manage all of those drones. A digital system that can manage UAVs activity and monitor those activities can be used for unmanned air traffic; it is called unmanned air traffic managment (UTM). A UTM is a networked collection of services that communicate together based on common rules [3]. With the use of a UTM, UAVs will no longer have to communicate to a single entity such as an assigned air traffic controller like traditional air traffic management (ATM). Instead, the UAVs will communicate freely between multiple service providers, which the service providers need to hold relevant security, performance, and safety standards given by authorities. A UTM system will ensure safety between unmanned and manned airspace.

Figure 1.1: Drone applications

1.2 Problem Statement

As for today, the UAV routing in airspace for UTM is centered around free-routing, which means the airspace is unstructured where point-to-point travel is possible. This kind of free-routing is restricted and/or forbidden by having huge volumes of UAVs in the airspace, which need special permission to fly the drone on a planned route. There will always be limitations when operating in free-routing. On the other hand, by utilizing structured airspace called corridor-routing or corridors, the airspace will be well defined for specific or several types of operation. Using corridor-routing will increase the capacity of UAV operations in the airspace, and it will enable safe distance in air traffic between unmanned and manned traffic. To meet the demand of operating UAVs safely in the European market, the EU developed a program under the Single European Sky ATM Research (SESAR) Joint Undertaking called U-Space. U-Space focuses on the operation of UAVs securely and safely in urban and rural areas. However developing structured airspace for UAVs will be challenging as there are a lot of factors that need to take into consideration, such as safety, risk, placement of the corridor, type of corridor, altitude, speed, weather impact and how the liability can be transferred in different corridor types.

Figure 1.2: Integration between manned and unmanned airspace[4]

1.3 Motivation

Current trends in research have demonstrated that using UAVs in different applications will rise in the future within urban and rural areas. In order to use UAVs in structured airspace within the law, a fundamental framework needs to develop in regard to factors such as safety, security, and quality of life for people and wildlife. A corridor-routing will enable safety in between the corridor and the surrounding environment. And this will be a trend in the future, which captures our curiosity to explore and develop a framework within an interesting area and future-oriented subject. This study, focusing on a fundamental framework for corridor type routing in UTM.

1.4 Objectives

The objective of this work is to develop a framework for corridor type routing in UTM by using guidelines from the Concept of operations for European UTM systems (CORUS) developed by U-space as inputs and basis for the framework. By handling different aspects of a corridor such as placement of a corridor, what kind of corridor to use, comparing corridor types, and transferring liability between corridors type.

1.5 Approach

To achieve our goals, we chose the SCRUM methodology. The choice of using SCRUM was based on the type of project to be carried out. SCRUM methodology allowed us to achieve maximum efficiency for each weekly sprint. In each iterative sprint, the tasks that were done in the last week were reviewed, and new tasks were created and organized then defined for the next week. In order to keep an overview of our task, we proposed the following sub-task:

- Researching in related topics within UAVs and UTM.
- Studying and evaluating literature review and current trends.
- Developing our framework by using guidelines from CORUS developed by U-Space.
- Define scenarios for placement and structuring corridors and junctions (in & out).
- Define what the major factors that differentiate the Static and Dynamic corridors and identify the risks when switching from static to dynamic corridors and vice versa are.
- Compare the types of corridors – Specific, Parallel, and Switching.
- Look into how the liability can be transferred in different corridor types between pilot, traffic management system, and supervisory control. And identify the benefits, risks, and mitigation when transferring liability.
- Validate our framework.
- Discussion about the framework and results.
- Final evaluation of the work and suggestions for future work.

1.6 Outline

The rest of the thesis is organized in the following way.

- In chapter 2, we present an overview of the literature review on topics related to UAVs and UTM. This covers a brief description of the different UAVs and what applications UAVs operate, technology such as Beyond Visual Line of Sight (BVLOS) and UTM interest areas within Europe and the USA.
- Chapter 3 contains our complete framework for corridor routing types in UTM. This chapter covers different scenarios regarding the placement of corridors, comparing different corridor types while looking at how liability can be transferred between multiple actors.
- In chapter 4, we present the validation of our framework.
- In chapter 5, a discussion about our framework is provided.
- Chapter 6 provides conclusions of our work, summarizing our contributions and our achievement. A suggestion on future work is presented in this chapter too.

Chapter 2

Literature Review

This chapter will cover the general aspect of UAVs or known as drones, UTM, and flight patterns to build the necessary foundations to understand the scope and results presented in this work. The chapter will also go through related works in the area of UAV and UTM.

2.1 Unmanned Aerial Vehicle (UAV)

UAVs or drones have been widely used for military and commercial purposes, from using the drone for video or photographs to using it in warfare. A UAV comes in various sizes and shapes [5]. UAV can be as small as handheld types to large aircraft, and can potentially be big as an airliner. UAV comes in a variety of configurations, multi-rotor, fixed-wing like the airplane, or a combination of rotary and fixed-wing. A UAV is typically made of light composite material to increase maneuverability and reduce the weight of the system [6], which will allow the UAV to reach high speed and high altitude. The most common UAV type is the multi-rotor drone, which provides a good solution for the most common applications, such as aerial photography and video surveillance. They are relatively easy to handle and give the user proper framing and a great control position [7]. Those are the cheapest options for professionals and hobbyists. Another advantage with multi-rotor UAV is they are compact. The design allows it to be compact with the use of multiple propellers to maneuver and is designed to fold down, which makes it easy to carry or transport the UAV. The multi-rotor UAV design allows high payload capacity, but higher payload capacity means a bigger UAV size. The multi-rotor drone has different configurations, such as tri-copter (3 rotors), quad-copter (4 rotors), hexacopter (6 rotors), and octocopter (8 rotors) [8]. Out of these configurations, the quad-copter is the most popular and most common to use. The quad-copter has two different configurations, one with 'x' wings and the other with '+' wing. Figure 2.1 illustrates the different configurations of a multi-rotor UAV.

The downsides of the multi-rotor UAV are limited-time flying, speed, and endurance. They work well for a small-scale project but are not suitable for a large-scale project which needs to cover a large area such as long-distance surveillance and aerial mapping. One of the fundamental problems with this system is the battery capacity: they need to use most of the energy to stabilize themselves in the air, and with equipment like the camera, it takes a significant toll on the battery life. The average battery time for a multi-rotor drone is about 30 minutes. The design of a multi-rotor makes it more vulnerable to wind, making the UAV unstable in heavy wind.

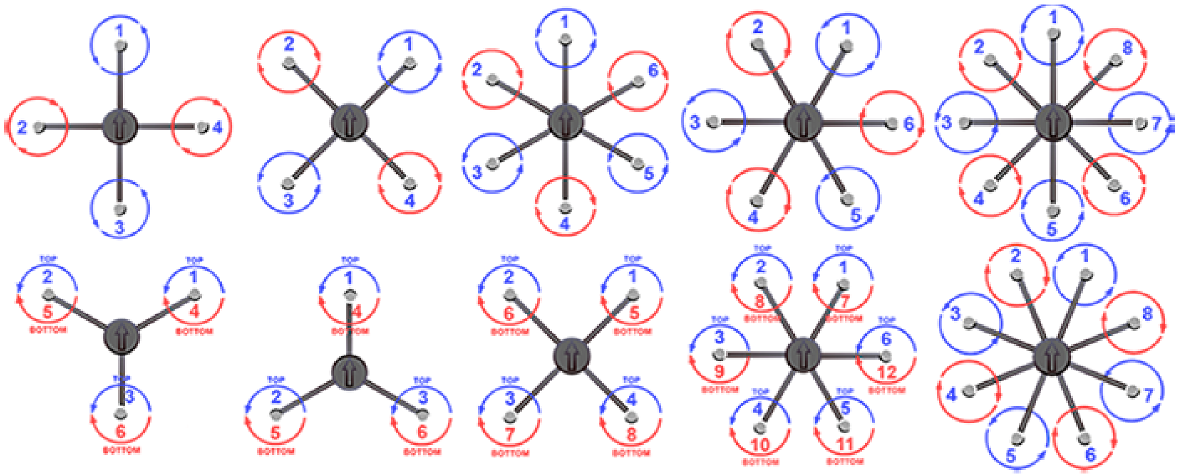

Figure 2.1: An illustration of the different configuration of multi-rotor drone [9]

A fixed-winged drone is an entirely different build and design than the quad-copter or multi-rotor drone. It uses the wings as in traditional airplane design. The design of a fixed-wing UAV comes with a central body that has two wings beside the body and a single propeller. To maintain itself in air, the two wings generate lift that compensates for its weight, allowing it to remain in flight [10]. Those types of UAVs are usually used in an application for oil & gas and agriculture. The drone's design allows it to cover a large area or long distance in a single battery cycle, which makes it great for mapping large or linear areas. It also provides excellent stability in high winds compared to multi-rotor drones. The design makes it ideal for flying in environments where rough and high winds are expected.

The downsides with a winged drone require a larger landing zone to takeoff and landing, thus making it take a longer time to set up the whole rig and not as flexible as the multi-rotor drone in that aspect. Another disadvantage it has compared with the multi-rotor drone is that it is not compact, the design of a fixed-wing drone is bulkier and more significant in size, which means the drone needs to be assembled before a flight. A fixed-wing drone is more challenging to fly than a multi-rotor drone. Figure 2.2 illustrates a typical fixed-wing drone model.

An comparison between multi-rotor drone and fixed wing drone is shown in figure 2.3.

UAV is equipped with the different latest technology such as Global Positioning System (GPS), infrared camera, laser, video transmitting, and obstacle detection. As UAV technology is getting more advanced, the UAV will be safer and better in all aspects. This will make the UAV more reliable in the city for more complicated services such as package delivery, emergency response, and healthcare.

Figure 2.2: Fixed wing drone model [11]

Summary Comparison

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

Figure 2.3: Comparison of multi-rotor drone and fixed-wing drone [10]

2.2 Beyond Visual Line of Sight (BVLOS)

In European countries like Norway, amateur operators can only operate a drone within Visual Line of Sight (VLOS), which means within 400 feet (120 meters) Above Ground Level (AGL) [12]. The aircraft must be visual at all times without visual aids like cameras, binoculars, or other tools. The UAV operator must be operated so that no collisions with other UAVs, people, construction, or vehicles occur. Figure 2.4 illustrates a VLOS operation where the pilot has the UAV in his visual.

Commercial UAV operators can apply for Extended Visual Line of Sight (EVLOS); this must be submitted to the Civil Aviation Authority (CAA). With the use of EVLOS, the operations can be above 400 feet AGL [12]. Beyond Visual Line of Sight (BVLOS) enables the UAV to operate greater distance, which means the UAV operator doesn't need to have the UAV insight. With BVLOS, it also creates a new opportunity to use UAV. As shown in figure 2.5, the illustration shows the difference between VLOS, EVLOS, and BVLOS, where BVLOS doesn't need any observer.

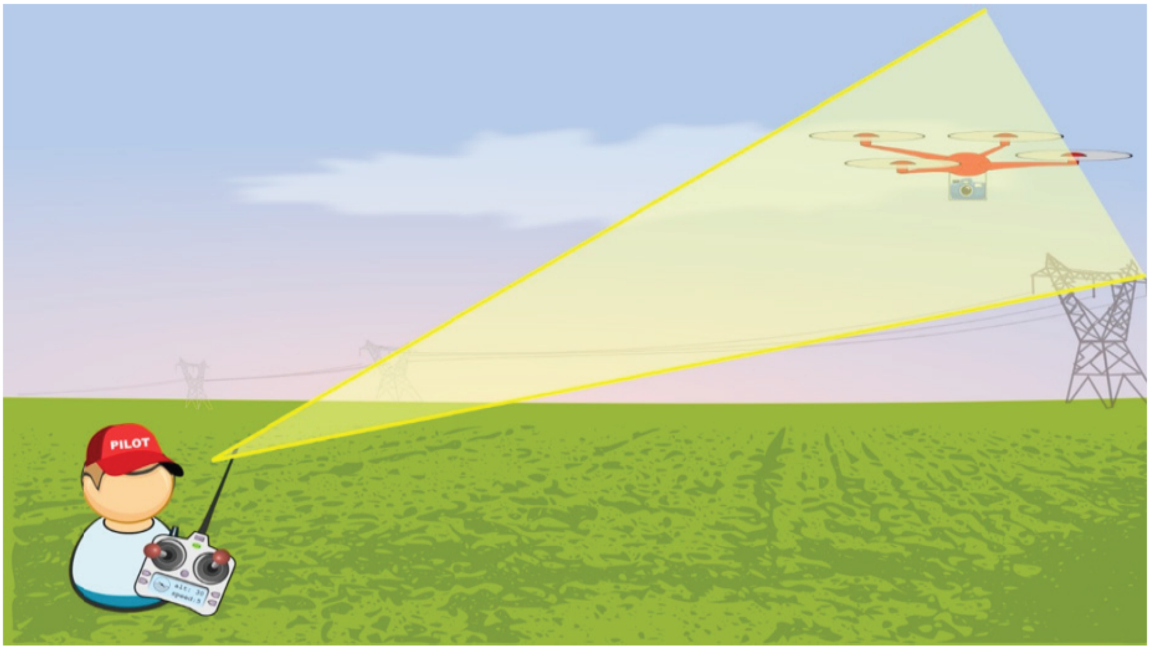

Figure 2.4: Illustration of VLOS operation [13]

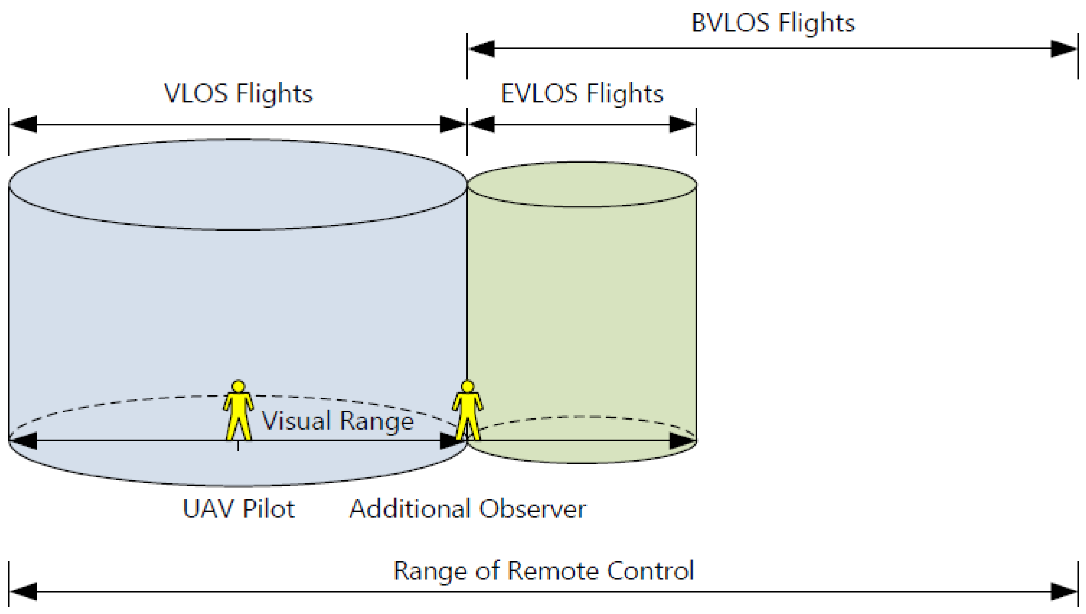

Figure 2.5: Difference between VLOS, EVLOS and BVLOS [14]

VLOS enables UAV services which have complex operations to fly without any human interaction [15]. To operate a UAV with BVLOS, the operator needs to get a qualification certificate for Unmanned Aerial Vehicle Operator (UAVO). The training consists of theoretical and practical performance of the UAV. From the training, the operator acquires knowledge such as flight rules, flight performance, flight route planning, and navigation on unmanned flights [15]. This training is necessary to operate BVLOS flights. Figure 2.6 demonstrates the difference application for VLOS and BVLOS operations.

BVLOS has been used in various scenarios where the technology can be executed safely and efficiently; one of those scenarios is package delivery by Amazon, which they call Amazon Prime Air [16].Other scenarios are agriculture, a linear inspection that stretches over a great distance, search and rescue, and border patrol [17, 18, 19]. BVLOS will become an essential requirement for developing autonomous passenger and air freight systems [20]. The UAV will depend on 360-degree radial technologies that allow it to be aware of its surroundings to deploy safely. As seen in figure 2.6, more complicated operations need BVLOS, such as package delivery. BVLOS technology will be crucial for the development of using a drone in UTM.

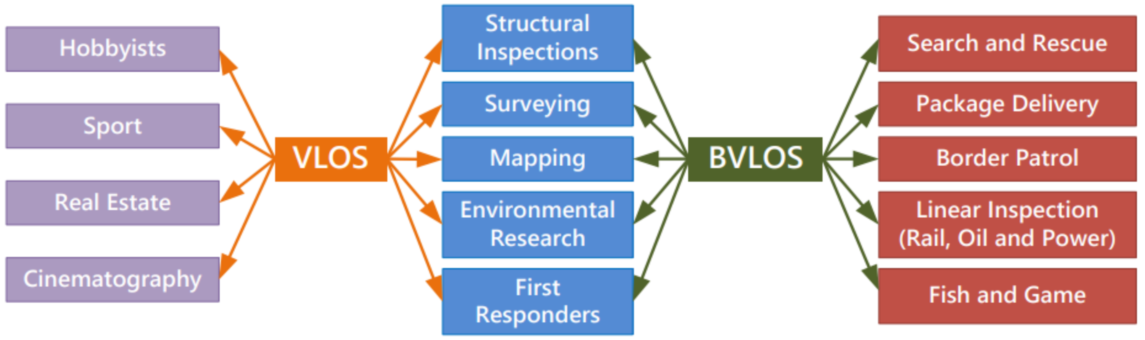

Figure 2.6: VLOS and BVLOS operation applications

Mission and test of BVLOS

In 2017 the first BVLOS application test in France performed by Delair-Tech was successful. The purpose of the flight was to inspect power lines by a remote camera and to record data to build models of the power grid. The drone flew 50 kilometers long with the use of the 3G network. The drone was guided in real-time and communicated through the 3G network (Figure 2.7).The flight itself was done in autopilot, but for the takeoff, two pilots were present, and another two pilots were present for the landing phase [21].

In 2016 a group of researchers from the University of Warsaw used a fixed-wing UAV of the type PW-ZOOM to perform a BVLOS operation to mapping glacier forelands in Antarctica. The UAV was designed, manufactured, and tested in the Warsaw University of Technology in Poland and was equipped with an automatic control system that can perform autopilot linked to a telemetry module. To communicate to the Ground Control Station, another similar module was connected to the computer running a unique flight path planning and managing the UAV flight. The flight was autonomous but could be interrupted by sending a return to base order. The operation was performed by a three-person team, which included the remote control pilot, the ground control station, and the technical operator. The three-person team had BVLOS licenses issued by the national authorities, and the flight itself was 500 meters above the sea level and covered a distance of 720 kilometers. Photogrammetric of the UAV BVLOS flights provided higher quality data than images from satellite [22]. Figure 2.8 shows the UAV routes during the BVLOS operation over the west coast of Admiralty Bay, and table 2.1 shows the parameters during the BVLOS operation.

Figure 2.7: Power line inspection by using BVLOS, Delair Tech [21]

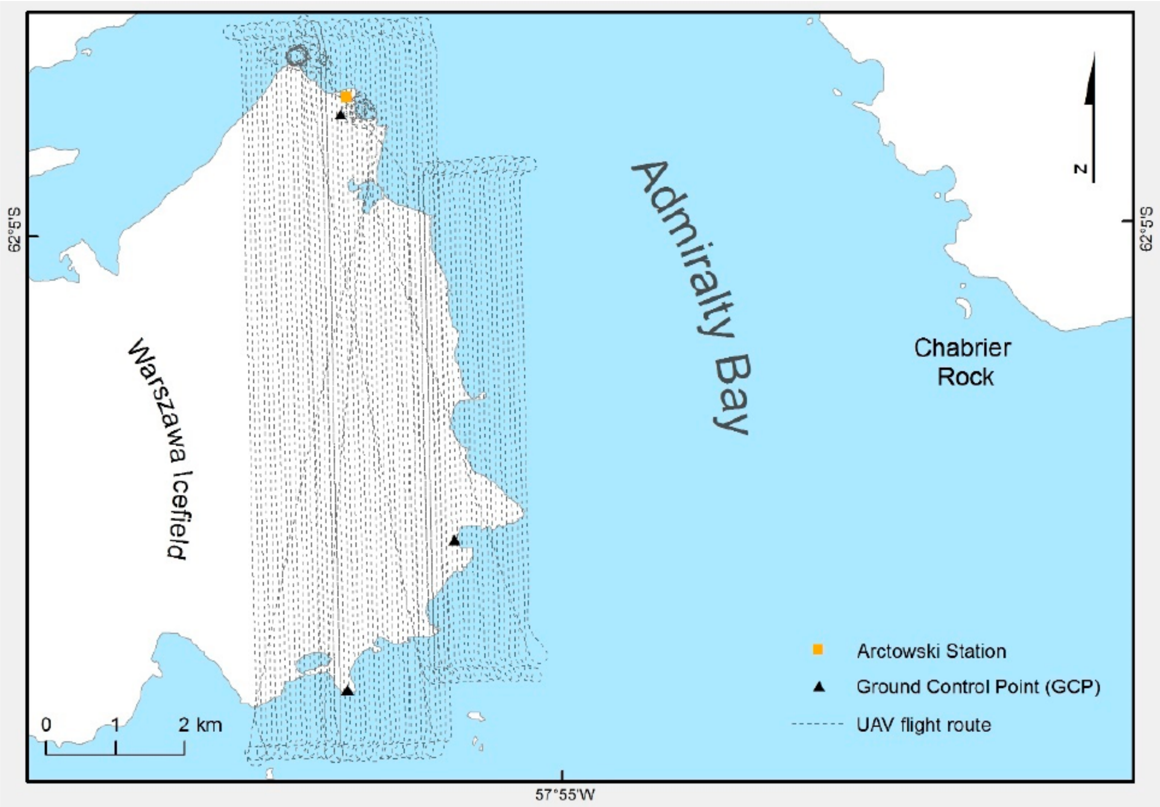

Figure 2.8: UAV flight routes during a BVLOS operation [22]

UAV	PW-ZOOM
Number of flights	3
Total time of flight	Flight nr 1: 2h 50 min 19 s Flight nr 2: 2h 12 min 35 s Flight nr 3: 1h 58 min 28 s
Camera set	Canon 700D with 35 mm lens (RGB)
Number of images	Flight nr 1: 3123 (RAW) Flight nr 2: 2377 (RAW) Flight nr 3: 2178 (RAW)
Distance	Flight nr 1: 296 km Flight nr 2: 227 km Flight nr 3: 197 km
Flight altitude	500 m a.s.l.
Cruise speed	Flight nr 1: 104.5 km/h Flight nr 2: 102.7 km/h Flight nr 3: 99.9 km/h
Ground Sampling Distance	0.06 m

Table 2.1: Parameters of the BVLOS operation in the Antarctic[22]

The use of BVLOS technology is widely in use around the world; in 2017, Israel was involved in the BVLOS industry and granted full permission for BVLOS flight. Airbotics was the first to be granted

BVLOS commercial drone operation with the use of computer software and artificial intelligence on the drone (figure 2.9). The use of artificial intelligence means that there is no need to have a human drone pilot interact with the drone in terms of decision and action. This means fewer labor costs and reduces the crew's lengthy training as well as allowing no drone experts to perform complex drone operations [23]. The first part of Airbotics BVLOS system is a UAV named "Optimus," which is a drone that can operate up to thirty minutes while being equipped with a payload up to one-kilogram. The second component in the system is an unmanned automated airbase that the UAV can launch from and lands on. The last and the third component is the software and the artificial intelligence (AI) software, which is the most crucial component. The AI software enables drone operators to easily use the software and manage the operation with just a click.

