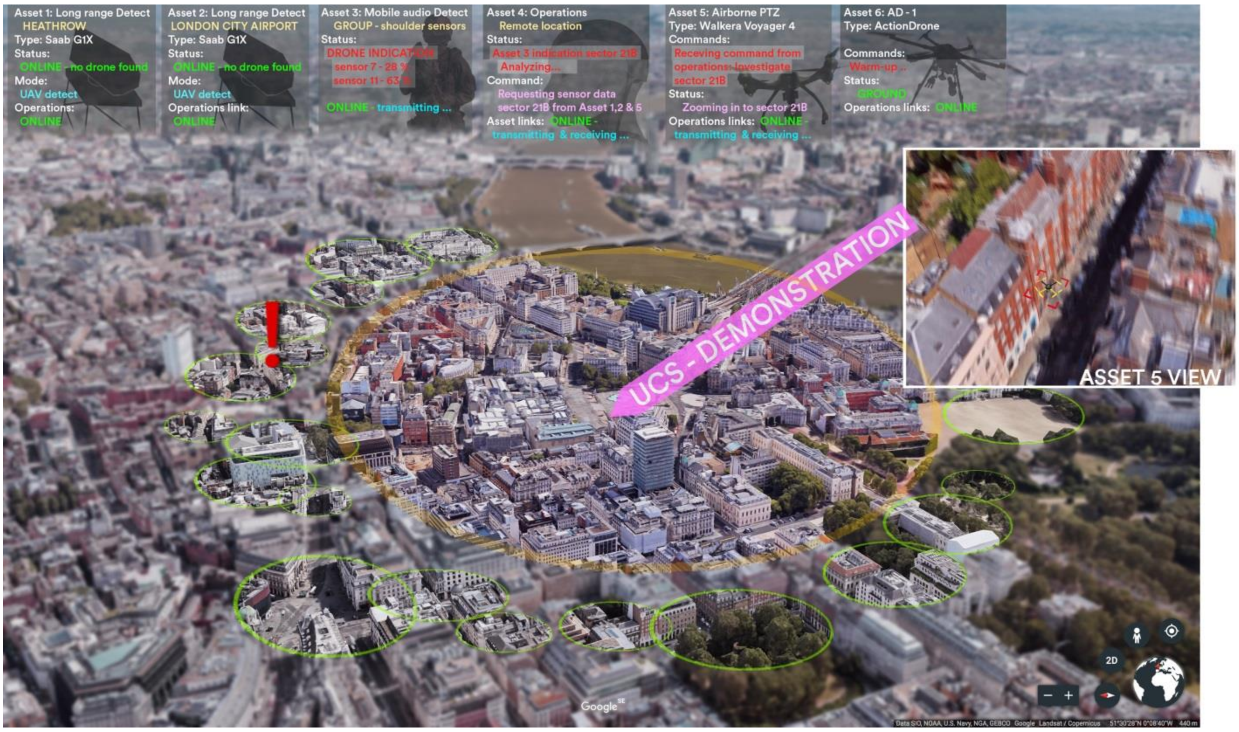

Conceptual study of a future drone detection system

Countering a threat posed by a disruptive technology

Master's thesis in Product Development

- ***NIKLAS ERIKSSON*** –

Department of Industrial and Materials Science
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2018

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Title: Conceptual study of a future drone detection system.
Sub-title: Countering a threat posed by a disruptive technology.

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This master's thesis project has been conducted at Saab Surveillance in Kallebäck.

Cover page Image: Graphics by Niklas Eriksson using Google Earth maps.

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Conceptual study of a drone detection system – Countering a threat posed by a disruptive technology
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ABSTRACT

This pre-study focuses on how to deal with trespassing and potentially dangerous multicopters in civil applications in the context of early concept development for a radar company. However, the results of this study can be used for military multicopter detection scenarios. The scope is that of a C-UAS system (Counter Unmanned Aerial System) as it is argued that drone detection cannot effectively be developed without a systems perspective including ways of stopping the drones.