Figure 2.9: Airbotics BVLOS system

2.3 UAV Services and Operations

UAV technology is getting more advanced and safer, which can provide services of using UAV to do more complicated operations such as goods delivery, mapping, inspection, medical services, and agriculture. In 2013 the founder of Amazon, Jeff Bezos, announced their development with a drone delivery service called Amazon Prime Air in an interview with 60 minutes. The service will use a drone to deliver packages to customers within 30 minutes of ordering by using an autonomous drone. To qualify for this service, the order must be up to 2.25kg and be within 16 kilometers of a participating Amazon center. The package must be small enough to fit in the cargo box that the drone is going to carry [16]. Figure 2.10 showcases the Amazon Prime Air system, with the drone and the cargo box to put in the package.

"A do it yourself" quad-copter drone delivering products was proposed in a paper from 2015. Gatteschi et al. [24] was looking into what kind of hardware to choose to limit the risk from autonomous delivery and a framework for ordering the products and shipping. The advantage of a system like this is to increase delivery speed in an urban area with heavy traffic and in an area where it is difficult to deliver goods and the drone ability to carry out consignments autonomously. One of the use cases the researcher used for this system is to deliver drugs where it is essential to get the product quickly because medications could require more urgently than other goods. Furthermore, medications are usually small and lightweight to fit in a cargo box that can be delivered by a drone. The paper presented a prototype of the system with a drone-based delivery service. Figure 2.11 shows the whole process related to the application, from customer login to payment to checking the weather, altitude, and shipping.

Figure 2.10: Amazon Prime Air [16]

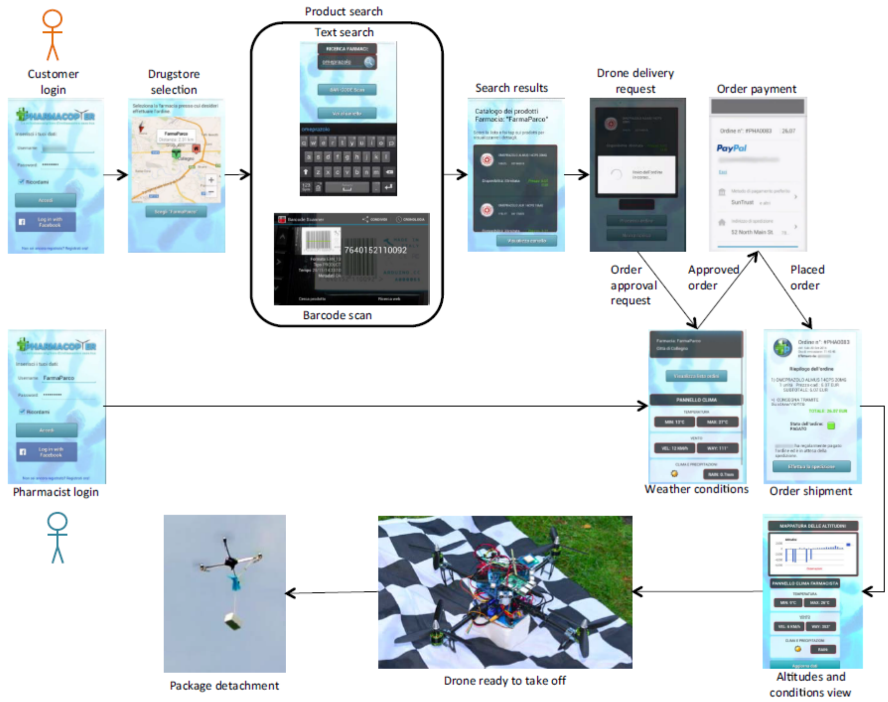

Figure 2.11: Application for medication system by using drone delivery [24]

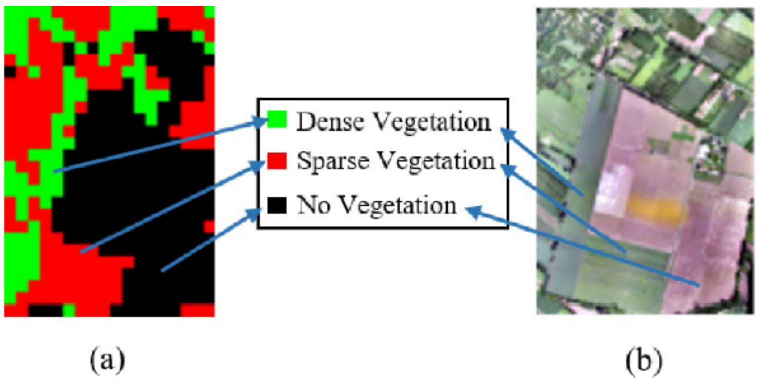

Figure 2.12: Comparing satellite image (a) with drone image (b)

In [25], the authors looked into the precision of agriculture monitoring by proposing a methodology to classify vegetation into sparse and dense vegetation by fusion free available satellite data (Landsat 8) and drone image. Drones are available at an affordable price with the advanced technology and the ability to take high-resolution image data and have geographic locations of the images. This will help the user to have a clear picture of the ground information for agriculture. By equipping a multi-spectral camera on drones, it gives the advantage of imaging the infrared portion of the electromagnetic spectrum over the crops, which can provide information about the health condition of the crops. The algorithm proposed in the paper proves to be successful by distinguishing between the two vegetation classes. It can be validated by comparing the satellite image with the drone image. Figure 2.12 compares satellite image and drone image, which is classified into sparse and dense vegetation.

Figure 2.13: Rendering of a medical transport drone [26]

Transportation of medical goods is mostly done by manned aircraft and wheeled motor vehicles, which can be costly and slow. In the article [26], the authors explore the use of UAVs to deliver medical products, including blood derivatives and pharmaceuticals to hospitals, offshore vessels, and mass casualty scenes in critical demand as well as the need for such services, how feasible it is, and risks associated with UAVs transportation. The authors anticipate that the UAV package delivery system will be a feasible and financially way of transport for the civilian sector soon. In a disaster environment that needs resource-intensive, speed will play a significant role and the capabilities of UAVs. UAVs can travel over rough terrain and closed roads without any risk to the flight crew. According to the article, the use of UAVs could be a viable way to transport medical products in a time of critical shortage. Figure 2.13 illustrates an early rendering of a medical transport drone. In paper [27], the authors explore the use of a medical drone system for amusement parks. The study proposes the implementation of Medical Drone Systems (MDS) that can be implemented in areas such as amusement parks and skiing resorts. These areas are usually filled with tourists who are scattered everywhere in a wide area. In case of emergencies in such areas, it is difficult to reach the patient quickly, it is time-consuming to locate the patient and could endanger the patient's life. A system like MDS is designed to do this task more effectively without human error, which will save a lot of time, effort, and successfully rescue the patient. By having a group of drones that can quickly identify and locate the scene of emergency through GPS data and travel to the required destination. Included in the MDS, a phone app will be used for further communication with the central station, so the correct aid is given to the accident location. The MDS block diagram is shown in Figure 2.14, and the two prototypes of an MDS drone is shown in Figure 2.15. The drones can carry different medical supplies, where the first drone is known by its high speed, which can carry less weight medical supplies such as allergy and insulin shots. The second drone is a Hexacopter that can handle more weight, such as first aid kit supplies.

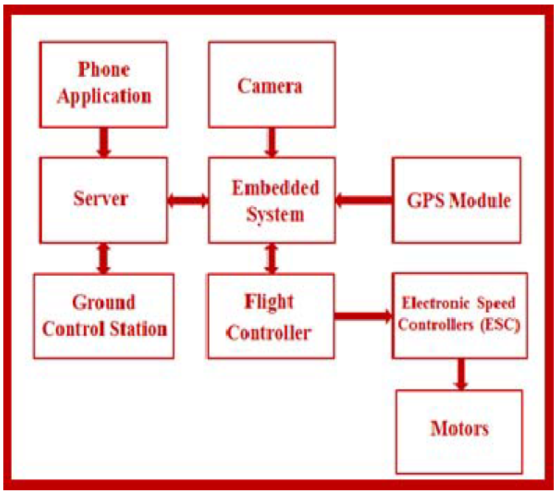

Figure 2.14: Block diagram for MDS [27]

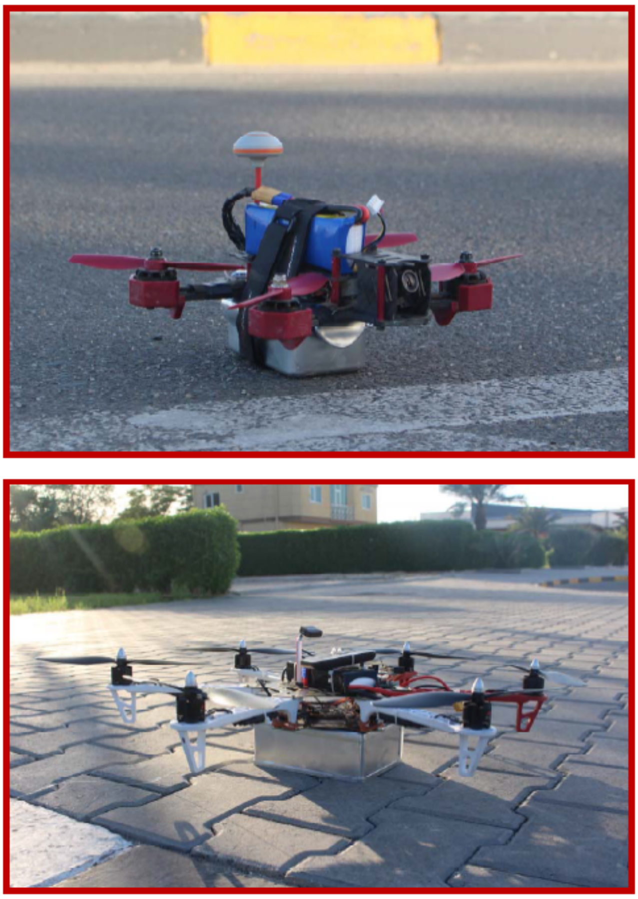

Figure 2.15: Prototype of a MDS drone

Drones are a powerful tool for different operations; construction site inspection is one of the services that could use a drone for assistance. A study [28] developed a real-time robust drone system that can perform a site inspection and, at the same time, detect violations in a construction site. The system uses drones to inspect and monitor numerous types of construction sites remotely from a nearby control station. The system was developed in collaboration with Abu Dhabi Municipality (ADM). The inspection is performed at different stages of the construction process and at different time intervals according to the ADM workflow. By using a drone, the inspector can detect any violation in the construction site, and the drone will send data periodically in that way, the inspector gets a live feed in their smartphone application or computers. If a violation is detected, the inspector can issue a warning or fines through the application.

In [29], the authors look into cooperative load transport with a movable load center of mass by using multiple quadrotor UAVs. The load itself is connected to the UAVs by cables. A single UAV does not have enough maximum thrust to transport the load, but by using four UAVs, it will have enough thrust to carry the load. In a multi-agent system, one of the methods is formation control, and in this study, the main structure that is considered in this paper is the leader-follower. In a leader-follower structure, one of the agents is the leader, and the other agents will follow the leader. Figure 2.16 shows an illustration of how to utilize multiple UAVs to transport a load.

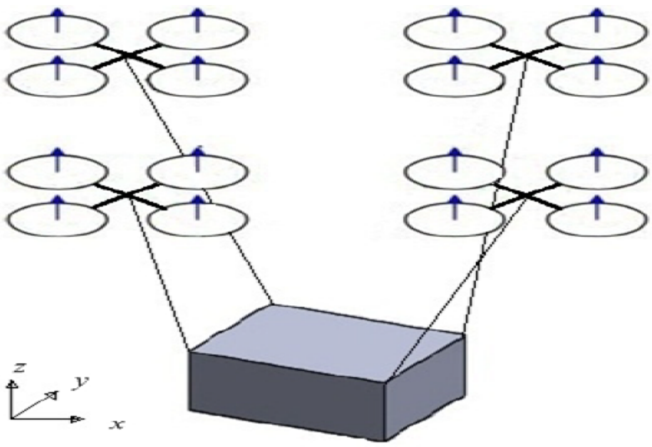

Figure 2.16: Load transportation with multiple UAVs

Using a drone to deliver has been looked into as a possible solution to future last-mile delivery. In [30], Yoo and Chankov discuss an innovative delivery method called Drone-delivery using Autonomous Mobility (DDAM). DDAM will solve three problems of future cities: (1) high demand for delivery (2) short delivery lead-time and (3) complex traffic congestion. By having interviews with experts from relevant industries and using the Design Science Research Guideline, the results indicate that DDAM is feasible as an alternative delivery method in high-demand seasons. The use of drones could increase the speed and flexibility of the delivery process, and it is possible to expand delivery capacity. With the use of an autonomous drone, it will reduce traditional transportation methods such as package delivery with a wheeled vehicle. However, the study needs further research for the concept because the evaluation was conducted by only two companies, which limited the study from gathering wider point-of-views. Figure 2.17 illustrates the concept of a single DDAM process.

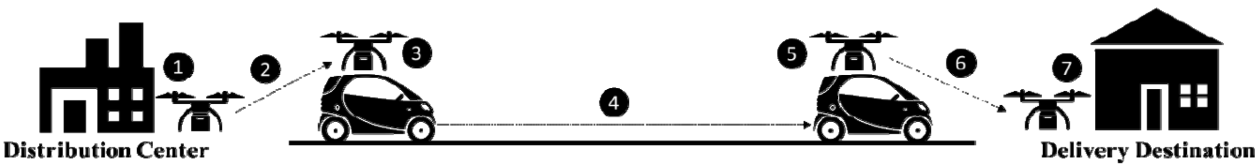

Figure 2.17: Concept of Drone-delivery using Autonomous Mobility [30]

2.4 Unmanned Air Traffic Management (UTM)

UAV has been rising in recent years by using UAV to make different applications such as deliveries, search, and rescue, videography, traffic monitoring, an inspection of a pipeline or electric wires, and agriculture. Those applications will likely occur in the same airspace of many dynamic and static constraints, such as high wind areas, urban cities, and airports. Therefore those operations need to be managed to ensure safety and efficiency [31]. In the same paper, a Concept of Operations (ConOps) is presented for the National Aeronautics and Space Administration (NASA) UAV UTM. The main focus of the ConOps is safely enabling large-scale small UAV operation in low altitude airspace, and the UTM supports large-scale VLOS and BVLOS operations. It can be broken down into two primary mantras; (1) structure where necessary and flexibility where possible and (2) a risk-based approach in terms of geographical needs and use case for airspace performance requirement. According to the paper, the UTM principles include only authenticated UAV. Which means only those UAVs are allowed to operate in the airspace. Other principles are; the UAV will stay clear of each other, manned aviation and the UAV system or operator need to have full awareness of all constraints in the air, and the ground and priority go-to UAV with public safety. Allowing the users to connect through a common application protocol interface with information about airspace constraints and other operations will provide much more flexibility. This would also enable operators to path planning their services that are ideal to their business needs while meeting all required constraints. For this UTM research, NASA evaluates four operations at four technical capability levels. These capability levels will increasingly be more complex and in denser environments, which will start from remote areas to urban airspace. The flow of each significant component is shown in figure 2.18 for the UTM ecosystem, and a test case is shown in figure 2.19 with the sequence of events.

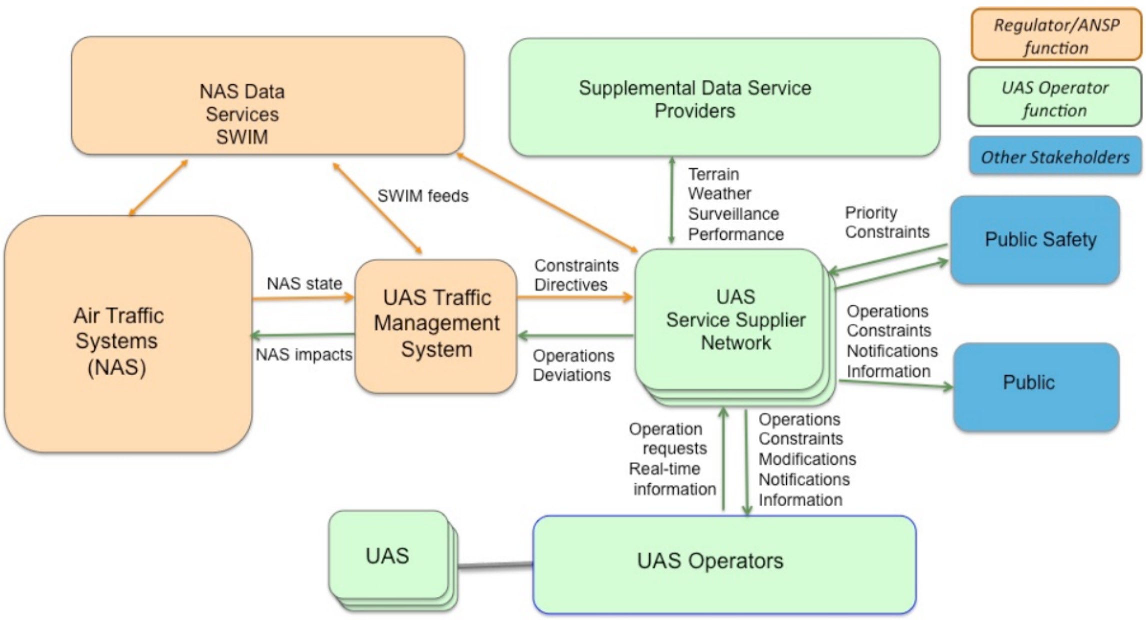

Figure 2.18: UTM ecosystem [31]

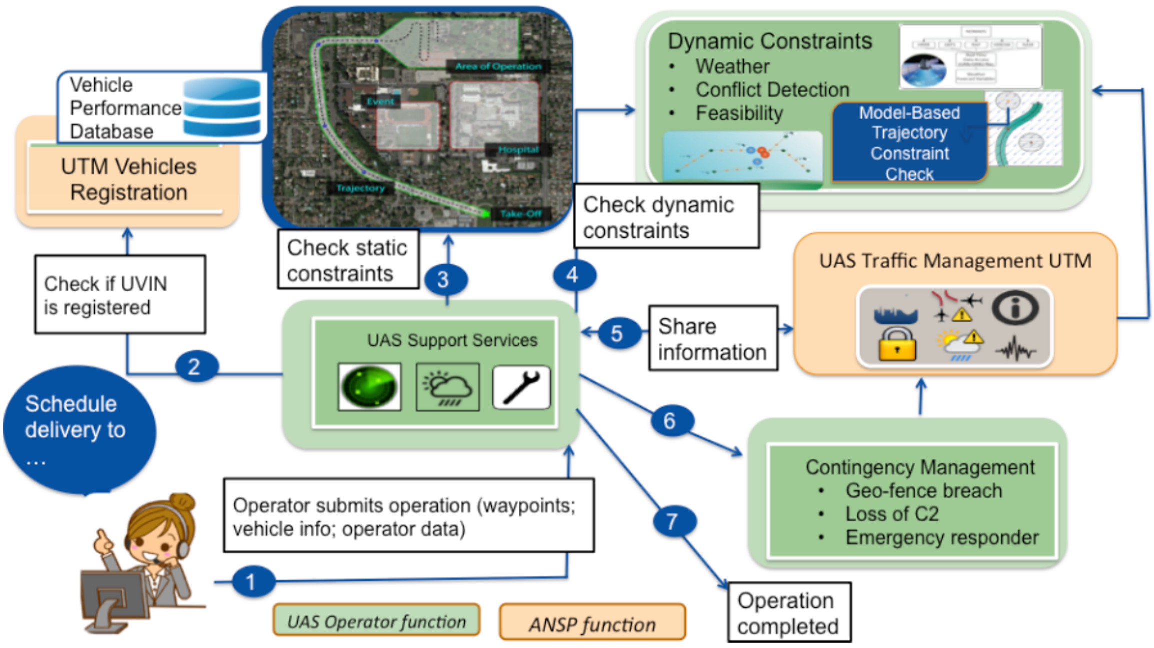

Figure 2.19: A test case of the UTM system [31]

In 2016 The European Union announced the development of a concept called U-space as the demand for drone services increased rapidly [32]. The U-space introduces new services and specific procedures designed to support safe, efficient, and secure airspace access for a large number of drones. U-space, provide a framework to support drone operations and effective interface to manned aviation such as air traffic management and air navigation services for providers and authorities. By utilizing U-space, the Concept of Operations for European Unmanned Traffic Management Systems (CORUS) sees this as an opportunity that can enable business activity related to drone use while maintaining an acceptable level of safety and public acceptance [33]. CORUS developed ConOps in regards to the use-cases of U-space.

U-space have eight fundamental principles [33]:

- To ensure the safety of all airspace users operating in the U-space framework, as well as people on the ground.
- To provide a scale-able, flexible and adaptable system that can respond to changes in demand, volume, technology, business models and applications, while managing the interface with manned aviation.
- To enable high-density operations with multiple automated drones under the supervision of fleet operators.
- To guarantee equitable and fair access to airspace for all users.
- To enable competitive and cost-effective service provision at all times, supporting the business models of drone operators.
- To minimize deployment and operating costs by building upon, as much as possible, existing aeronautical services and infrastructure, including Global Navigation Satellite Systems, as well as those from other sectors such as mobile communication services.
- To accelerate deployment by adopting technologies and standards from other sectors where they

meet the needs of U-space.

- To follow a risk-based and performance-driven approach when setting up appropriate requirements for safety, security (including cyber-security) and resilience (including failure mode management), while minimising environmental impact and respecting the privacy of citizens, including data protection.

The implementation of U-space services will slowly be introduced over four phases. Those phases depend on the increase of drone automation, availability of services, and technologies. Figure 2.20 shows a graphic of U-space phases by starting from U1 to U4. Table 2.2 describes each phase.

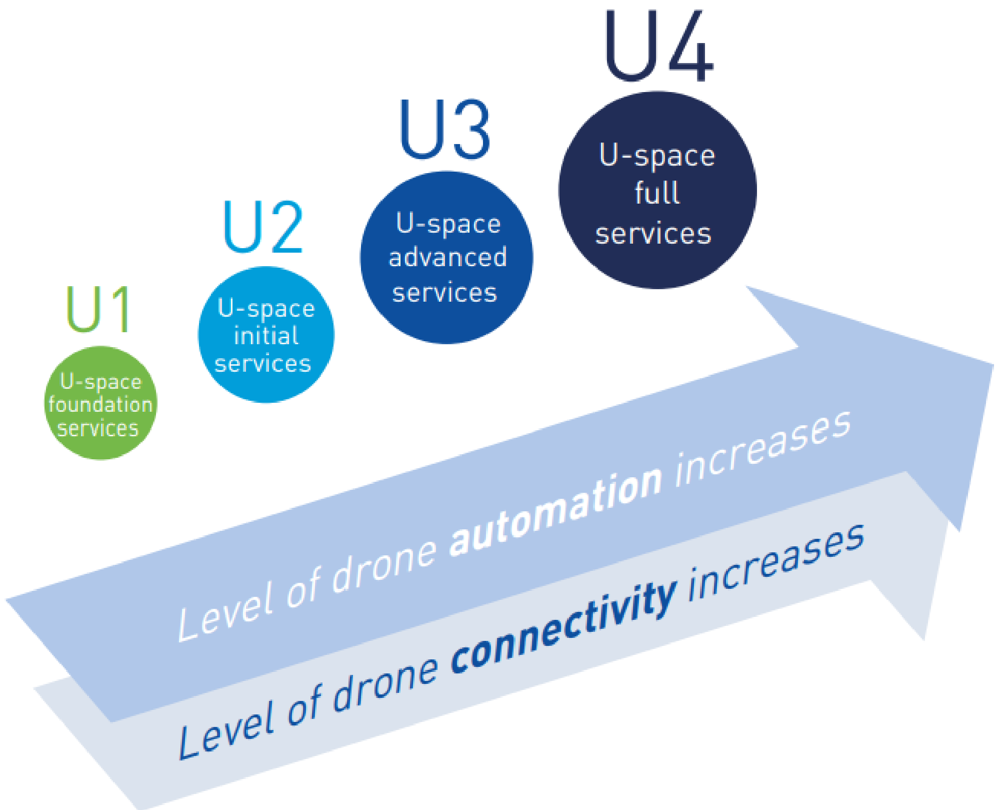

Figure 2.20: U-space phases [32]

U1	U2	U3	U4
U-space foundation services provide e-registration, e-identification and geo-fencing.	U-space initial services support the management of drone operations and may include flight planning, flight approval, tracking, airspace dynamic information, and procedural interfaces with air traffic control.	U-space advanced services support more complex operations in dense areas and may include capacity management and assistance for conflict detection. Indeed, the availability of automated 'detect and avoid' (DAA) functionalities, in addition to more reliable means of communication, will lead to a significant increase of operations in all environments.	U-space full services, particularly services offering integrated interfaces with manned aviation, support the full operational capability of U-space, and rely on a very high level of automation, connectivity and digitalisation for both the drone and the U-space system.

Table 2.2: Description of each phases in U-space implementation [33]

A study from [34] shows that having the UTM using the air parcel model can be a viable solution for the Unmanned Aircraft System (UAS) regulation issue. The system divides the airspace's low altitude in a 3-D air parcel map in which the land parcel owners possess the airspace above their real estate and approve or disallow any overflights. It allows the UTM to control every UASs and to identify pilots and detect non-compliant flights. In the study [35] presented a realistic approach to designing an unmanned traffic network over low-level urban airspace. The design is based on data-driven airspace modeling to understand manned traffic behavior and then find an available network area before determining the network structure in unmanned traffic. A sample using primary UTM interventions in airspace with autonomous point-to-point drone traffic is presented in [36]. The samples are based on statistics and synthetic images and interactive simulation of simulated situations. In paper [37] an air tracking and monitoring for UTM are presented. A UTM prototype monitoring system that can be implemented as a microservice to a complete UTM ecosystem. The system can monitor, track, and control all operations done by drones by utilizing telemetry and sensors that send velocity and position.

UAV flight planning and corridor

To ensure safe usage of drones in the city, flight path and planning plays a huge part in facilitating the operation of drones in the city. Increasing the use of drones will increase the amount of traffic flight management. In airspace, it can be used as three dimensional with different layers for the flight path. The three-dimensions are used today by conventional air transport, where the plane is given a set of height it needs to have its course on. The same method can be applied to drones with different levels of horizontal layers. In airspace, there is no fixed, which means flight paths can be dynamically routing.

Figure 2.21 shows the flight plan for a drone with the departure (S) and arrival (E) [38]. The yellow path shows a fixed path for the drone, and the fixed path will be the path the drone will take if there is no interrupt in the path. The green path is an alternative route if any interrupt or occurrence happens to the fixed path. It will ensure that the drone will be at arrival point (E) even if the fixed or the alternative route have any interrupt or occurrence in either of the paths.

An alternative way to have multiple drones in the same path is to have coexisted multiple fixed paths. The paths will have different layers in the airspace in which the UAV can change its fixed path with an intersection, and those intersections will shift the UAV from one level to another. Figure 2.22 shows how multiple fixed paths can be in use. The green path shows a fixed path in the lower level, and the blue path is the upper. The grey point is where the drone can shift from lower to upper level or from upper to lower level. The yellow path is the standard fixed path for the drone. Multiple layers in the airspace will double the UAV in the flight paths, making it more efficient in the use of UAVs.

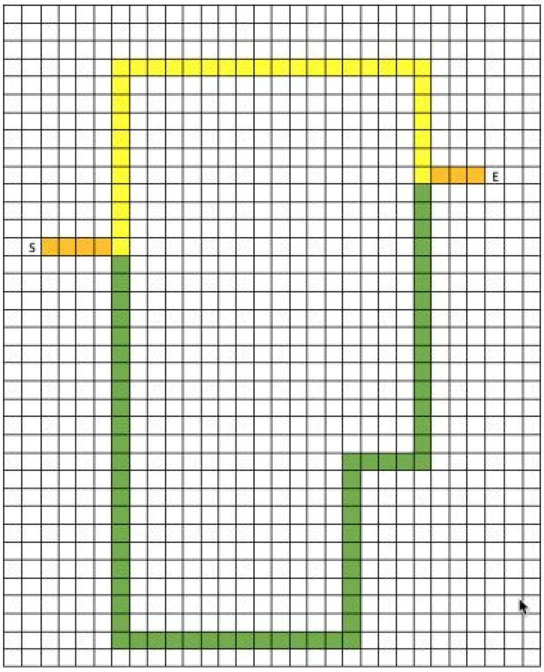

Figure 2.21: Flight plan [38]

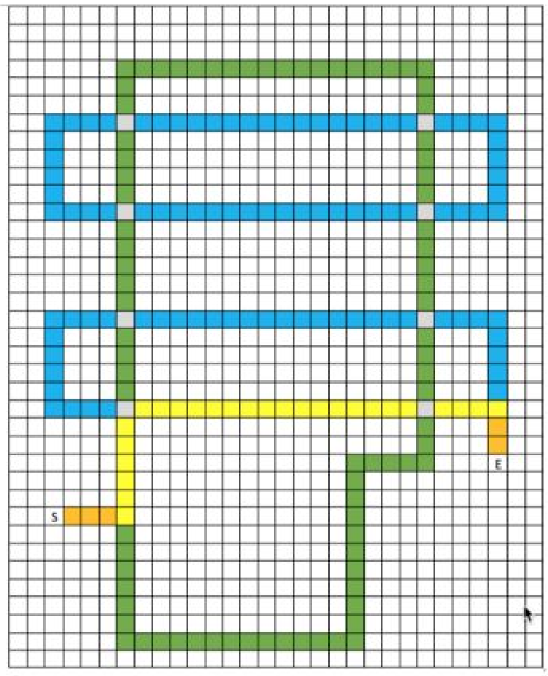

Figure 2.22: Multiple flight paths in different levels [38]

The Northeast UAV Airspace Integration Research Alliance (NUAIR Alliance) is testing drones in the corridor with AirMap [39] as the selected UTM provider. The corridor will be America's first unmanned aerial vehicle traffic management for BVLOS. The corridor will be 50 miles long, stretching from Syracuse to Griffiss International Airport in New York. AirMap provides visualize, manage, and support ongoing drone operations with its UTM platform; thus, the project can ensure safely and efficiently drone operation. The project will test the ecosystem [40] with functionality, including tracking of cooperating and non-cooperating targets, simulation capabilities, and secure data collection. The foundation of the project is the system and technologies at the NY UAV Test Site. To meet with the future UAV standard, the project has certification of UAV detect-and-avoid systems to integrate into the national airspace system. Figure 2.23 shows a 50-mile corridor with the flight path, radar, and air-born aircraft.

A study showing [34] by having the UTM using the air parcel model can be a viable solution for the UAS regulation issue. The system divides the airspace's low altitude in a 3-D air parcel map in which the land parcel owners possess the airspace above their real estate and approve or disallow any overflights, which allows the UTM to control every UASs and to identify pilots and detect non-compliant flights.

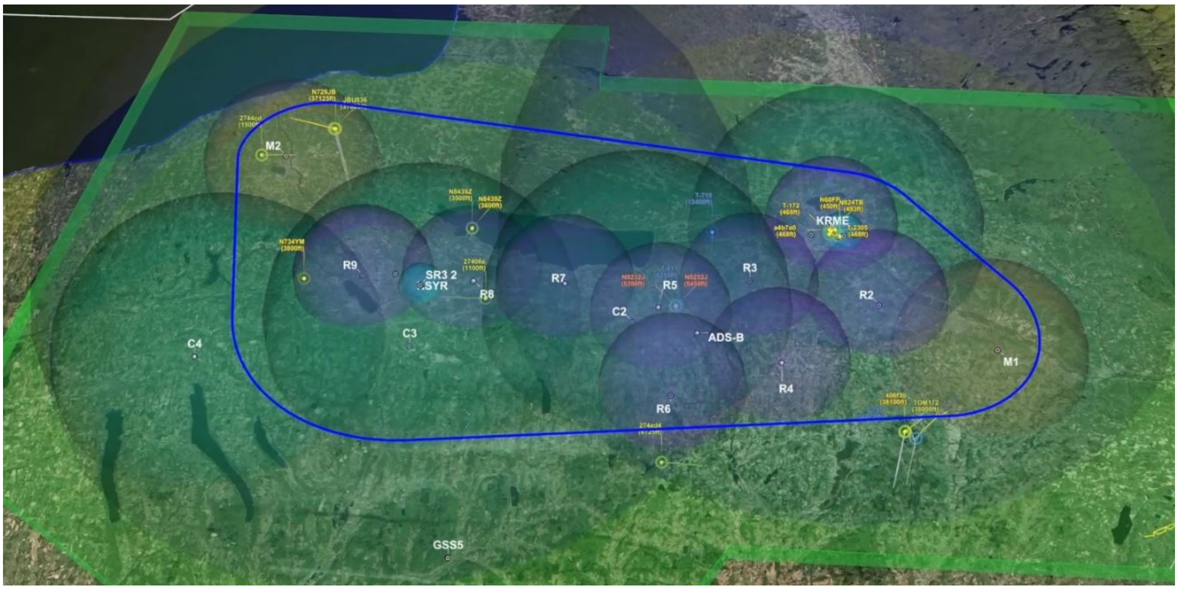

Figure 2.23: 50-mile corridor [40]

Chapter 3

Framework of Corridor type routing in UTM

3.1 Placement scenarios and structuring corridors and junctions

At the moment, drone routing in airspace for UTM is centered around free-routing, which means the airspace is unstructured where point-to-point travel is possible. This kind of free-routing is restricted and/or forbidden by having a huge volume of airspace which needs special permission to fly the drone on a planned route. There will always be limitations when operating in free-routing. On the other hand, by utilizing structured airspace called corridor-routing or corridors, the airspace will be well defined for specific or several types of operation. This means that in a corridor routing, there will be a physical separation between different air traffic types, and separation factors could be based on the type of operation like delivery of medical or logistics, weight and speed, junction points, and endpoints. Thus it will enable a safe distance in the traffic separation. Figure 3.1 shows a high level system of UTM with drone in the corridor. It also shows the connection between the UTM and other factors like ATM service provider, UTM service provider, UTM airspace authority, and third-party provider, which provide data like weather, security, and environment monitoring. This framework will follow the guidelines from CORUS developed for the U-space program deployed by the SESAR Joint Undertaking.

3.1.1 Very Low-Level airspace

By the guidelines of CORUS, the maximum altitude in a Very Low-Level (VLL) airspace is 150 meters or 500 feet above any obstacles except for having permission or when taking off or landing. To ensure safety to the ground and surroundings, the UAV operations would be 100 meters (330 feet) to 120 meters (400 feet) above ground level (AGL). In this way, the maximum altitude has a buffer between 30-50 meters, which can be used in case of an emergency. The maximum height is measured above the ground and not above sea level. This means that even if the height of terrain changes or varies, the maximum altitude will change for UAV.

In Figure 3.2 shows the maximum altitude changes if the height of the terrain varies.

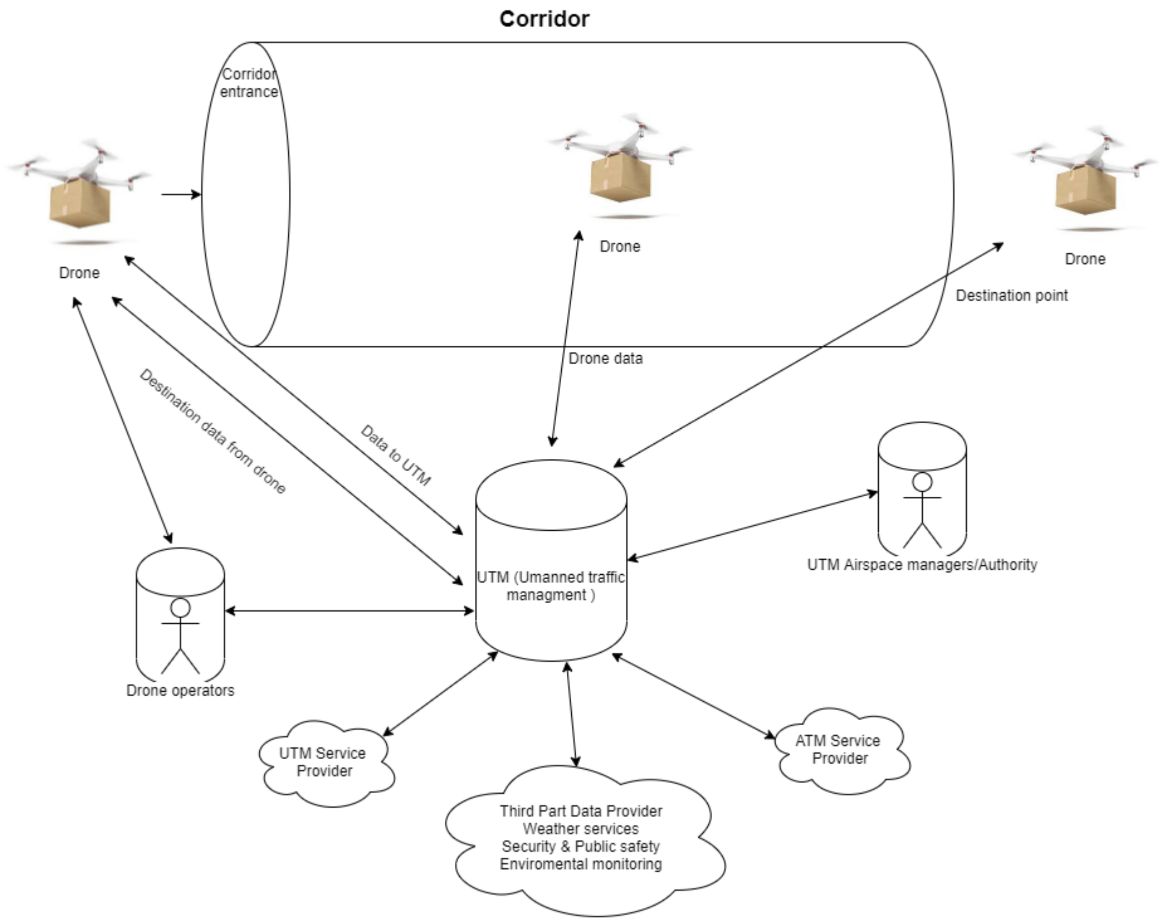

Figure 3.1: High level system of UTM with drone in corridor

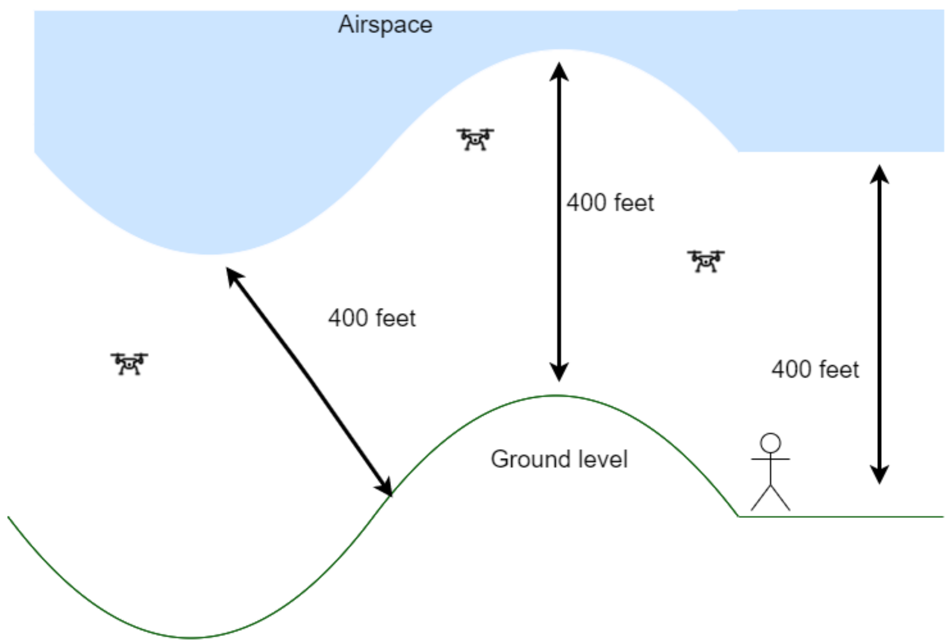

Figure 3.2: Maximum altitude changes based on the terrain

3.1.2 Separation

Separation is a concept for keeping aircraft a minimum distance from each other and the surrounding obstacle to reducing the risk of collision. The minimum separation is maintained through procedural rules and situational surveillance methods such as primary radar [33]. The separation standard is based on the capabilities of the service offering by using, for example, radar resolution or the capabilities of all aircraft involved, such as maintaining a horizontal flight level accuracy of at least +/-100 feet. With the advanced technology of small, high-accuracy positioning and tracking systems, the minimum safe separation distance of aircraft can depend on the overall navigation and surveillance system's performance. Weather conditions can affect UAVs in a variety of ways that must be taken into consideration when defining safe separation. From the guidelines of CORUS, conflict management can be divided into three categories.

Strategic (pre-tactical) de-confliction	Tactical separation provision	Collision avoidance
The ability to plan a flight that does not conflict with other users, before departure. This involves operators sharing operation plans with relevant parties and reducing any potential loss of separation either by an agreed procedural separation or by planning routes that avoid other aircraft.	The ability to maintain situational awareness, visually or with instruments. Air traffic control (ATC) uses radar to predict aircraft trajectories and issues clearances to resolves potential conflicts. Similarly, Visual Flight Rules (VFR) defines the tactical actions necessary to manage potential loss of separation between two aircraft in uncontrolled airspace.	The ability to prevent a collision as part of a last course of action, if the above separation plans and provisions fail.

Table 3.1: Separation conflict management

A safe separation between the corridor and the surrounding environment will be 150 meters (500 feet) for structures, people, and motor vehicles. Figure 3.3 illustrate the distance from the building and people. Those distances are safe distances that are not under the UAV pilot control. The term "under control" means that if someone is part of the drone flight or is briefed and instructed about the safety procedures to avoid any accidents occurring during the UAV flight. The safe separation in a corridor needs to factor the speed and navigational accuracy of the aircraft. All UAVs that use the corridor will need to have collision avoidance systems onboard to prevent any accident occurring in the corridor. The separation distances between aircraft are usually measured in seconds; for example, a speed of 90 km/h takes four seconds to cover 100 meters, which could be set as a safe separation distance. We can compare the same to cars, in which the safe separation distance is three seconds. With that in mind, we set the minimum horizontal distance to 100-300 meters between UAVs in the corridor to ensure safety.

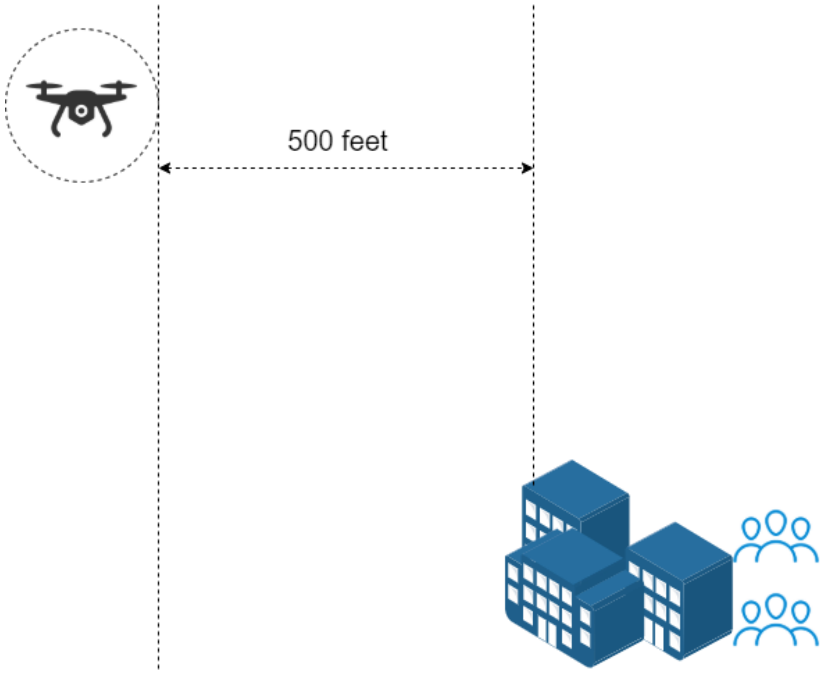

Figure 3.3: Caption

3.1.3 Weather impact on corridor

In [41], the authors look into how weather impacts UAV operations. The main weather factors are wind and turbulence, temperature, humidity, fog, cloud, and haze. The most significant weather hazard is wind and turbulence, causing most weather accidents for aviation. According to a study conducted by the Federal Aviation Administration (FAA) [42], 53,4 percent of all-weather accidents are caused by the wind for manned aircraft. This is 35% more than any other weather factors. Even though this is for manned aircraft, the same can apply for UAV as the wind can change trajectory or flight path, or in our case, out of corridor boundary. Other factors that wind can affect are limiting control over the UAV and reducing endurance, such as battery life. Extreme temperature can affect the physical components of a UAV as well as the performance of the aircraft—typical operating temperatures for UAV lie between - 20-degree Celsius and 50-degree Celsius. Batteries and airframe material are the components that will be most affected by extreme temperatures. For high temperatures, it will affect the material like plastic as it can potentially deform the airframe, and low temperature would affect the capacity of the batteries like LiPo batteries as it would discharge the battery faster. Another weather hazard that can cause problems is humidity because the moisture produced by humidity could damage the electronics onboard the UAVs. The damage done by water can result in odd or inaccurate behavior, loss of functionality, or in extreme cases, fire as the electronics get high amounts of heat. Fog, cloud, and haze can potentially affect a BVLOS operation because, in a BVLOS operation, the pilots require a first-person view, mostly in the form of an onboard camera. Heavy clouds, fog, or haze will reduce the distance the camera will see and could cause dangerous situations as the UAV could fly into buildings, power lines, and other vehicles. Figure 3.4 shows the weather hazards and the severity of each hazard.

Severity	Hazards	Weather Types
Moderate	• Reduced Visibility	• Fog • Haze • Glare • Cloud cover
Adverse	• Loss of communication • Loss of control • Loss of command • Diminished aerodynamic performance • Reduced operator effectiveness	• Wind and turbulence • Rain • Solar storms • Temperature and Humidity • Snow and Ice
Severe	• Severe damage to or loss of aircraft • Unacceptable risk to operator and personnel	• Lightning • Hail • Tornadoes • Hurricanes

Figure 3.4: Weather hazards for UAV [41]

3.1.4 Two corridor scenarios

The placement of the corridor will be important to determine all the drone services that will use the structured corridor for their operations. We will look into two different scenarios for the placement of the structuring corridor.

- **Scenario one: Rural area**
- **Scenario two: Urban area**

3.1.4.1 Scenario one: Corridor placement in rural area

In rural places, there will not be much hindering in terms of building or people. The area will be much more open space compared to an urban area. To mask the noise of UAVs traffic, the corridor can be placed near the main road or near the ocean, depending on its topography. If the area has a lot of mountains or tall structures taller than 120 meters, the corridor needs to reroute around those areas to minimize the risk of conflict with manned airspace. This is because the maximum altitude of UAVs operation is 120 meters or 400 feet in Norway to have a safe separation between manned and unmanned airspace. A corridor in rural areas will be open for higher speed for the UAVs as long the separation between the UAVs and the surrounding of the corridor is safe.

The corridor width is placed to 500 meters, 250 meters each side from the centerline. The width is placed to be 500 meters to ensure fixed-wing-UAVs can turn in the corridor without leaving the corridor. For a rotary-drone, the corridor doesn't need to be wider than a few meters, like 10 meters each side because a rotary-UAV can stop itself and adjust to the corridor's structure. The width can always be changed and adjusted if the surrounding area allows it. The corridor will have mixed traffic with different UAVs configuration to make it safe for the surrounding environment. In the corridor, the UAVs need to have the ability to separate the safe distance between other UAVs and keep the distance during the whole flight. In figure 3.5 shows the distance to ground and corridor width.