There are multiple inputs that define a strong anti-drone system that will change over time and concepts are aimed to be future proof. Potential areas of application are identified and translated into customer segments where the threat and complex need widely differs from each other. Except for market and customer needs inputs, underlying technologies for both finding and stopping the drone are mapped and benchmarked over a larger number of attributes generated from needs analyses in the given segments. This quantification is necessary to facilitate fact-based design choices in creating a strong and robust system. The segment scenarios are analyzed and defined with black boxes and flowcharts that clearly demonstrate varying complexity. Perspective shifts between the needs and the solutions domains throughout the thesis.

The study results in a conceptual **M**odular **M**ulti **A**sset **S**ystem at a high level of abstraction that is robust to both a moving target and different drone scenarios. Existing and conceptual building blocks for such a system are presented and justified from findings in the benchmark scores of the study. Application specific system concepts are presented for several customer segments.

Department of Industrial and Materials Science
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Gothenburg, Sweden 2018

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Prologue

This concept study is the result of a master's thesis in the product development programme at Chalmers. The thesis was proposed by Saab Surveillance as a possible market had been detected, possibly not adjacent to their core products. The study was carried out at Saab Surveillance's site in Gothenburg. The office is home to a large variety of competences and people with great technological knowledge house every floor of the building. I had no prior knowledge about radar technology but was drawn to this concept study as the important market need, need for creativity, width and hi-tech factors inspired me greatly.

The deep technological knowledge at Surveillance and integrated low volume products has resulted in Saab being a rather functional organization with some implications in speed of development which is likely common also for their competitors. Things like activity based work-environment and scrum meetings indicate a will for change towards lower functional barriers and facilitate effectivity in new product development (NPD). The company has during my study gone through a structural re-organization in most of the Gothenburg site's departments. Cross-functional teams were in the pipeline of being created and I could not help to think that this is all very relevant to my concepts study. My task was to find a way in to a new market that seems to have great future potential. To do that I would have to focus on both identifying the market to see what opportunities there are, but also look at the company to understand what strengths could be utilized in creating a competitive product for a new market. I soon came to the conclusion that to have a chance of bringing something relevant to market means having to understand the need of customer better than competitors do. Saab and its military competitors have had a way of developing products with long development time and sparse competitor analysis as an effect of military secrecy and large and information sensitive customers. I believe the secrecy of military applications have blocked new product development trends of modern times of getting real traction. If this is true, entering a new civil market could be hard and show a greater need of fast product development, extensive multi angle understanding of customer needs, and being able to maintain aim on a moving target during a development project.

Images

This study contains multiple images, figures, and illustrations and to optimize the image reference texts some clarifications are made here.

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This type of image license waves all rights of a photographer and lets an image be used for even commercial purposes and can also be modified. It does not require a reference to the photographer. All images in this report that are not references are CC0 images except for Google Earth and Google Maps images.

Google maps and Google earth

These modified images do not require more reference than the text shown at the bottom of the images themselves according to Google.

Modified images

Many modified images show situations that aim to look real. They are illustrations made by the author of this study. These illustrations also use CC0 images except for the map illustrations.

Graphics and silhouettes

All graphical contents are made by the author and silhouettes and sketches sometimes appear without figure texts. In those cases the topic of that section is a direct description of the silhouette or sketch.

Numbering

Tables, Figures, and Images share the same numbering which resets for each chapter.

1 Introduction

This chapter is a description of a problem, an emerging market, Saab Surveillance's current products and Saab's interest in this project.

UAS driving a disruptive technology shift

Over the last few years UASs have become more technically advanced whilst prices for these products have dropped with an underlying reason in the occurrence of efficient Li-Po batteries and brushless DC-motors. Military drones have taken dangerous jobs from pilots with gains in safety and cost. In the private use of non-military drones one finds an even bigger development. *Image 1.1* demonstrates a large U.S. army unmanned aircraft.

Image 1.1 shows a large American military drone.