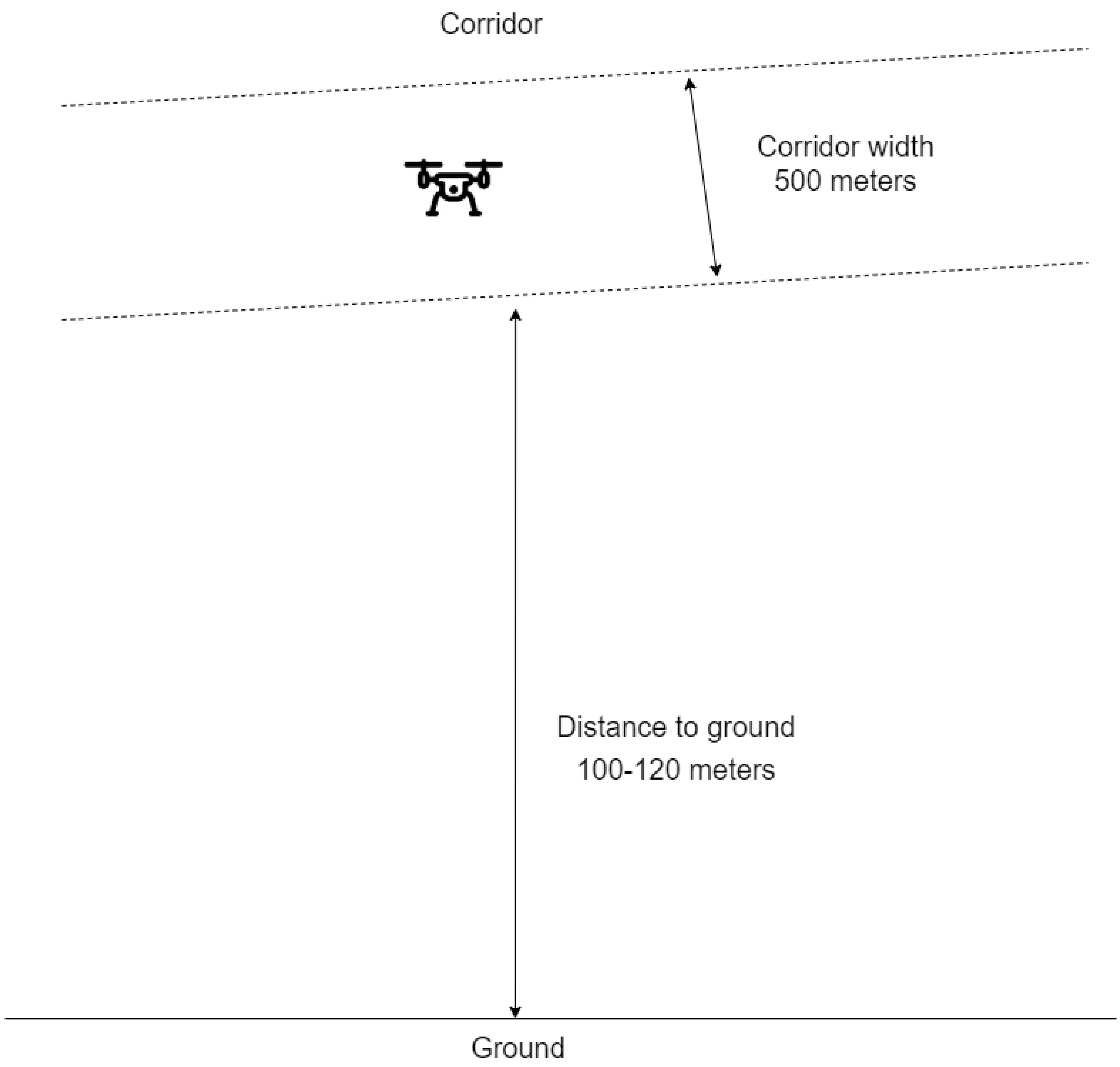

Figure 3.5: Corridor distance from ground and corridor width

We will look further into the corridor with flight paths for the UAVs in a rural area with different route points. In this scenario the entry point of the corridor is placed in a rural place near Kaltenbakk in Buskerud and stretched to Hellvikskog in Nesodden. The corridor length is approximate around 35 kilometers and the given flight route is mostly over Oslofjord to avoid obstacles for UAVs.

In figure 3.6 shows the map with the corridor placement in a rural area with an entry point and exit point.

Point one is the entry point for the corridor; here is the starting zone for all the UAVs. Between points, one and two is the transition point, where the route changes from land to sea. In this transition point, the flight path crosses over a road that the UTM and pilot need to be aware of. Most of the route from point two to four is over the sea, but in the middle of the route, the flight path goes over an island called Håøya that needs some precaution. Point four to six the corridor crosses over some roads and settlements, as there are no tall structures or obstacles the pilot only needs to take some precaution in case of emergency. Point six is the landing zone/exit zone for this particular corridor.

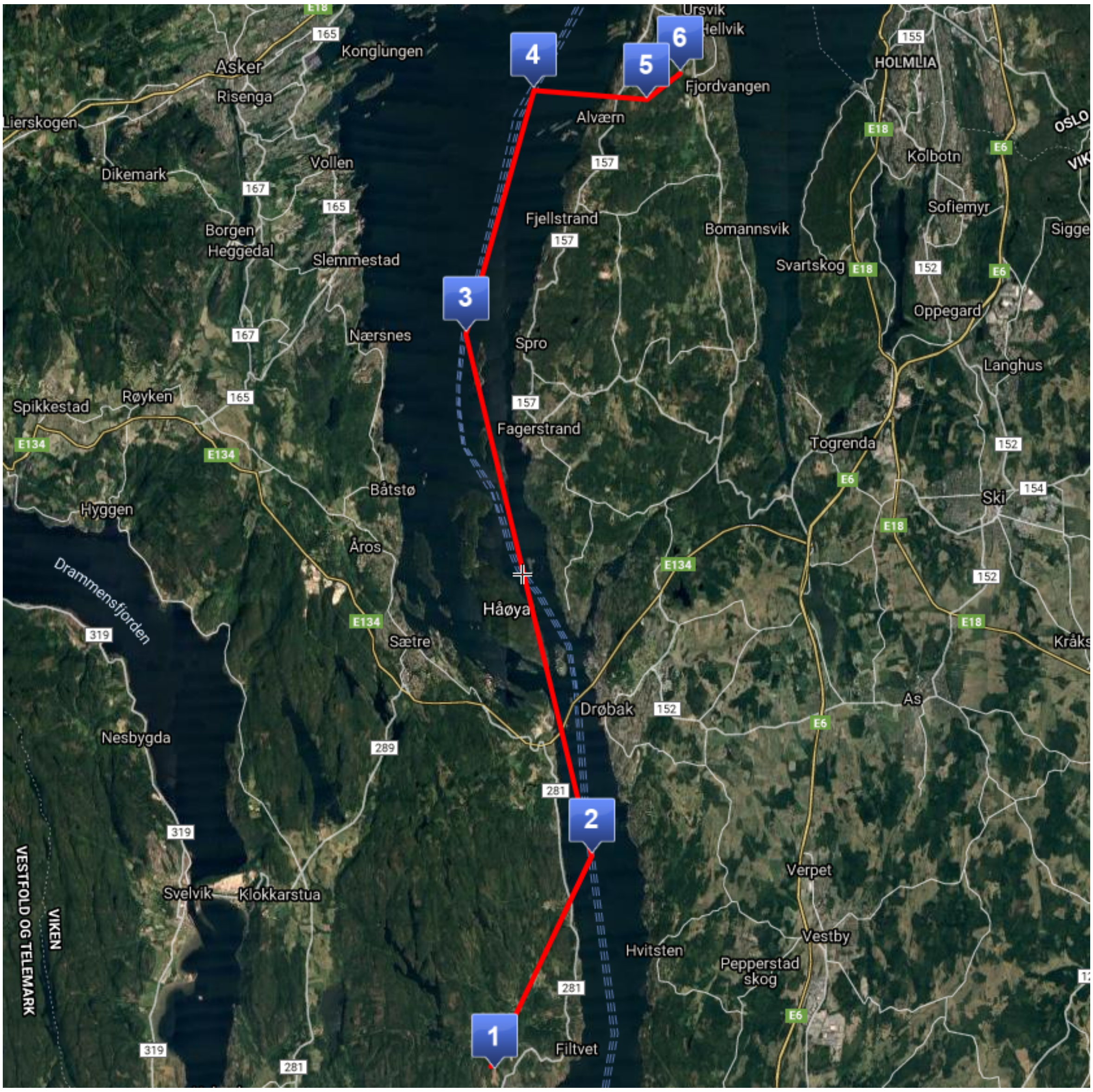

Figure 3.6: Corridor in rural area

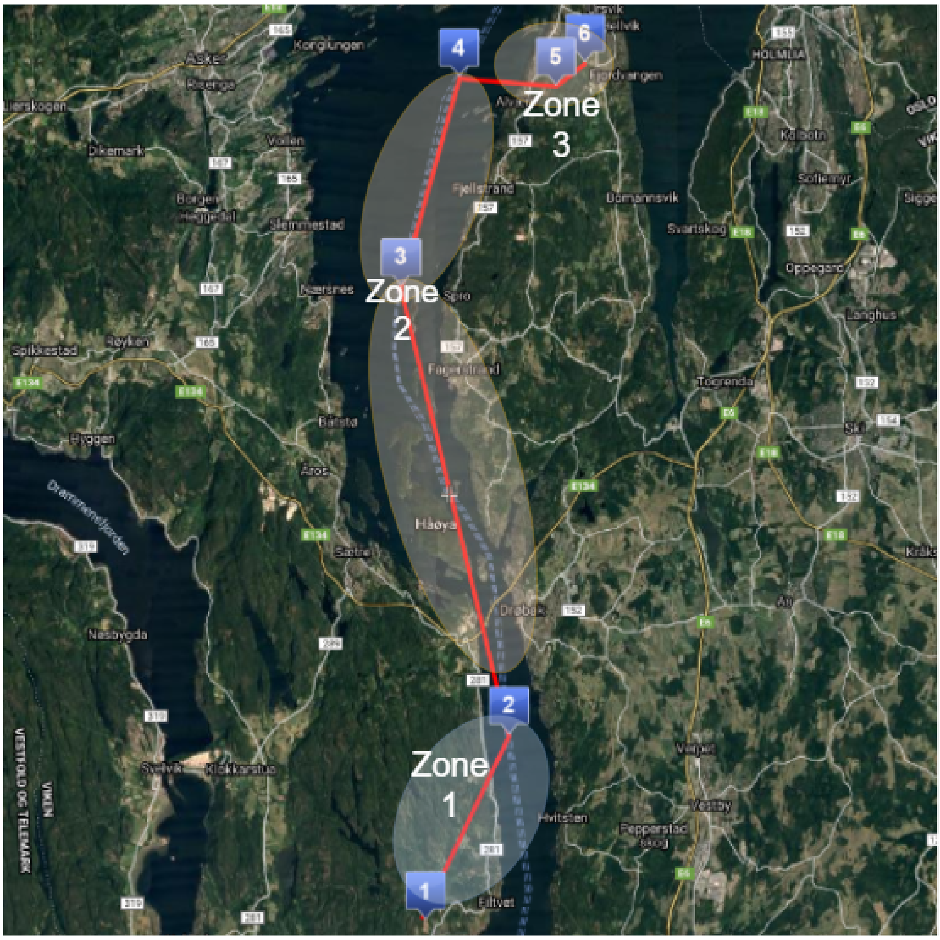

Figure 3.7: Speed zone for corridor in rural area

The speed in the corridor can be regulated; when crossing roads or settlements, the speed needs to be lowered to ensure safety. In Norway, the maximum speed is 60 knots (110 km/h) for Remotely Piloted Aircraft Systems (RPAS) RO1. For RO2 and RO3, the maximum speed is 80 knots (148 km/h). In our corridor, we define speed zone as zone one, zone two, and zone three. We define the speed limit in zone 1 and zone 3 to 70 km/h. Zone 1 and zone 3 crosses over settlements that need to have lower speed when the UAVs cross over those places, thus the speed limit is set to 50 km/h. The route of zone 2 is mostly over the sea, which means the speed limit can be increased. We set the speed to 90 km/h in zone 2.

As mentioned, those speed limits in the corridor can be changed depending on the factors such as weather, traffic in air, ground or sea, and other external factors that need to be taken into consideration that can affect the UAV's operations or the corridor.

The separation is defined in 3.1.2, and it is defined as 100 meters horizontal distance, and the UAVs need to have a collision-avoidance system to ensure no collision will occur in the corridor. With that in mind, we can calculate the density of traffic.

$$density = m/L$$

m = number of vehicles
L = length of corridor

In a perfect condition with a length of 35km long corridor and 100m separation between UAVs will give us 350 vehicles flying through the corridor. In this case:

m = 350 vehicles

L = 35 km

Which gives us:

$$density = 350/35km = \textbf{10 vehicles/km}$$

Based on our calculation, the density of the corridor is ten vehicles per kilometers in a perfect condition. A more realistic number would be much lower, because factors such as weather condition, maintain right separation distance and speed.

The flow of the traffic can be calculated by:

$$flow = n/t$$

n = number of vehicle passed through a point.

t = time frame.

From out speed definition in 3.1.4.1, the average speed in corridor is:

$$averagespeed = (50 + 70 + 90)/3 = \textbf{70 km/h}$$

By having the average speed, we can find out the time it takes the UAVs to fly 1 km and then use the time to find the traffic flow.

$$time = 1km/70km/h = \textbf{51 s}$$

n = 10 vehicles/km

t = 51 seconds

$$flow = 10/51s = \textbf{0.19608 vehicles/sec ->} \textbf{ 705 vehicles/h}$$

This will give us a flow of 705 vehicles per hour in a perfect condition without any external factors impacting the corridor. A more realistic number would be way lower than this where different factors would impact on the traffic flow.

Junctions can be added to the corridor to make it even more flexible. The junctions are an entry zone for entering another corridor that goes to other places. In our scenario, we put in three junctions that lead to another corridor in the west, north, and east. In figure 3.8, point three and six have junction points that lead to another corridor; those new corridors are highlighted in green. Point three has two junction points, one corridor leads to the west, and the other one leads to the east. Junction in point six leads to a corridor heading to the north. Each of those new corridors has a different set of rules with new speed limitation and separation distance.

With 4G or 5G network, the drone operators can always be connected with their UAV. In this way the UAV will be tracked for every movement in real time and broadcast to other operators in the area and the UTM. This will provide extra safety for all involved in the corridor.

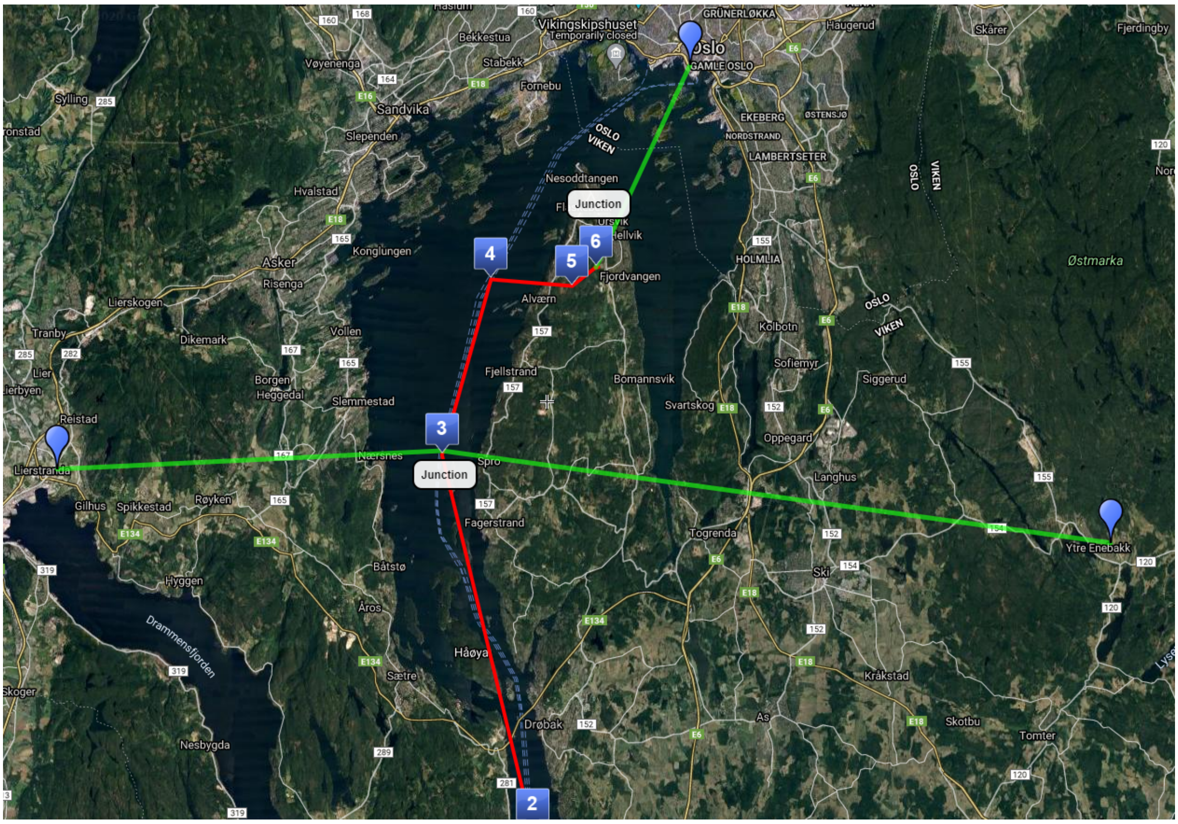

Figure 3.8: Junction points

3.1.4.2 Corridor placement in urban area

A corridor in an urban area needs to be carefully placed as there are a lot of safety factors that need to be taken into consideration, and external factors like to not disturb other people and privacy. The corridor can be placed near a highway or near busy roads to mask the sound from UAVs traffic from people or buildings. It needs to be rerouted around tall buildings to have enough safety distance between the corridor and the surrounding area, in this case, tall buildings and people. The corridor will have mixed traffic with different UAVs configuration to make it safe for the surrounding environment, and in the corridor, the UAVs need to have the ability to separate safe distance in the corridor between other UAVs and keep the distance during the whole flight.

In this scenario, the corridor height will be 120 meters AGL, with 120 meters; it would clear most buildings, as mentioned before, if there is a tall building in the path the corridor needs to reroute around the building or place the corridor somewhere else to avoid conflict. The width will be set to 500 meters, 250 meters each side from the centerline to provide enough space for turning left or right. Another factor that the width is set to 500 meters is weather could impact the UAV and drift it away from the corridor, but with 500 meters in width, it would provide enough space for UAVs to be within the corridor. An illustration is shown in figure 3.9.

The entry point in this scenario is marked with number one in figure 3.10. This is where every UAV starts before entering the corridor. Mark two is where the first junctions are placed. The junctions lead to two separated corridors, one in south-west marked with blue and another one in south-east marked with green. Based on the application of the UAV and flight path, the operator could choose the corridor for their needs. The corridors in this scenario are placed mostly over busy roads to mask the noise of the corridor traffic. In this way, the corridor traffic won't disturb the surrounding area. A collective endpoint is given for both corridors marked with an airplane sign. The blue corridor length is approximately 11.8 km long, and the green corridor length is approximately 11.9 km long.

In figure 3.11, a third junction is added to have a flight path into the city. In this area, the type of flight is restricted by factors such as the UAV's weight, what type of operation, and need special permission to enter. Those restrictions are made to avoid any conflict or accident.

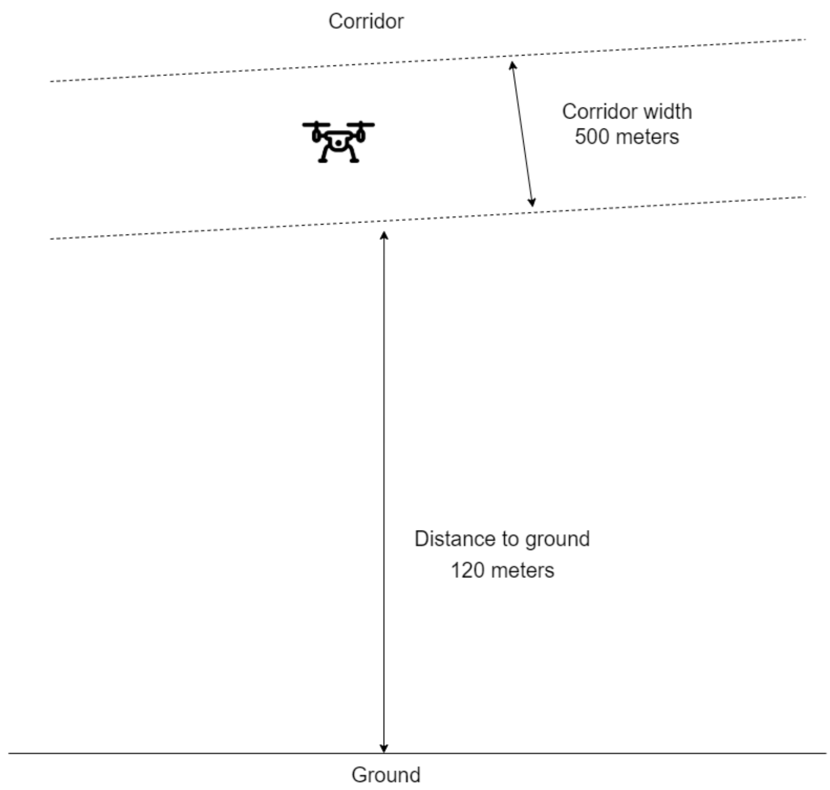

Figure 3.9: Corridor distance from ground and corridor width in urban area

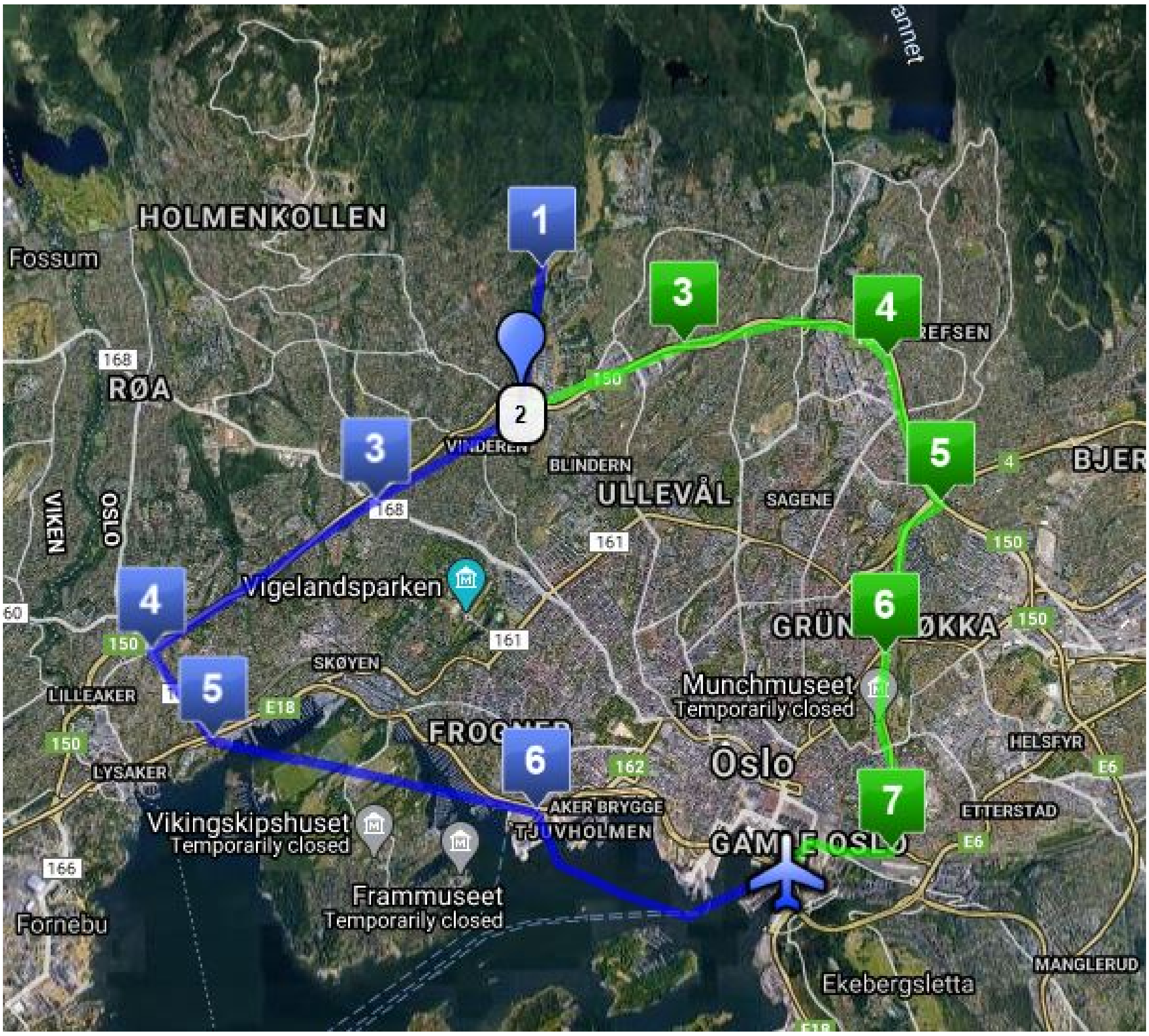

Figure 3.10: Corridor in urban area

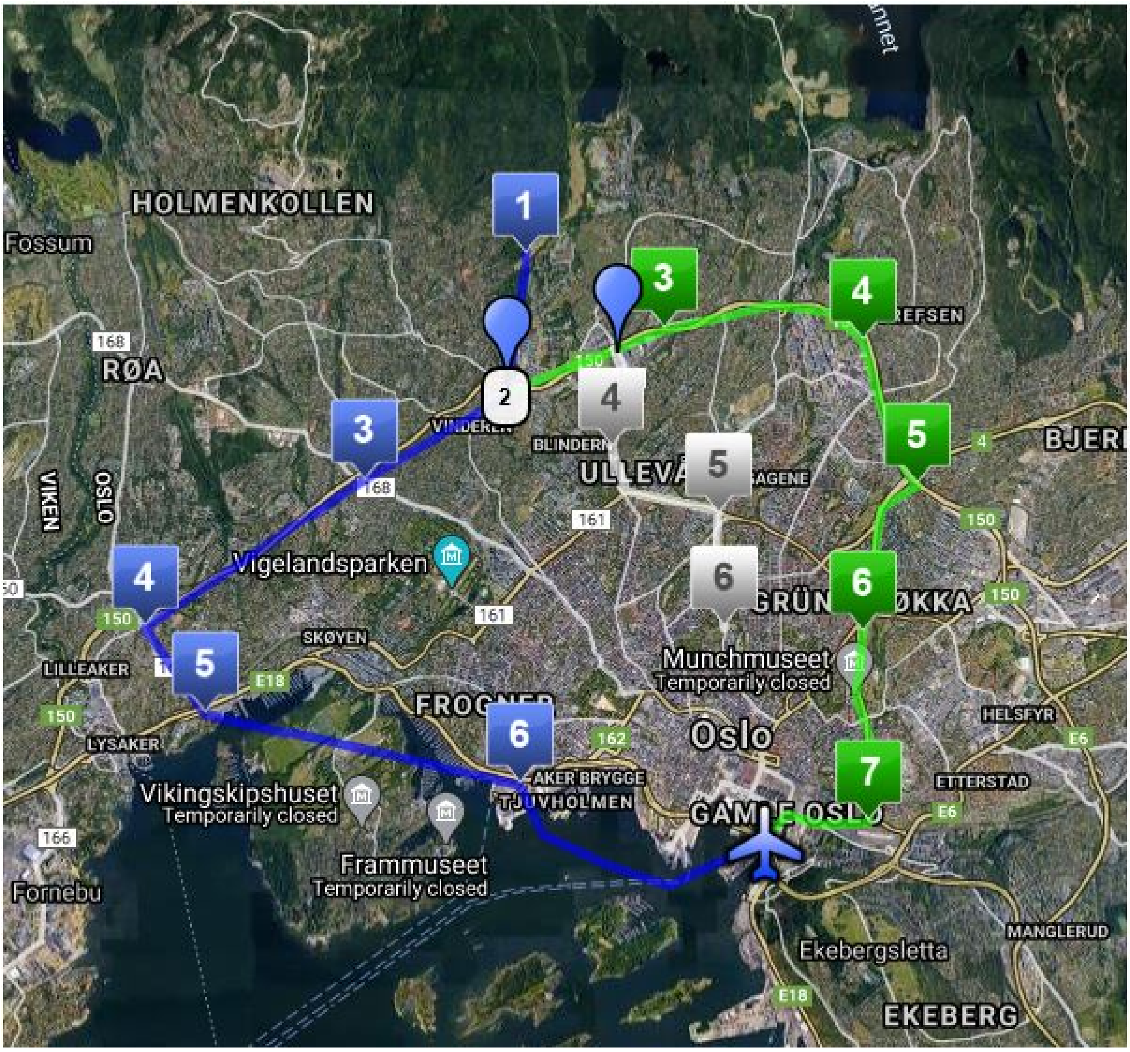

Figure 3.11: Corridor in urban area

Since the corridor is in an urban area, the speed limit must be regulated to fit each zone to make it safe as possible. In our scenario we defined two speed zones, zone 1 and zone 2. Zone 1 is placed in the outskirts of a city which means the speed limit could be faster than zone 2. The speed limit in zone 1 is set to 60-70 km/h. Zone 2 is more central in the city which means the speed limit must be slower. In this scenario the speed limit is set to 40-50 km/h. Those speed limits could always be regulated depending on the traffic, weather or any interruption in the corridor.

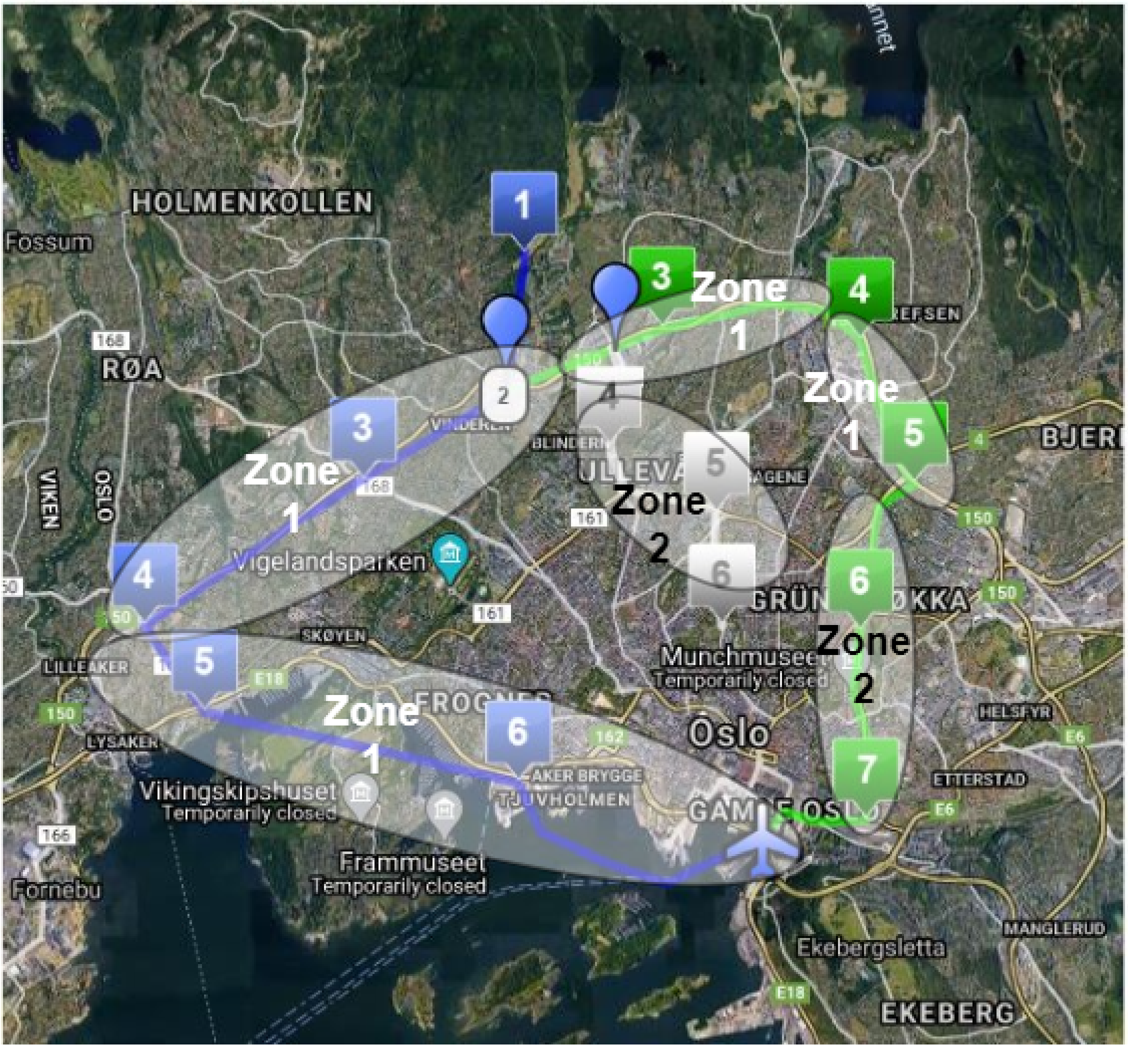

Figure 3.12: Speed zone in urban area

The separation is defined in 3.1.2 and is defined as 100-300 meters horizontal distance. The UAVs need to have a collision-avoidance system to ensure no collision will occur in the corridor. As the corridor is in an urban area, 300 meters horizontal separation distance would yield the safest distance.

Calculation of density can be done by the formula:

$$density = m/L$$

m = number of vehicles
L = length of corridor

In an ideal condition with a corridor length, around 12 km and 300m separation between UAVs will give us 40 vehicles flying through the corridor.

m = 40 vehicles
L = 12 km
Which gives us:

$$density = 40/12km = \mathbf{3\ vehicles/km}$$

Based on the calculation, the traffic density would have three vehicles per kilometers. But a more realistic number might be lower because of factors like weather conditions, maintaining right separation distance and speed could impact on the traffic density.

By having the average speed in this case, 50 km/h, we can find out the time it takes the UAVs to fly 1 km and then use the time to find the traffic flow.

$$time = 1km/50km/h = \mathbf{72\ s}$$
$$\text{n} = 3 \text{ vehicles/km}$$
$$\text{t} = 71 \text{ seconds}$$
$$flow = 3/71s = \mathbf{0.0422\ vehicles/sec\ \text{-}\!> 151\ vehicles/h}$$

This will give us a flow of 151 vehicles per hour in a perfect condition without any external factors impacting the corridor. A more realistic number would be way lower than this where different factors would impact on the traffic flow.

3.2 Static and Dynamic corridor

In an airspace based transport, the paths may be established in three dimensions since the airspace can be divided into several horizontal layers. The use of several horizontal layers is already done for conventional air transport, which UAV will use the airspace below that used by conventional air transport.

3.2.1 Static corridor

In a static corridor, the flight path is predefined, which means the route in the corridor is well known for all the actors involved. The travel distance, as well as the travel time, is known beforehand. All rules are pre-set to the corridor, and the corridor route won't change. If any accident or anything could interfere with the corridor, the corridor would close, and all traffic would need to exit into the nearest exit point.

In figure 3.13, the entry point is marked with (S), depending on the departure location every UAVs need to find the nearest entry point (S). The static corridor is marked with green and is a fixed route. The UAV will follow the predefined path from (S) to (E).

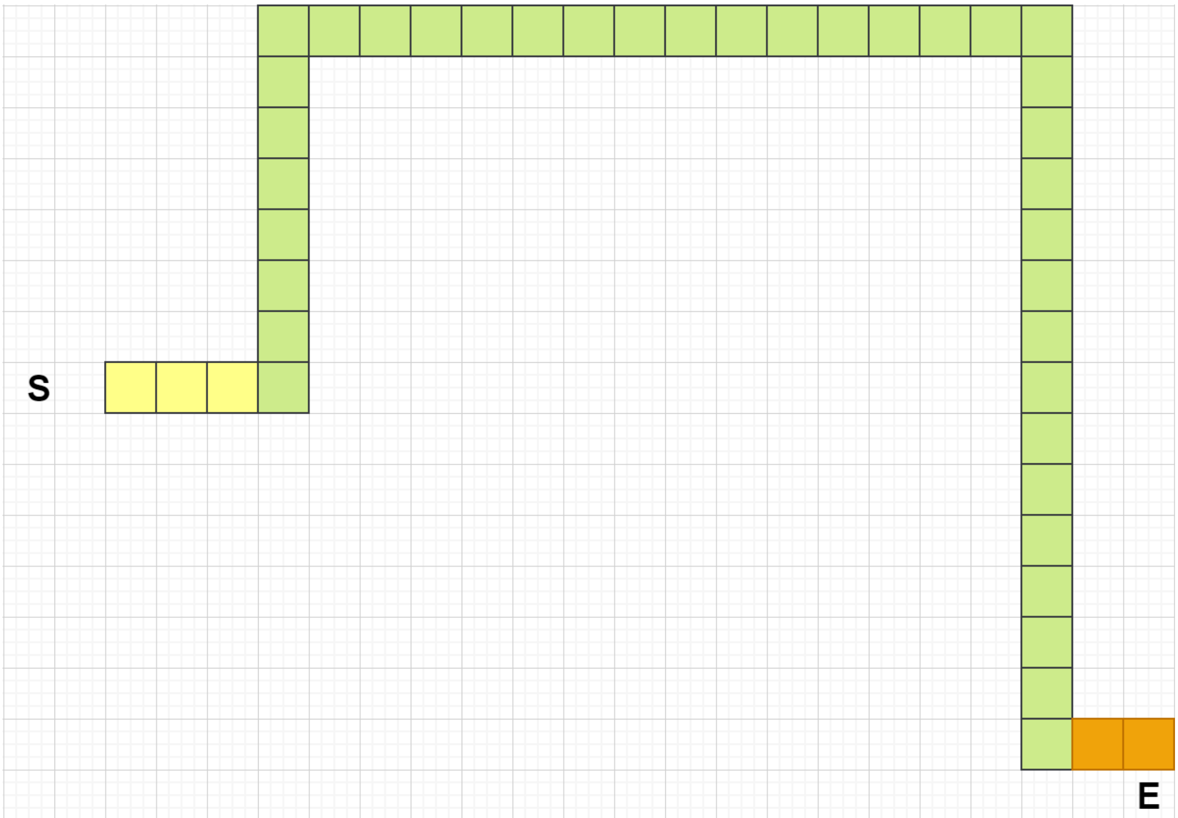

Figure 3.13: Fixed corridor

The following steps are used before entering the static corridor:
1. Find the nearest entry point to enter the static corridor
2. Calculate the nearest exit point based on the destination
3. Calculate distance from the entry point to the destination point
4. Check current traffic in the corridor
5. Search for available time slot
6. Reserve slot time
7. Check for collisions in the entry area, if there is collision move to next entry point
8. Check for collisions in the destination area, if there is collision move to the nearest exit point
9. Submit flight plan
10. Departure

If a temporary no-fly zone is established in the corridor, the corridor needs to shut down and wait until the lift of the no-fly zone. All traffic in the corridor needs to find the nearest exit point and exit the corridor. A disruption may happen because of danger for the people on the ground or accidents where UAV traffic could disrupt emergency service operations. Other disruption may also be caused by priority traffic, for example, medical delivery of needed medication or heart defibrillator.

A no-fly zone is shown in figure 3.14, where the established no-fly zone in red blocked the static corridor. The nearest exit point would be sent to every operator to exit the corridor (see figure 3.15).

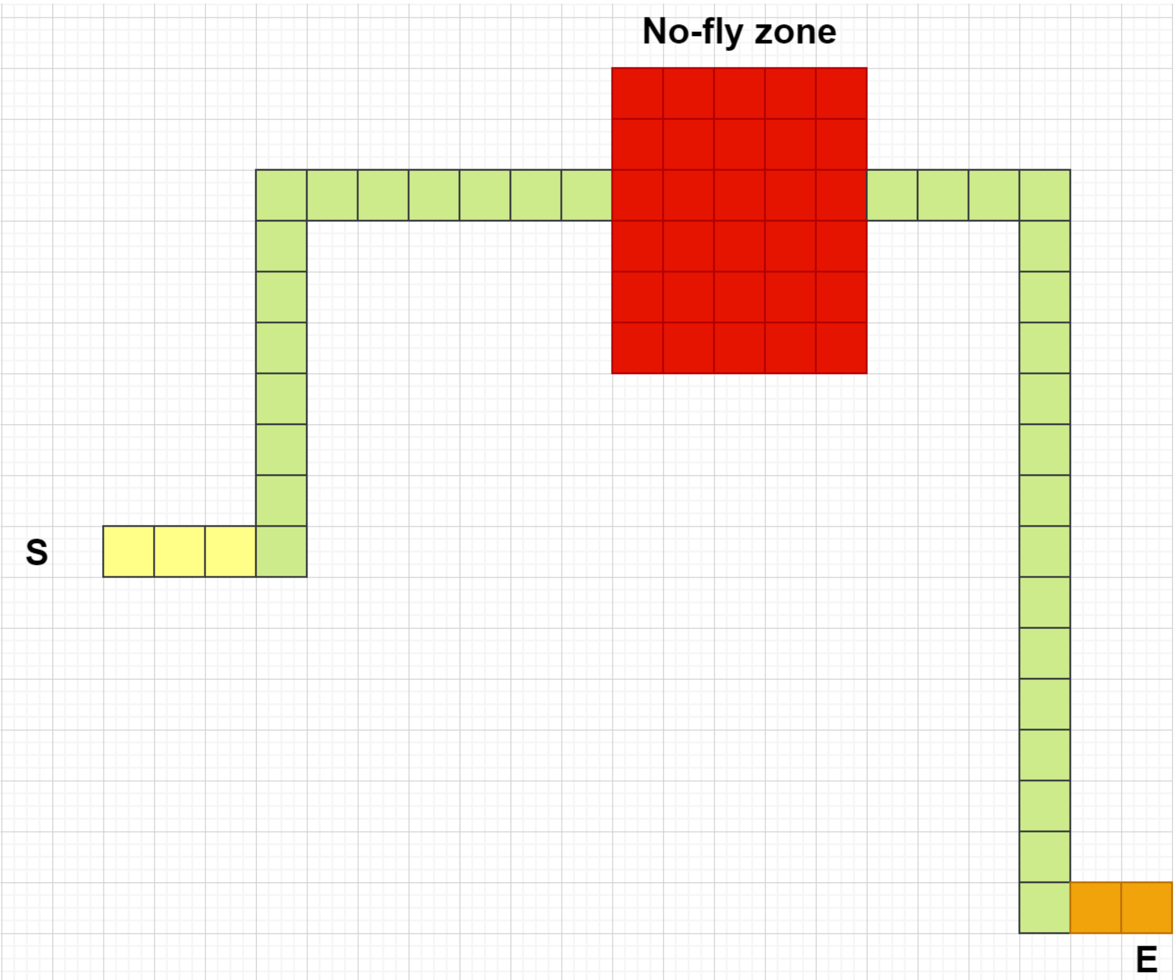

Figure 3.14: No-fly zone

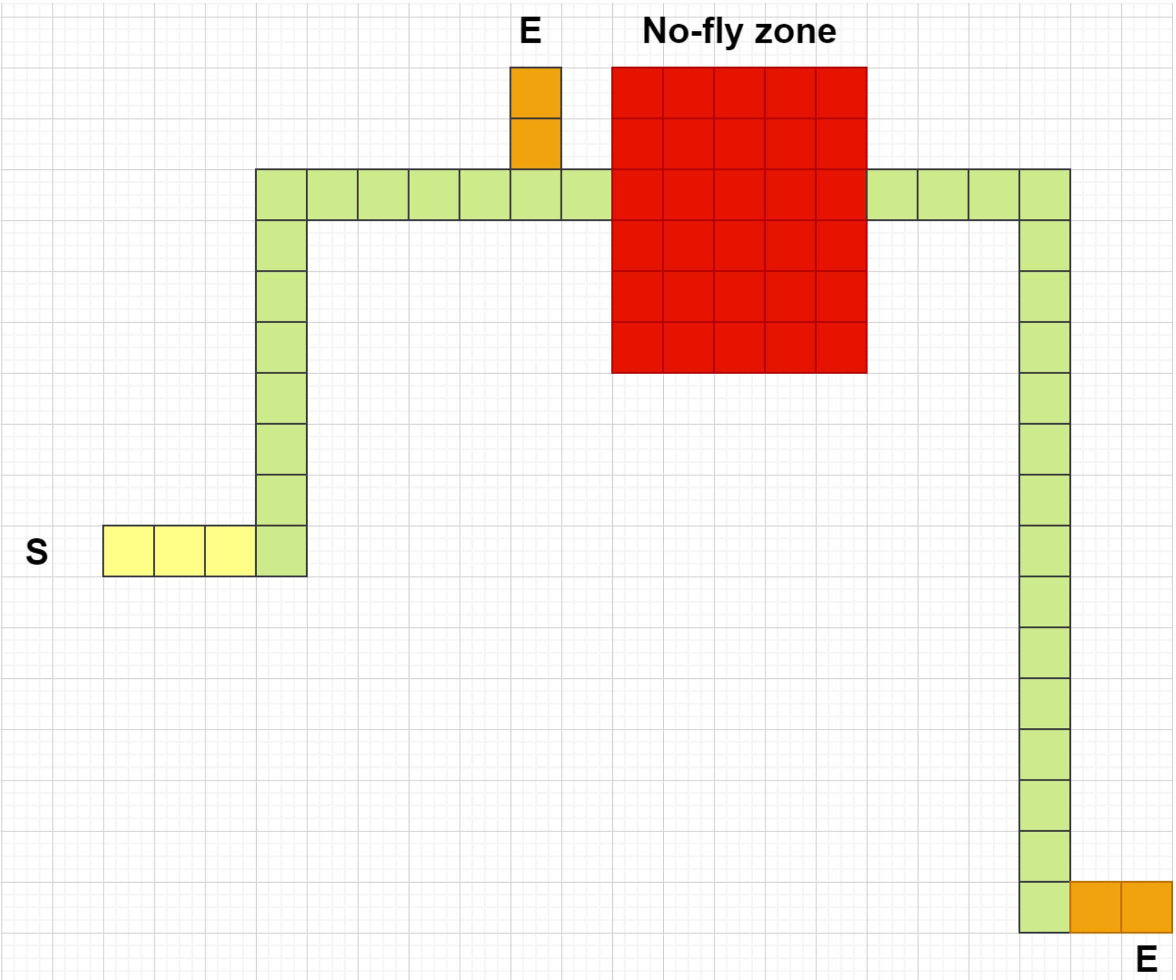

Figure 3.15: No-fly zone with a nearest exit point

3.2.2 Dynamic corridor

As airspace is not fixed, the paths may be dynamically established and removed based on needs [38]. A dynamic corridor is more flexible in changing its layout and can be changed based on the situation. As mentioned earlier, the airspace can be divided into multiple horizontal layers in which a dynamic corridor can be used. The number of layers can be increased based on needs. Like in the static corridor, the UAV will follow a fixed path, but the path can be changed due to disruption in the corridor. A dynamic corridor is shown in figure 3.16, with entry point (S) and exit point (E). The green path shows the fixed path from the entry point (S) to exit point (E), and the blue path is the upper layer in the corridor.