In civil use, airborne filming and photography for both film and television has moved from the use of helicopters and cranes to drones. The change of procedures has pushed technological development forward in terms of usability, reliability and affordability in a way that indicates a disruptive technology shift within broadcast and film industry. The technology also has disruptive potential in other fields, like for example agriculture and industrial inspection. *Image 1.2* shows a professional camera drone. On the other end of the civilian UAS market toys and competition drones are found where attractive attributes are speed and dexterity. The combination of speed, dexterity, high resolution cameras and an ability to carry a payload makes for a potentially dangerous mix and at the dark side of the coin we find the public debate of personal integrity and both personal and national safety. After recently having introduced legislation to reduce civil drone activity in Sweden, legislation have once again (July 2017) moved towards less control and drones are no longer prohibited to fly in most areas of Sweden.

Image 1.2 shows a professional camera drone.

Walmart and Amazon are taking steps towards delivering online purchased goods with drones. In the dark reflection of that development these airborne borderline-toy products now move contraband to prisons and over national borders. Furthermore consumer grade drones are physically able to carry dangerous objects to unprotected and exposed targets. Camera equipped low cost drones can be used to spy while available products for protection against this new threat are limited in number and affordability.

Saab Surveillance

Saab Group is a Swedish company with a larger part of their 15 000 employees working in Sweden. Surveillance is one of six business areas and it is based in Gothenburg. The company has a competitive spot on the market for various high end radar systems and with its deep technological competence it competes with substantially larger government or military supported companies in other countries.

Saab Group state that their company strategy has changed to fit the change the company is going through. A significant number of large-scale NPD-projects have crossed the finish-line (especially at the Surveillance business area) and the company is therefore going into a phase where the products are going into the respective markets. Efficiency in manufacturing is now an important issue to work with to ensure an overall profit margin according to C.E.O. Håkan Buskhe in an interview 2017. This development is also true for the business area Surveillance and there is great interest in efficient manufacturing with focus on reducing costs.

Saab's radar product line

Saab offers a variety of military grade radar products ranging in size and application. *Image 1.3* shows the Giraffe ground radar product family. Ground-, air-, and sea-radars are divided in subdivisions but all products can be described with some common factors:

- ✓ *Low sales volumes with varying sales over years.*
- ✓ *Extreme performance.*
- ✓ *Military standards for durability.*
- ✓ *Integrated product platforms with low re-usability of sub-systems.*
- ✓ *Often high need of customization for new customers and applications.*
- ✓ *Long product life time.*
- ✓ *High product development costs.*
- ✓ *High manufacturing cost.*
- ✓ *High level of manufacturing sourcing.*
- ✓ *Costly verification process.*

Image 1.3 shows Saab's Giraffe ground radar family of 2017. (© Saab AB, 2016)

Counter-Unmanned Aerial System (C-UAS)

Looking at existing or soon to be on the market products of relevance, some clues are given on different technological concepts, which actors are involved, market maturity but less information about price and relevant market segments. High differentiation both appearance and technological solutions indicate that the maturity of the market is low as no dominant design is yet in sight. According to individuals at Surveillance there was a market for only spotting drones but the product could likely be used as part of a C-UAS system.

Today Saabs Surveillance offers a product line with state of the art performance. To some extent Saab's most affordable ground radar G1X offer everything except the neutralization step in a C-UAS-system although it is not developed for this specific purpose. However Saab suspects that an interesting market for drone spotting radars will imply a product price that is lower than today's product range. The company obviously has substantial experience in developing competitive radar detections systems but not at all in the predicted price range. Consequently the company has a large distribution and service network for their radars but today it is not necessarily built to serve low price civil products.

1.1 Aim/purpose

The aim of this study was to develop early concepts for a drone detection system, exploring measures to utilize Saab Surveillance's core competences to create an attractive product offering.

1.2 Scope

This concept study includes planning and early concepts with special regards to needs identification of new product development (NPD). The moving target is very present in the study and understanding customer needs over time is very important to understand how to design a system.