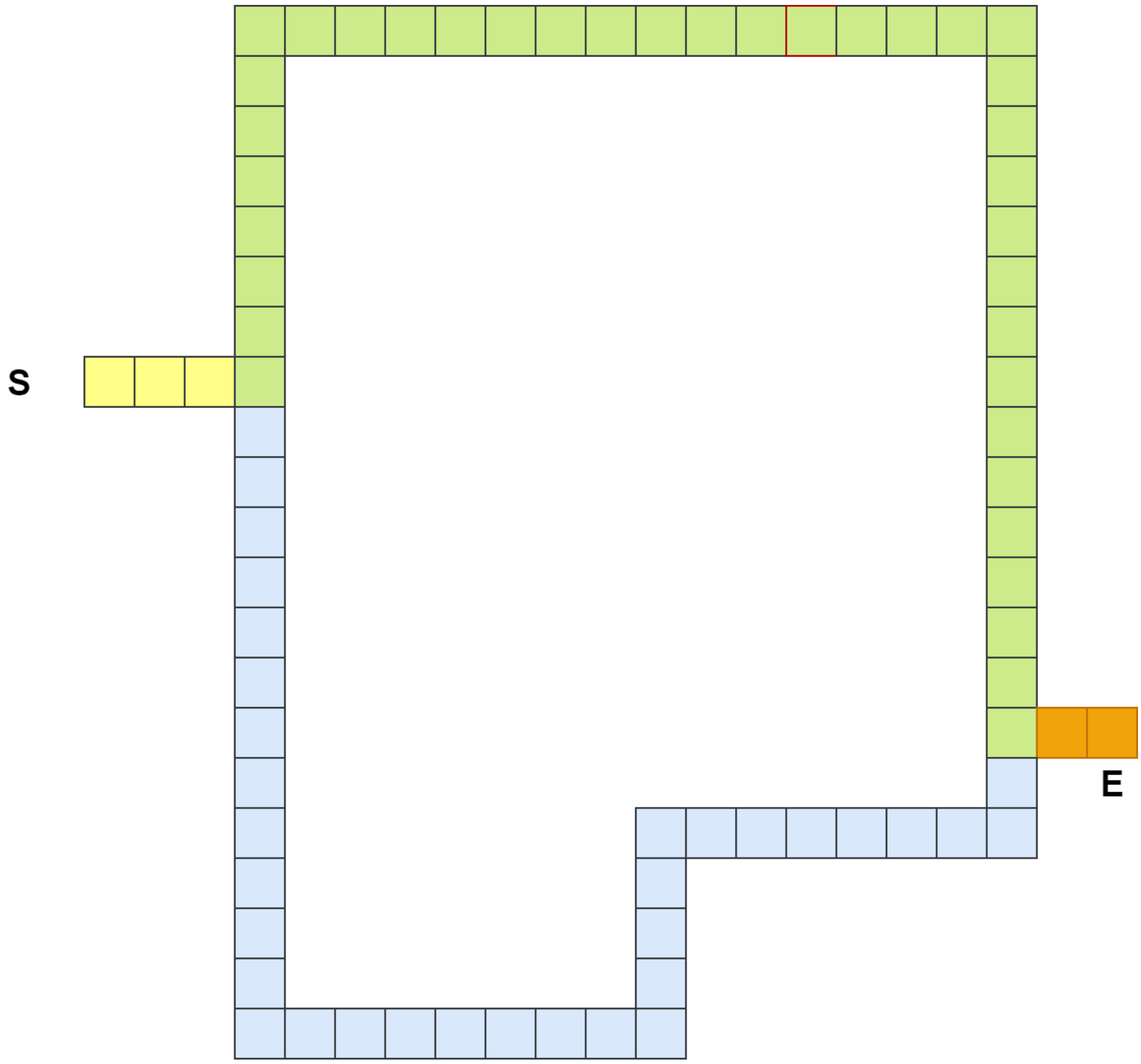

Figure 3.16: Dynamic corridor

The following steps are used before entering the dynamic corridor:

1. Find the nearest entry point to enter the dynamic corridor
2. Calculate the nearest exit point based on the destination
3. Calculate distance from the entry point to the destination point
4. Check current traffic in the corridor
5. Search for available time slot
6. Reserve slot time
7. Check for collisions in the entry area, if there is collision move to next entry point
8. Check for collisions in the destination area, if there is collision move to the nearest exit point
9. Submit flight plan
10. Departure

Like in a static corridor, disruption may happen in dynamic corridors too, and an established no-fly would be in place. Those disruptions can be caused by accident or dangerous situations for people on the ground, such as an event or gathering where the UAV traffic could interrupt emergency service. A dynamic corridor can establish a new flight path around the disruption area as long as the UAV has communication capabilities [38]. With communication capabilities, it is possible to upload new flight instructions to the UAV and make it use the newly established corridor. Figure 3.17 shows the no-fly zone marked in red on the green path. The green path needs to be reconfigured. By rerouting the green path, the corridor can bypass the no-fly zone and not conflict with the no-fly zone. A possible rerouting is shown in figure 3.18. Those flight paths are based on the research study A Strategy for Drone Traffic Planning [38].

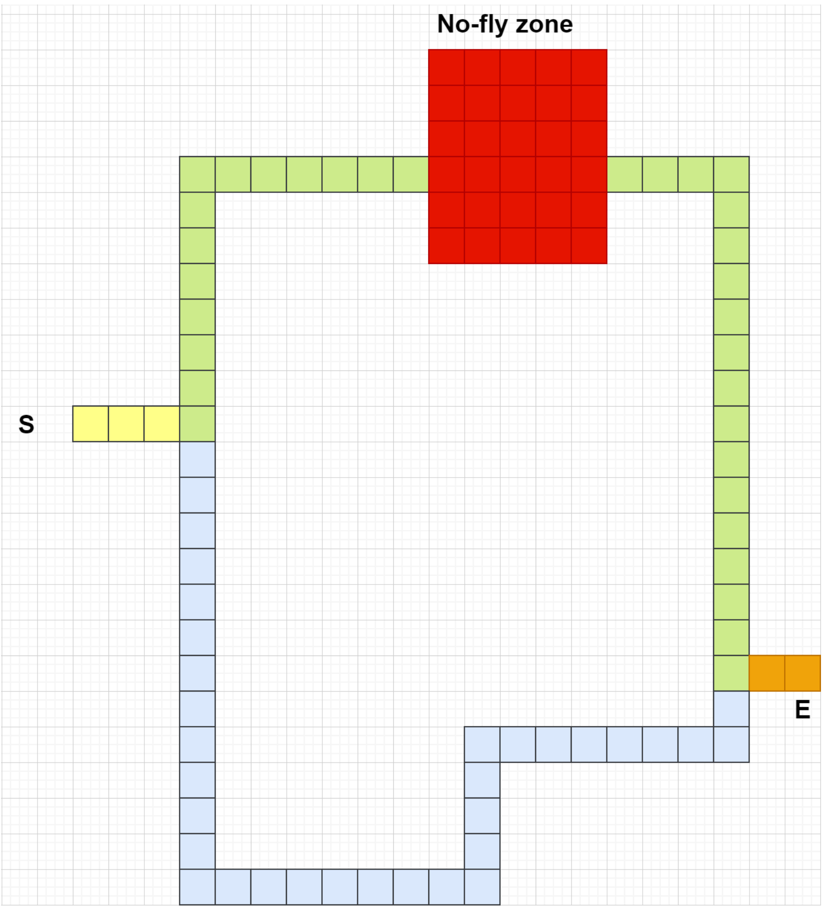

Figure 3.17: Dynamic coridor with no-fly zone

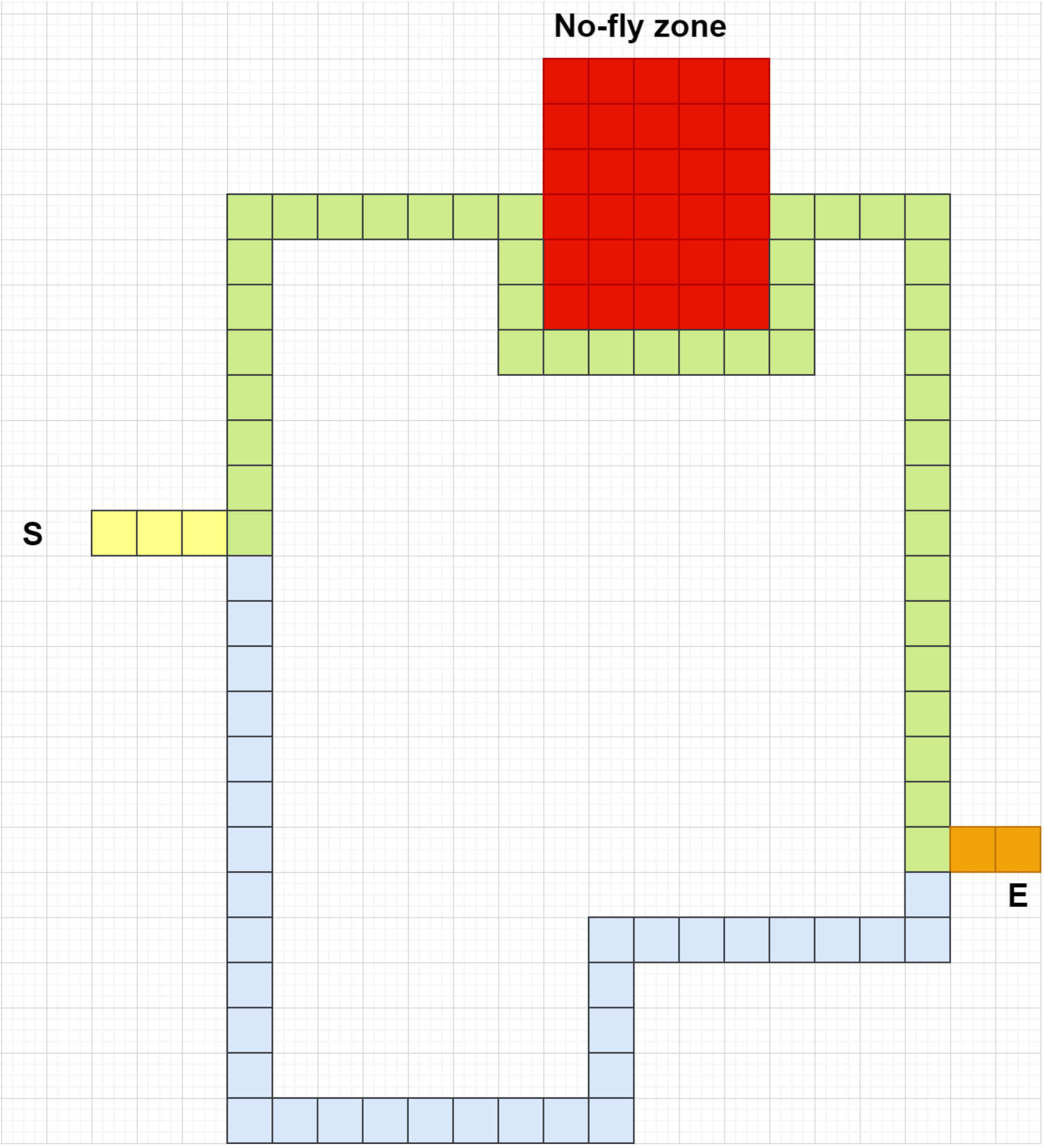

Figure 3.18: Dynamic Rerouting

A dynamic corridor could increase the airspace by allocating different flight paths in the corridor depending on the traffic and destination area, assuming all the UAVs have communication capabilities to get a new flight instruction. In a dynamic corridor, it is possible to establish new flight paths on the go, which mean if flight path (A) marked in green going to exit point (E) is full, a new temporal flight path marked in blue (B) would open and redirect the traffic from (S) to (B) to have efficient traffic flow and increase the airspace capacity. A dynamic corridor could also be used to increase capacity when factors such as weather, ground event, or special event where the corridor interferes. The corridor could redirect from, for example, heavy wind in a specific area to a less windy area where the traffic could go as normal. Managing the airspace dynamically could reduce delays and emissions while increasing the airspace capacity.

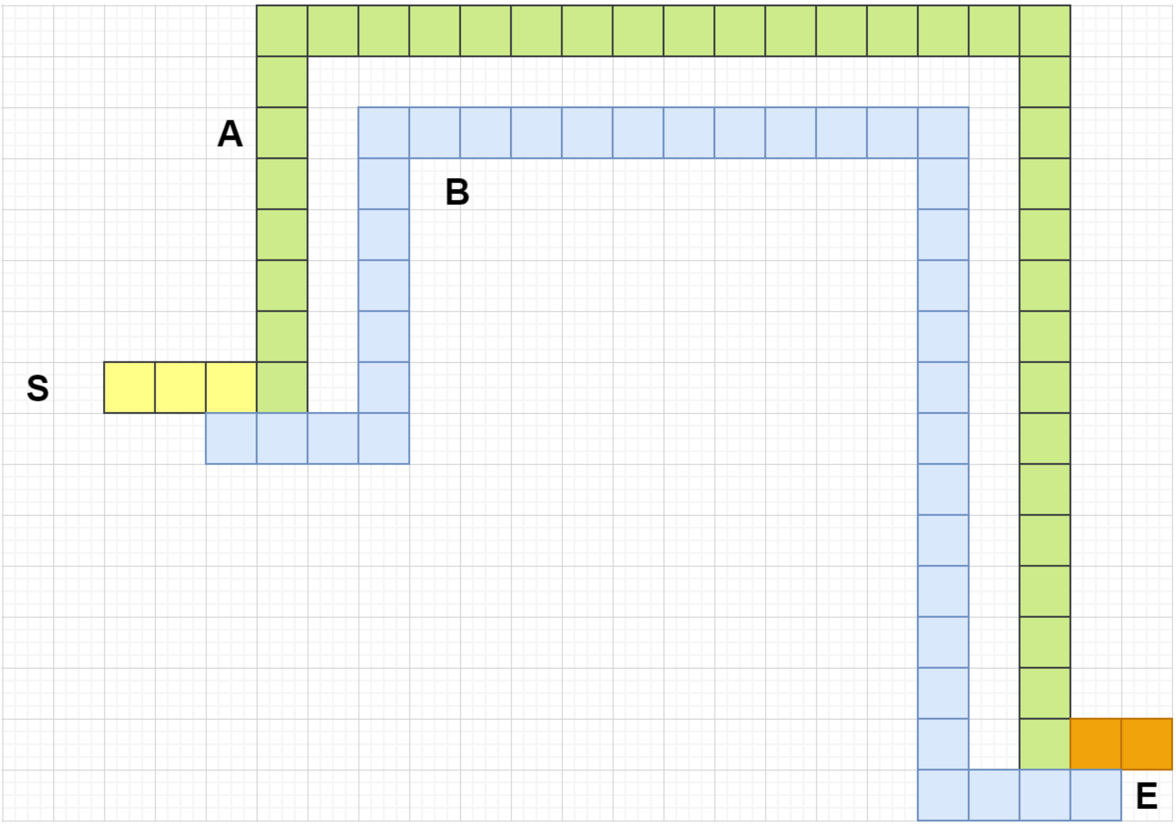

Figure 3.19: New flight path

3.2.3 Switching between Dynamic and Static corridor

There could be instances where it would be feasible to switch between dynamic and static corridors. For both corridors, there are advantages and disadvantages. The pros and cons for both corridors are shown in tables 3.2 and 3.3.

Static corridor	
Pros	Cons
The flight path is known	Can't change the flight path
Distance is known beforehand	Need to close the corridor when there is disruption in the corridor
Travel distance is known	Can't give new instruction to the UAV if it doesn't have advance communication capabilities
UAV doesn't need advance communication capabilities to use the corridor	Can't be adapted to user demands
The cost will reduce in a static corridor as there will be less to handle for UTM	Can't be adapted to any situations

Table 3.2: Pros and cons for static corridor

Dynamic corridor	
Pros	**Cons**
The flight can be changed when there is disruption in the corridor	The flight path might be longer when changed from fixed path
Can be adapted to any situations	The UAVs need advance communication capabilities to receive new instruction
Can be adapted to user demands	Travel distance might change
Less delay for UAVs	More demanding on the UTM to monitor all dynamic/new routing and traffic
Can increase airspace capacity	More expensive system
Flexible system	

Table 3.3: Pro and cons for dynamic corridor

We will look into the risk involved when switching between the two corridor types. A risk table is shown in 3.4, with the severity, goes from moderate to severe, where moderate is the mildest form of risk and severe the most catastrophic form of risk.

As seen in the table 3.4, the most severe risk is collision when switching between the dynamic and static corridor. When switching between the two corridors, all the risk needs to be taken into consideration before deciding if it's feasible to switch a corridor.

Severity	Risks	Description
Moderate	Traffic density	Traffic density might increase when changing corridor.
	Monitor and tracking	Monitoring the traffic will changes from a static corridor to a dynamic corridor as dynamic corridor are more flexible in term of creating new routes for the traffic. The same can occur for tracking the traffic.
	Change of terrain/flight path	When changing a corridor, a given corridor might be longer in distance as such the operator of UAV need to be aware if their UAV can handle the extra distance in terms of battery capacity.
Moderate/Adverse	Schedule time	Delays can happen for schedule flight time; this will impact every UAVs and their operations.
Adverse	Information	Changing the corridor type required all the information is given to every party that use the corridor this include operators, UTM, and third parties.
	Communication	Communication between UTM and operators should always be there when changing corridor.
Adverse/Severe	Weather hazards	Weather can impact on both corridor type, weather need to be taken into consideration when changing a corridor type.
Severe	Collision	In an instance where changing the corridor with the lack of information and communication, might cause collision in the corridor.

Table 3.4: Risks when switching between static and dynamic corridor

3.3 Compare the types of corridors

In structured airspace, the physical or logical structure and temporal allocation of corridors can be fixed or dynamic. In the most extreme fixed scenario, all corridors can be considered as one-way streets or railways, where only one vehicle can operate in a given direction at a time. On the other hand, the most flexible scenario can be likened to a 3-dimensional matrix of cells that can be reconfigured (dynamically) with regard to the class of traffic and direction. We will look into three types of corridors, Specific, Parallel, and Switching and compare the corridors.

3.3.1 Specific Corridor

A specific type of corridor is a static, fixed flight path. In a specific corridor, the corridor predefined and only allow the traffic to flow one direction, which means the corridor can't change the direction if there is a UAV operating in the corridor. The direction of the corridor would change based on the UAV destination. A specific corridor could be considered a railway, where only one operating UAV could use it at any given time. An illustration in figure 3.20 shows the flow of an UAV using a specific corridor. Figure 3.21 shows the direction is based on UAV destination.

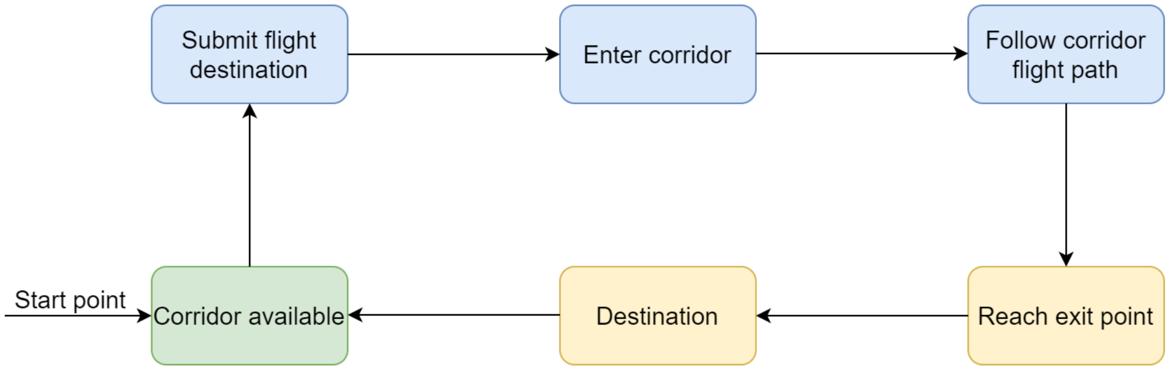

Figure 3.20: Flow of a specific corridor

Figure 3.21: Direction is determined by UAV destination

If any other UAVs want to use the corridor, it needs to wait at a waiting point/station till the operating UAV in the specific corridor has flown over the waiting point and exits the corridor. A waiting system needs to be implemented in the corridor to make it as efficient as possible. Illustration of waiting point is shown in figure 3.22. Schedule overview of incoming, outgoing, and waiting UAV will be sent to all the operators that will or use the corridor and the UTM.

It could only be open or close in a specific corridor if something happens in the corridor or surrounding area near the corridor. This means it can't redirect or be flexible in changing the flight path when something happens. The close time would cause problems for all UAVs involved and delay all operations in the corridor. The capacity is limited in the corridor as there is only one UAV at all times in a given direction.

A specific corridor would be great for locations where there is not much demand for UAVs services, for example, rural areas. It is a relatively cheap alternative in terms of resources that need to invest and maintain.

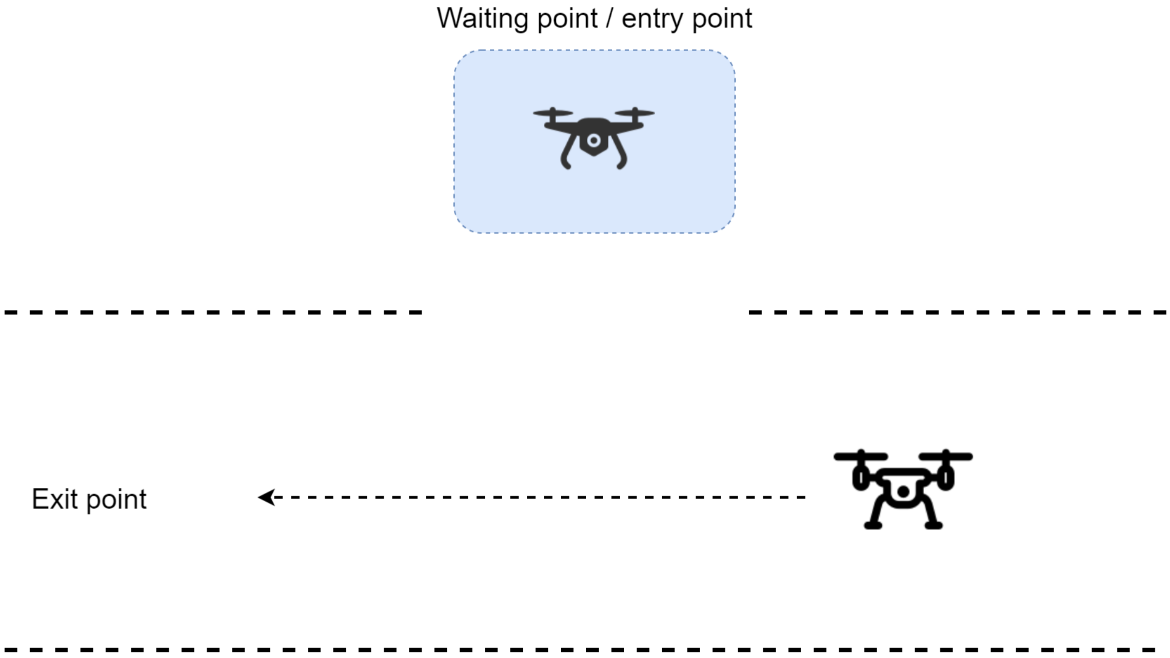

Figure 3.22: Waiting point in a specific corridor

3.3.2 Parallel Corridor

A parallel corridor could be considered two-way traffic with a fixed path. In two-way traffic, it allows UAVs to travel in both directions, which would allow good traffic flow in either direction. Like a specific corridor, the parallel corridor flight path is predefined beforehand, which means the flight path can't change in any circumstances. Parallel corridors have the same pre-set as a static corridor mentioned in 3.2.1, which means the distance and travel time are known beforehand. The corridor could only be open or close if anything happens in the corridor or surrounding area around the corridor. Figure 3.23 shows a two-way traffic in a parallel corridor.

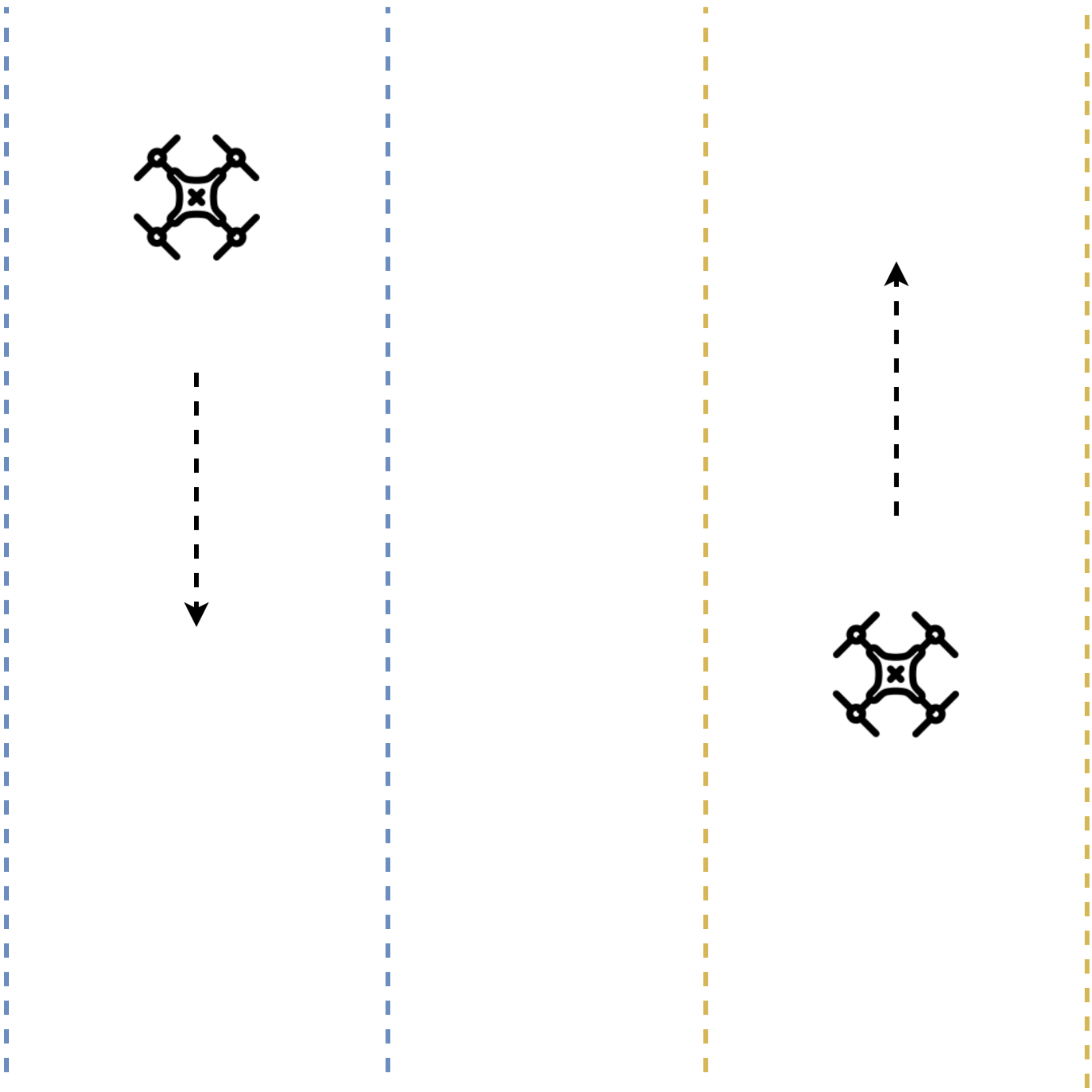

Figure 3.23: A two-way parallel corridor

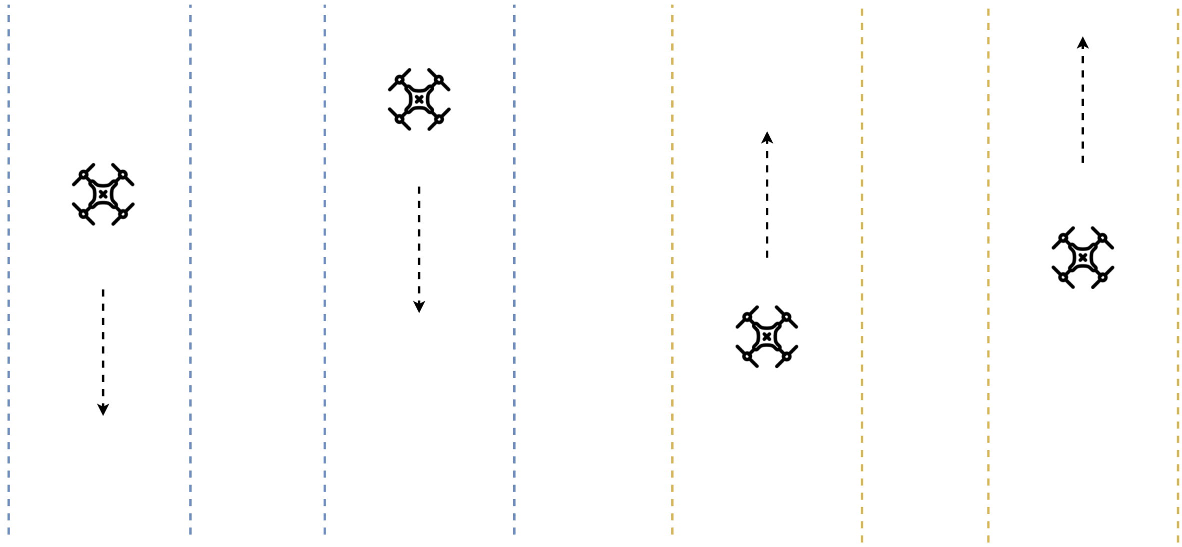

Figure 3.24: Multiple lanes in parallel corridor

Lanes could be added to the corridor similar to highways for cars as seen in figure 3.24, where each lane has a different speed limit. An implementation of multiple lanes could open for more traffic and differentiate the traffic class by speed.

As seen in figure 3.25, each lane is classified by the speed limit. In our case, the high-speed lanes are 90 km/h, and the slower speed lanes are 60 km/h. To enter a high speed lane in our case the 90 km/h lane the UAV needs to have atleast the speed of 90 km/h, the lane restricts any UAV that doesn't fit the lane specification. Any UAV that doesn't fit lane specification needs to enter a lower speed lane if it is within the specification. To know which UAV fits which lanes, the operator needs to submit their flight path and their UAV speed before entering the corridor. Based on that information, the UAV will be given a lane that fits the UAV specification. More lanes could be added depending on the need, and if there is space for it, speed could be regulated depending on weather, traffic density, and safety.

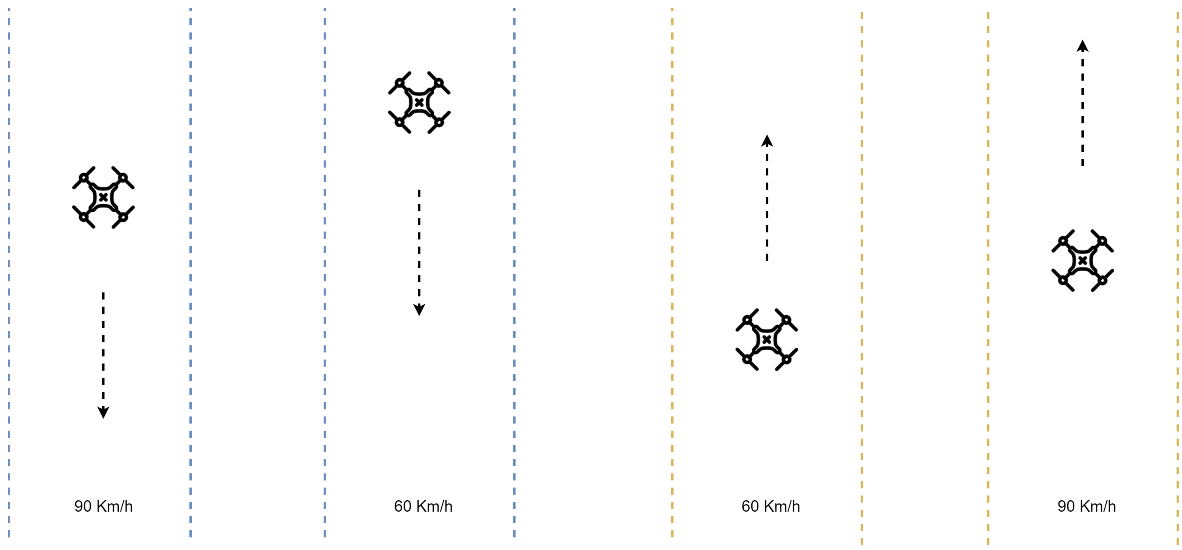

Figure 3.25: Multiple lanes with different speed limits

A UAV could enter the corridor through the entry points, or an alternative is to have lane merge points added to the corridor along the corridor as shown in figure 3.26, where UAVs could enter in the corridor if there is space in the corridor. Unlike specific corridors, parallel corridors are not limited to one aerial vehicle at all times, but there could be numbers of aerial vehicles as long as the safety and separation distance allows it. Using a parallel corridor could increase the traffic capacity as there is no limitation on how many UAVs could be in the corridor as long as the safety could be maintained.

The parallel corridor works well for moderate to dense traffic areas, as it could give a constant traffic flow. With multiple lanes added to the corridor, the corridor can have different speed limits to each lane and adds variety to all UAVs operations using the corridor.

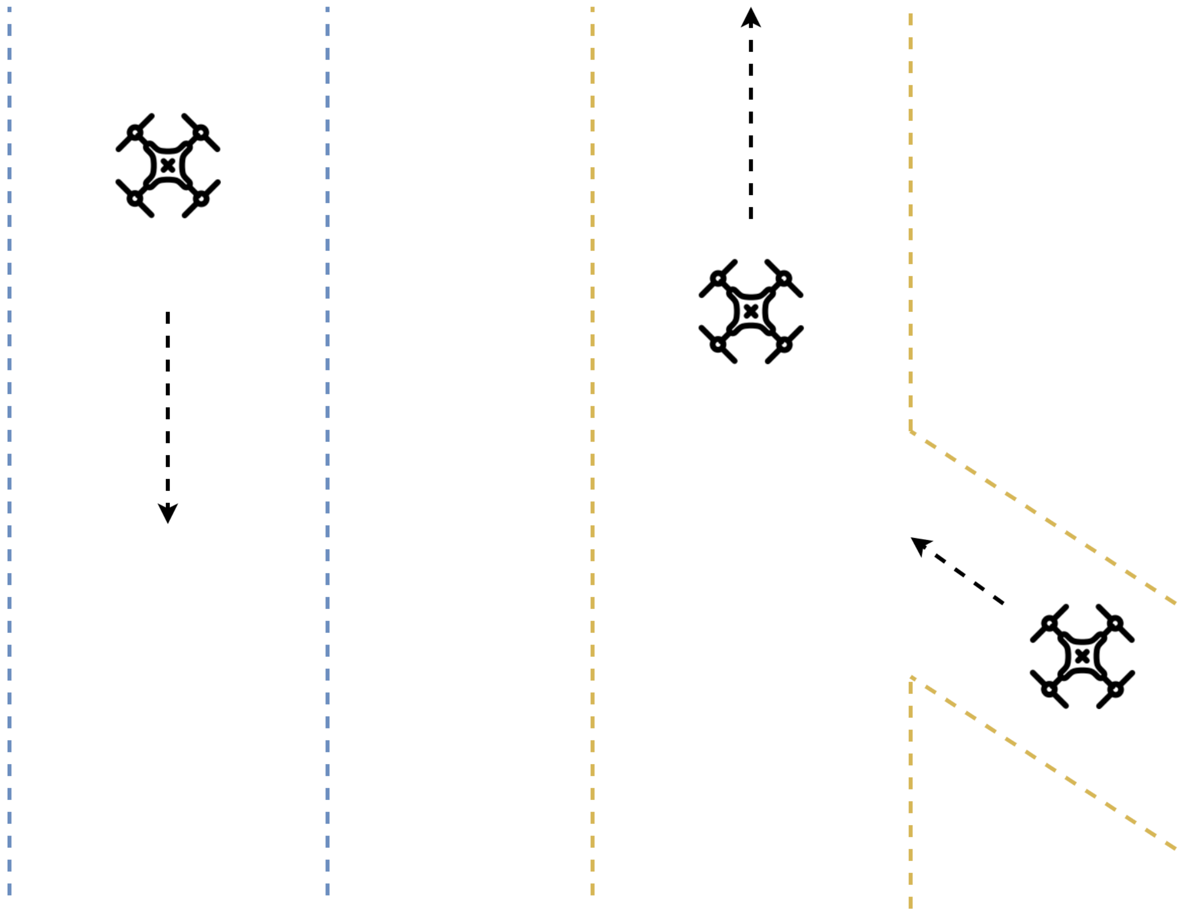

Figure 3.26: Lane merging in a parallel corridor

3.3.3 Switching Corridor

The airspace can be thought of as three dimensional since it's possible to divide the airspace in multiple layers. This is already used by conventional air transport and the same could be applied to unmanned airspace for UAVs. The switching corridor has the same concept as a dynamic corridor mentioned in section 3.2.2, the flight paths are not fixed and could be established or removed based on needs. By using multiple horizontal layers, the corridor could have multiple fixed paths depending on layer level. The numbers of layers could be increased if necessary. In this case, we are using four levels of layers.

Upper path 1 "highway"
Upper path 2 "highway"
Layer 1
Layer 2

Table 3.5: Layer design for switching corridor

Fixed paths 1 and 2 present the "highways" for UAVs traffic and the upper layers, where UAVs can use those "highways" corridors to connect other lower-level corridors. The use of "highways" is to mask the UAVs traffic noise in cases where the corridor is placed in a noise-sensitive area like urban areas. Layer 1 and 2 present a lower level corridor, which leads to another location; those corridors are placed lower than the "highway" corridor. A visual of layer design is shown in figure 3.27.

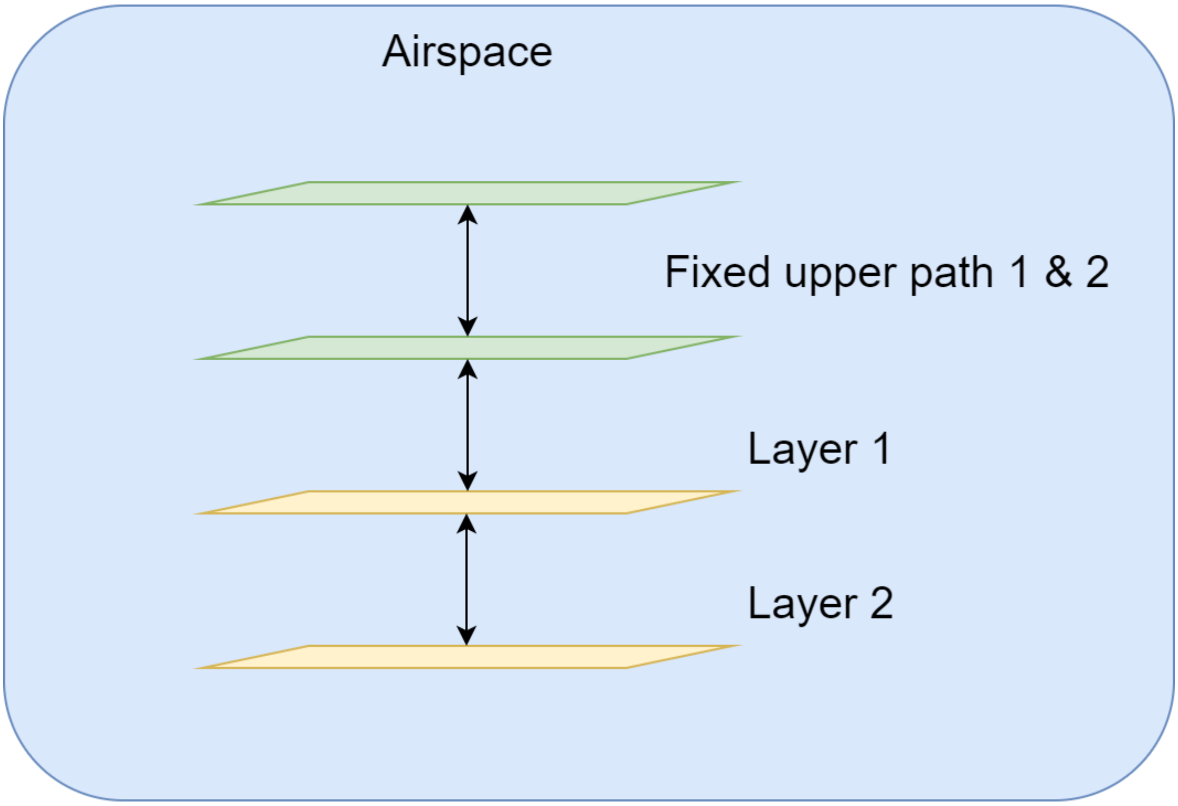

Figure 3.27: Illustration of layer design

To enter or exit from the upper path, the UAV would be given a separate path connecting the two layers. The newly established paths are allocated dynamically to each UAVs entering or exiting a layer. All of the flight paths on each layer can be reconfigured with regards to the class of traffic and direction. The traffic class could be divided into speed, weight, and type of operation. UAVs with the same speed class could be in one corridor to separate from another lower or higher speed class in such a way the speed limit will be the factor that differentiates the traffic. The same could apply to weight and type of UAV operation and differentiate each corridor by class. The UAVs could change from one corridor to another through the intersection points by adding an intersection to the multiple horizontal corridors.

If something happens or the capacity needs to be increased, the corridor could be reconfigured on the fly to meet those situations. In a situation where a no-fly zone is established because of disruption like an interruption of emergency services or an event where there is a gathering of people, see figure 3.28. The switching corridor could be rerouted by establishing a new dynamic flight path around the no-fly zone, the same concept as a dynamic corridor mentioned in section 3.2.2, see figure 3.29.

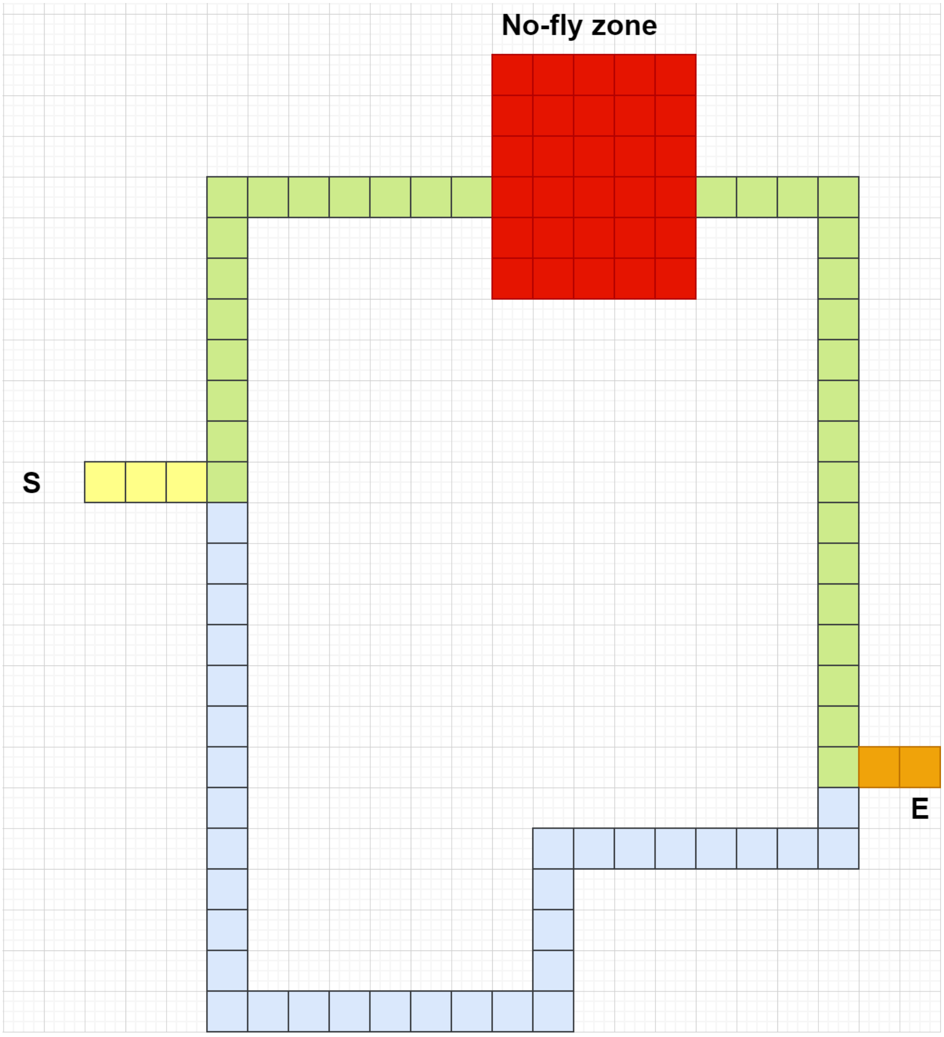

Figure 3.28: Established no-fly zone in the corridor

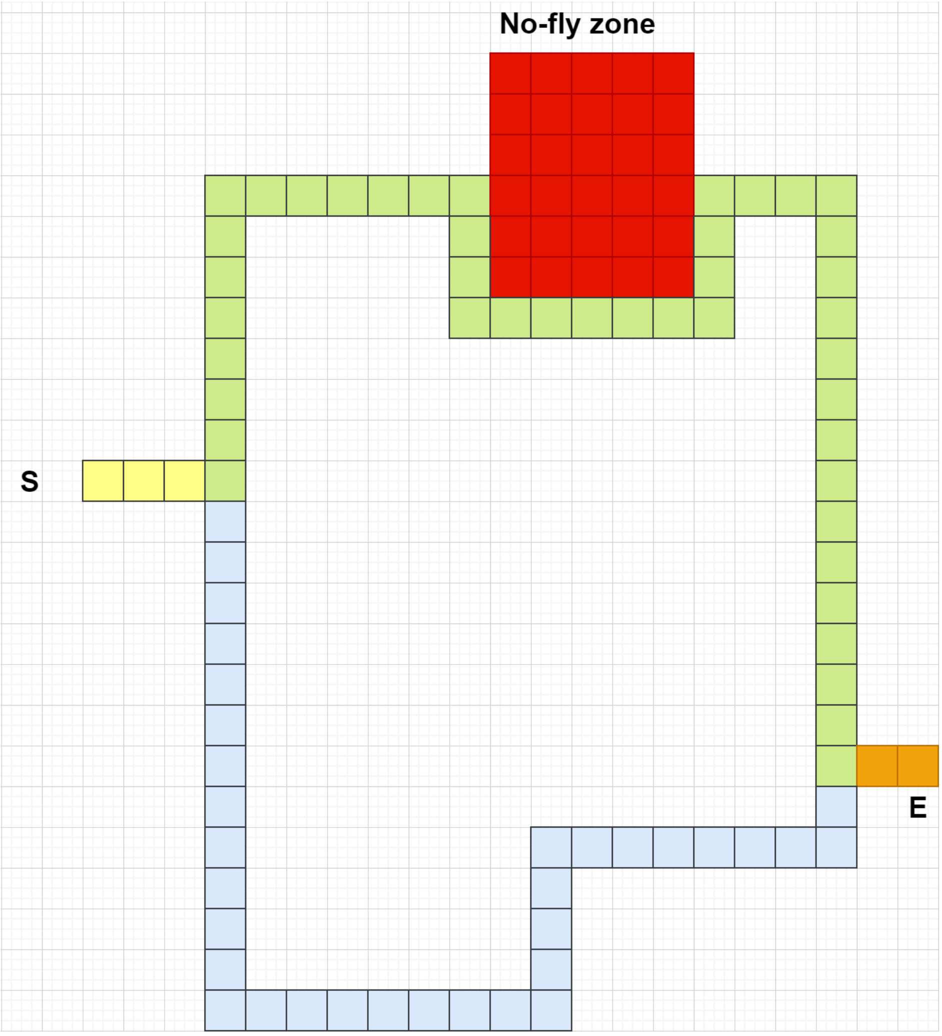

Figure 3.29: Rerouting around the no-fly zone

It is possible to coexist multiple paths in the corridor by utilizing horizontal layers, as mentioned in the study [38]; by having intersection points in the corridor, the UAV could change from one layer level to another layer. Before changing layers in the intersection, the system would check if there is any conflict in the given intersection before giving the green light to the UAV to change the layer level. A coexist multiple is shown in figure 3.30; the entry point starts in (S), which leads to a green path. In the green path, there are grey sections, which are the intersection points where the UAV could use to enter another path in an upper layer. In this case, the purple path is the second upper layer and blue path third upper layer. The switching corridor is the most flexible corridor among the three corridors, which makes it great in urban areas or areas with heavy traffic as it can handle heavy traffic and reroute around no-fly zones.

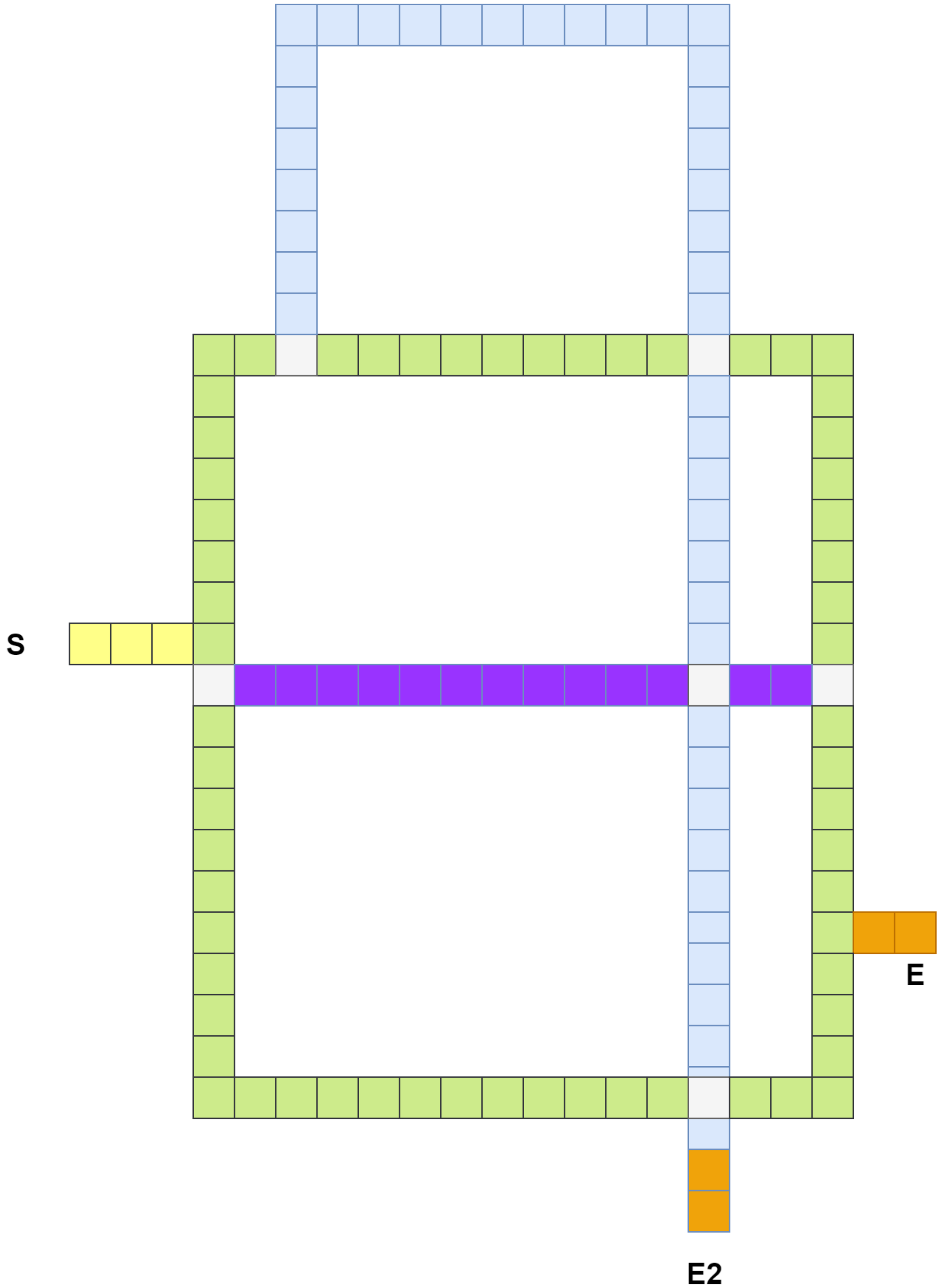

Figure 3.30: Coexist multiple lanes

3.3.4 Comparison between Specific, Parallel and Switching corridor

We will now compare all three corridors to each other. In the comparison table 3.6, we highlight the key points for each corridor.

Specific corridor	Parallel corridor	Switching corridor
Pre-defined flight path	Pre-defined flight path	Pre-defined flight path but could change dynamically if needed
Static	Static	Dynamic
Travel distance are known	Travel distance are known	Utilizing multiple horizontal layers
Travel time are predefined	Travel time are predefined	Horizontal layers could increase if necessary
Only one direction	Two-way	Reroute around established no-fly zone
Only one operating UAV in any given time	Multiple lanes same as highways for cars	Increased capacity by having temporal airspace
Waiting station/point for other UAV	Each lane have different speed limit, thus classify UAVs by speed	Upper layers are highway for UAVs, to mask the UAVs traffic
Capacity are limited	Increased capacity by using multiple lanes	Intersection for going from one layer to another
The corridor need to close down if something happens in the corridor or surrounding area near the corridor	The corridor need to close down if something happens in the corridor or surrounding area near the corridor	The corridor doesn't need to close down, instead it could dynamically reroute around the point of no-fly zone
Specific corridor are great to use for location with light traffic or rural areas	Parallel corridor are great for moderate to heavy traffic, good placement for middle point between rural and urban areas	Switching corridor are great for heavy traffic and in locations such as urban areas

Table 3.6: Comparison table for specific, parallel, switching corridor

From the table and in sections about the corridors, we'll see that specific and parallel corridors have a lot of points in common. Both of those corridors are static corridors with a predefined flight path, unlike switching corridors that have a flight path that could dynamically change based on needs. The capacity would play a significant role depending on what type of corridor to use because each corridor has a different capacity. A specific corridor has limited capacity as the corridor only allows one operating UAV at any given time. However, in return, the corridor needs fewer resources to monitor the traffic. For parallel and switching corridors, the capacity is higher than the specific corridor because of the use of multiple lanes and layers. The switching corridor is the most flexible between all three corridors and the corridor that could handle heavy traffic as it could adapt to any situation. Which means the switching corridor works well for urban areas. To summarize, each corridor has its use and could be used depending on placement, capacity, and noise.

3.4 Liability in corridor

With the emergence of UAVs and corridors, the liabilities need to be clear, so all actors are involved to know their responsibilities. A complex environment like shared airspace with multiple stakeholders with different interests, goals, and experiences will need to collaborate to define responsibility and liabilities. In a given corridor, each stakeholder has its liability; in our case, the stakeholders are pilots, traffic management systems, and supervisory control. The pilots are the main responsible for the safe operation of their aircraft. At the same time, the traffic management system is responsible for traffic planning, monitoring, and communicating with pilots and third parties. In this case, the supervisory control regulates laws like civil aviation authority in Norway or the United Kingdom. They are responsible for all actors involved in the corridor to uphold the laws and regulations.

The liability could be transferred in a given corridor type between three main stakeholders, Pilots, Traffic Management System, and Supervisory Control. To transfer liability, each stakeholder would need a reasonable reason to allow liability to be transferred between the three stakeholders. Before any liability could be transferred, there would be an investigation in which part should hold responsibility and liability.

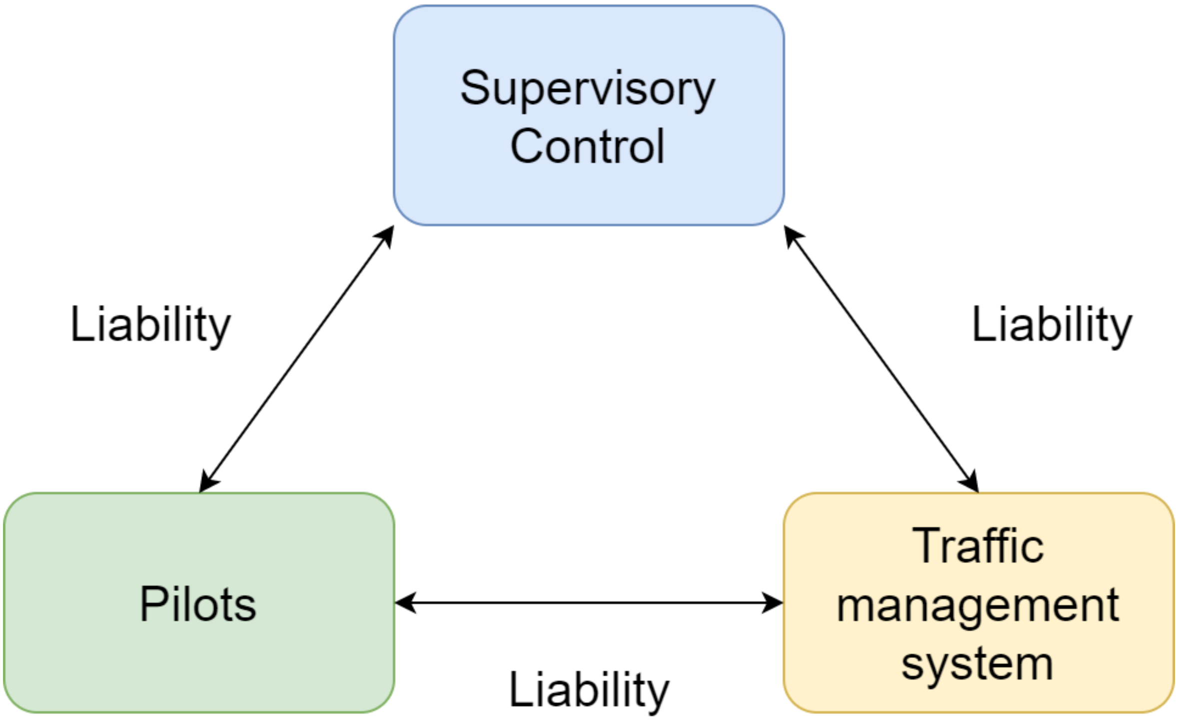

Figure 3.31: Liability diagram between supervisory control, pilots and traffic management system

We will look into a use case where the UAV pilot could transfer the liability to the traffic management system. The use case used here is from [43]. The UAV pilot is the main responsible for the safe operation of their aircraft according to International Civil Aviation Organization (ICAO) [44], but if the UAV pilot could prove that the damage isn't caused by the pilot behavior but caused by a technical problem for an example the communication link between the pilot and the UAV was broken, the liability could be excluded and instead transferred to the traffic management. However, before excluding the pilot liability, he needs to take all appropriate mitigation measures and notify relevant actors in traffic system management so they can manage the situation with counter-measures.

When transferring liability, naturally, there would be risks involved. We will look closer into risk and mitigation measures in the risk analysis. In the risk analysis in table 3.9, we identify the risks and how each risk would impact when transferring liability. The probability of occurring and the severity is scaled from one to five, where one is rare, and five is almost certain to occur. This scale can be viewed in table 3.7. The risk impact is determined by the risk management matrix shown in table 3.8. The sum of probability and severity determines the risk impact. The risk matrix will help us prioritize the risks.

Scale	Likelihood of occurrence
1	Rare
2	Unlikely
3	Moderate
4	Likely
5	Almost certain

Table 3.7: Risk management grade scaling

		Probability				
		1	2	3	4	5
Severity	5	5	10	15	20	25
	4	4	8	12	16	20
	3	3	6	9	12	15
	2	2	4	6	8	10
	1	1	2	3	4	5

Table 3.8: Risk impact matrix

Risk	Description	Probability	Severity	Impact
Finance/cost	When transfer liability, there might be a cost that one party or both parties need to pay. The cost could be from who needs to pay for damage fee in case of damaging other property or transfer fees or other costs that that might occur.	4	4	16
Disagreement	There might be instances where one or both parties have a disagreement on who is the one responsible or which party should hold the liability.	1	3	3
Laws and regulations	When transferring liability, it needs to be within the laws and regulations. Which mean the laws and regulation need to be followed by all parties during the liability transfer.	2	5	10
Third party liability	Companies working with drones may face damages caused due to malfunction drone activity causing liabilities for the service provider.	2	4	8
Human error	Human error may occur during transferring liability. Errors such as wrong information, communication, written statement.	1	5	5
Time constraint	Not enough time to go through all necessary transferring process, which may cause problems for all parties involved.	2	3	6
Poor documentation	Poorly written documentation which could cause a problem for understanding the whole aspect of transferring liability.	2	4	8

Table 3.9: Risk table for transferring liability

From the risk analysis, we will see that risk around finance is the one with the highest impact, which means that this risk would highly occur during a transferring liability. The second most impact risks are laws and regulations which have low probability but high severity.

A mitigation plan is used for each risk to reduce the impact. The description of mitigation measures for each risk is shown in table 3.10.

Risk	Mitigation
Finance/cost	All parties must agree on who pays which part of the cost. It could be partially cost where all parties involved pay a sum each or one party takes the full cost. To make it clear a written agreement must be signed by all parties involved.
Disagreement	The liability or responsibility should be clear to all parties involved. An agreement must be made by all parties involved and signed in order not to make any confusion or disagreement in the future.
Laws and regulations	The laws and regulations should be known by all parties involved when transferring liability. If any, regarding laws or regulations are unclear, the parties involved should ask the authority to make the law and regulation clear before continue with the liability transfer process.
Third party liability	Third-party companies should be notified and be included in the process of transferring liability. Excellent communication with a third-party.
Human error	Double or triple check every information or have a checklist for every important points. Have a second person checking everything to reduce human error.
Time constraint	Have proper time management. Give enough time for all parties involved to go through the transferring process.
Poor documentation	Have multiple persons who can review the documentation.

Table 3.10: Mitigation for identified risks

Chapter 4

Discussion

In our thesis, we present four research topics that make the foundation for our framework. For our first research topics, we look into placement scenarios and structuring corridors and junctions. We defined VLL 3.1.1 airspace, which is the airspace where UAVs will operate and where the corridor will be placed. VVL airspace is essential as it is the boundary between manned airspace and the safety distance between the ground. The defined very low-level airspace is followed by the guideline of CORUS (cite), but the airspace is not empty and could be used for emergency aircraft, gliders, and paragliders, landing aircraft, or taking off that need to be considered when having a corridor in the VLL. Separation is a concept for keeping aircraft at a minimum safety distance from each other and surrounding obstacles, which is vital in traffic management. A well-defined separation would help with the safety in and outside of the corridor and surrounding and follow the guidelines of CORUS. But there are weaknesses in the proposed definition of separation; external factors such as weather, pilot skills, and equipment failures are not taken into account, which could cause huge problems for the traffic in the corridor. The weather would impact on both the corridor and pilot performance, as the weather is an unpredictable factor. From our findings, the wind would be the most significant weather impact on the corridor, as the wind could offset the pre-defined path of the traffic in the corridor. However, weather factors could be compensated by having a good overview of the weather by using a third party that offers weather information or redefining the corridor's parameters. We explore the placement of the corridor in urban and rural areas. From our findings, the corridor has a different speed zone depending on the location of the corridor. In urban areas, the speed and the traffic would be lower than in rural areas, as the risk would be higher in an urban area. Based on our findings, the placement of the corridor would be important as it would be the main routing for the UAV traffic.

For our second research topic, we analyze static and dynamic corridors and what differentiates the two. The main points with a static corridor are the flight path, distance, and travel time are known beforehand, it also includes that the UAVs in the corridor does not need advanced communication capabilities. For a dynamic corridor, the main points are the flight path, which could adapt to any situation and user demands, making the corridor a flexible system. By being a dynamic system, the airspace can quickly increase the capacity. Those findings lay the foundation of each corridor, which can be used for further research. The dynamic corridors are built on previous research done one dynamic routing [38]. The findings have limitations due to the lack of data for both corridors because of the limited research done on static and dynamic routing. In section 3.2.3 we look into the risks involved when switching from static to dynamic corridor or vice versa. We found out that the most severe risk is collision when switching corridors; the reason for collisions is because of the lack of information and communication to all the traffic in the corridor. The finding of risk makes it easier to identify how the risk would impact the corridor and build a risk foundation when switching corridors. The foundation of the risk could be used further to develop more detailed and more in-depth risk analysis, as of now the risk analysis lack of data makes it not reliable enough and needs more research and data.

On our third research topic, we analyze three kinds of corridors, specific, parallel, and switching. A specific corridor uses the same analogy as a single railway line, which means the corridor uses one-way traffic by using a fixed path. Such systems have a limited traffic capacity as it is only allowed one operating UAV at any given time. A parallel corridor uses two-way traffic that uses the same principle as a motorway for wheeled vehicles. The traffic capacity will increase significantly by adding multiple lanes, and the lanes could be divided into different speed limits. Common for both of those corridors are; they use a static corridor, and if something happens in the corridor, the corridor must be closed. The most flexible corridor among the three is the switching corridor. Switching corridors utilized a dynamic corridor that could adapt to any situation, even increase the traffic capacity by adding temporal allocation in the airspace. Another advantage with switching corridors, it can reroute around established no-fly zones, which means the corridor doesn't need to close down if something happens. The exploration of different corridors gives us more options to optimize the UAV traffic and introduce it into the UTM system. As for today, the airspace for UAV is centered around unstructured travel, which means the UAV traffic is based on free-routing. A corridor type routing would make the airspace structured. Due to the lack of data, it is hard to tell which corridor is most effective and safe, which needs more further research on the topic.

In our last research topic, we look into how liability could be transferred between three actors. The three actors are pilots, traffic management systems, and supervisory control. In our case, the supervisory control is the one who regulates laws like the civil aviation authority in Norway or the United Kingdom, and the traffic management system is responsible for traffic planning, monitoring, and communicating with everyone using the corridor. When transferring liability, there will be risk involved. From our risk analysis, which is determined by the impact matrix, the most impactful risks are finance or cost when transferring liability. Another high impact risk is following laws and regulations that could occur during a liability transfer. For each risk we have, we create a mitigation plan to reduce the impact. The risk analysis helps us to identify the most impactful risk when transferring liability when operating in the corridor. Due to the lack of available data, it is hard to tell if the risk identified in our risk analysis is reliable and needs further research to establish a more advanced risk analysis for liability transfer in a corridor.

Chapter 5

Conclusion and Further work

5.1 Conclusion

In our work, we looked into various UAVs and UTM technology, solutions, and techniques for corridor routing. The goal of our study is to explore the use of corridor routing for UAV in structured airspace and analyze different corridor types as well the liabilities transferring that could occur during any given corridor. We first studied literature and looked into related works related to UAV and UTM. In the literature review, we looked first into UAV and its technology. A UAV or commonly known as a drone is an aircraft that comes in various sizes and shapes. The most common one in the commercial market is the multi-rotor UAV, which provides the right solution for most common applications and an affordable price. Another type of UAV is the fixed-winged, which uses traditional airplane design. The design of this type of UAV allows it to cover large areas or long distances in a single battery cycle. To be able to operate UAVs at a greater distance, it needs to use a technology called BVLOS. The technology of BVLOS allows the operator to operate a UAV without having the aircraft in his sight, which creates new opportunities in the drone market. To manage vast numbers of UAVs, the UTM will play a big part. With the use of a UTM, UAVs will no longer have to communicate to a single entity such as an assigned air traffic controller like traditional air traffic management (ATM). Instead, the UAVs will communicate freely between multiple service providers, which the service providers need to hold relevant security, performance, and safety standards given by authorities. A UTM system will ensure safety between unmanned and manned airspace. To meet the demand of operating UAVs safely in the European market, the EU developed a program under the SESAR Joint Undertaking called U-Space. U-Space focuses on the operation of UAVs securely and safely in urban and rural areas. As of today, the airspace is unstructured and based on free-routing travel from point to point. This kind of free-routing is restricted and forbidden by having a massive volume of UAVs in the airspace, which needs special permission to fly the drone on a planned route.

Based on our literature review, we proposed four main research topics within our conceptual framework; Placement scenarios and structuring corridors and junctions, Static and Dynamic corridor, Comparing three types of corridors and liability in corridors. In our first research topic, we explore scenarios where a corridor could be placed and defined various definitions that could impact on the corridor. In our case, the corridor would be placed in a maximum altitude of 120 meters or 400 feet, by the guideline of CORUS a UAV operation could be used in very low-level airspace which is defined as 150 m or 500 feet. A safe separation is given to ensure safety in the corridor and to objects on the ground, such as buildings, people, and motor vehicles. The safe separation distance in a corridor needs to factor the speed, navigational accuracy of the aircraft, and all UAVs in the corridor need a form of a collision-avoidance system to be able to enter the corridor. We also took a look into how the weather could impact UAVs and corridors. From our case, we have two scenarios of corridor placement, one in rural areas, and one in urban areas. In both cases, we define different speed zones, depending on where the corridors are located. In locations where there are roads or buildings nearby, the speed zone would be slower. Common for both corridors in rural and urban areas is the corridor width, which is placed at 500 meters, 250 meters each side from the centerline. Corridors in rural areas will have higher speed limits compared to corridors in urban areas, as urban areas have more factors that need to be taken into consideration.

For our second research topic, we look into static, dynamic corridors, and what differentiates the two corridors. For static corridors, the flight path and the distance are known beforehand, which means the flight time is calculated before the UAV enters the corridor. A static corridor is not flexible, which would cause the corridor to stop all traffic when a no-fly zone is established because of accidents or events near the corridor. On the other hand, a dynamic corridor is flexible and can adapt to any situation. When there is a disruption in the corridor, a dynamic corridor can reroute the pre-defined path around the disruption, in our case, a no-fly zone. The dynamic corridor can also increase the capacity by having temporal airspace with allocated flight paths. When switching between a static and dynamic corridor, there would be risk involved. Risks involved range from traffic density, schedule delays, communication between all actors involved in the corridor to weather hazards and collisions. Based on our risk analysis, we found out that collisions have the most severe risk impact among all the risks.

On our third research topic, we go through and analyze three types of corridors and compare them to each other. Specific and parallel corridors have some points in common such as both corridors are pre-defined flight paths, the travel distance is known, the travel time is pre-defined, and both of the corridors are static corridor types. For a specific corridor, the corridor will have limited capacity as it only allows one operating UAV at any given time and only allows one direction. A parallel corridor has more capacity than a specific corridor by using two-way and multiple lanes in a given direction. The most flexible corridor of the three is the switching corridor, which is a dynamic type corridor. Like the other two corridors, the switching corridor uses pre-defined flight paths but could change the flight path to suit many situations. By having multiple horizontal layers, the capacity of the corridor would increase substantially, and the use of the intersection between each layer allows UAVs to move from one layer to another layer. The corridor does not need to close down when a disruption occurs in the corridor. Instead, it would reroute around established no-fly zones and keep the traffic ongoing.

For our last research topic, we look into liabilities in the corridor and the risks involved when transferring liability. The three main actors here are pilots, supervisory control, and traffic management system. In our case, the supervisory control is the one regulating the laws like civil aviation authority in Norway or the United Kingdom. Meanwhile, the traffic management system is responsible for traffic planning, monitoring, and communicating with pilots and third parties. The pilots are the main responsible for safely operating their aircraft. When transferring liability, naturally, there would be risks involved. For every risk, we use risk analysis to determine the impact of each risk. The risk impact is determined by the sum of probability and severity, which goes from a scale of 1 to 5. By using risk analysis, we found out that among all risks, the finance/cost has the most potential risk impact when transferring liability as this risk could impact all parties involved. Moreover, for every risk, we made a mitigation plan in order to reduce the impact of the risk. Based on the result of our conceptual framework, the framework could be used as a foundation within corridor routing and extend the framework further to include other types of corridors in the future.

5.2 Further work

Although this study evaluates and analyzes the proposed framework, due to time constraints and limitation of knowledge about corridor routing, our framework is still too limited to achieve the best optimization results. The next would be to focus on examining more extensive ranges of the use of a corridor type routing and look into which corridor provides the most efficient in terms of traffic flow, density, and capacity. One direction is to expand all three corridor types by looking into the placement of the corridor and changes to the corridor, to see which corridor gives the best outcome in terms of traffic flow and capacity or add a new corridor type into the framework. Another direction is to create a simulation environment for a corridor by using the parameters proposed in this framework. The simulation environment can start with a specific corridor placed in a rural area and then change it to an urban area and compare the results between the two. The same can be used to the other two corridors and then compare all the simulations with each other. Using a simulation environment will give us a rough idea of how each corridor performs and then changes the parameters to give us better results.

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