The concept was not restricted to only radar technology for UAS and should not necessarily meet the description of a C-UAS product as it might not perform the neutralization step in such a system's definition. The mission was not set to produce a low-budget version of any existing product in Saab Surveillance's current product offering, but to look for technological opportunities of solving the task without restrictions. Countermeasures are included in the study, as it is a vital part of a whole system and generates performance requirements for the detection task.

1.3 Research questions

To maintain aim at the goal of the study, work was focused on answering the following questions:

1. ***Problem:*** *What do we need protection against?*
2. ***Need****: What are the needs of the customer, and how do they rank?*
3. ***Market research****: What is the new market, and how should that be segmented?*
4. ***Company analysis****: How do the company's competences match the need of the customer?*
5. ***Concept****: How could Saab create a market offering that puts them in a leading market position? How can they reach a wide market?*
6. ***Moving target****: What is changing in the near future?*
7. ***Development plan****: What would be the first step, a way in to a new market?*

2 Methodology

This project started in the fuzzy end of development and emphasis initially lied in defining the task, where to start and what results that was expected. Many of the initial inputs proved to be deficient and more product planning efforts had to be included. As a counterweight to a fuzzy environment, this the methodology chapter shows an almost overly defined methodology.

2.1 From start to end

When formulating a methodology, starting and ending points of the project was defined as shown in *Figure 2.1*. The starting point was a combination of factors found in the company, the market, and results from adjacent studies at the company. The ending point was defined from a combination of agreed deliverables with both Saab and Chalmers and with respect to other stakeholders including my own engineering skillset.

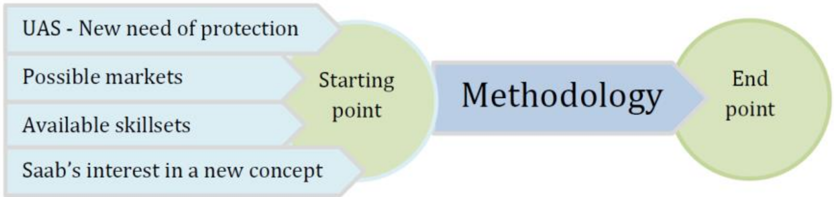


Figure 2.1 illustrates how methodology helps moving from starting point of the project to the end point.

Unfolding the end point of *Figure 2.1*, the following deliverables were found:

- ***Saab**: Drone detection system pre-study.*
- ***Saab**: Drone detection system concepts.*
- ***Saab**: Recommendations to further development*
- ***Chalmers**: Demonstration of clear ties to my master's programme in the written thesis and presentation*
- ***Chalmers**: Contribution to Chalmers sustainable development*

2.2 Stakeholders

In each area of application for the product concept, stakeholders could be found. Here, the stakeholders of this project are presented.

- ***Saab Surveillance** needs help to quantify their possibilities and efforts when it comes to entering a new market.*
- *It is in the interest of **the public** to have protecting technology that well matches the threat of a disruptive technology - drones used to spy, smuggle, and attack a variety of both civil and national objects. In this way the project serve the **social aspect of sustainable development.***
- *The **customer** of the radar system needs a product that is takes away their Pain factor and solves their drone problem better than competitors do.*
- *The **end user** wants to have an effective product that is easy to install, use, and that have a sufficient degree of automation.*

- *The **environment** is a stakeholder in that the concepts produced in this project follows directives of a sustainable development. In a green development, a product with a fuzzy environmental profile can be damaging to both product sales and brand name.*

2.3 Methodology scheme

Figure 2.2 shows a graphical representation of the methodology of this thesis. A pink arrow represents the thesis report which through continuous writing drives progress of the projects activities/gates (blue boxes) and result in deliverables to both Chalmers and Saab. The green area represents Saab Surveillance with its available knowledge and in the core of the figure the **reference team** at Saab is illustrated. Arrows shows current flows of information in different parts of the project where every gate ends with a two-way information flow to the reference group.

Saab Surveillance reference team

The reference team was put together by supervisors at Saab and consists of a cross-functional mix of material, mechanical design, signal processing, hardware and marketing competence. Its purpose is to provide guidance and spot flaws or problems in different aspects of the concept designs.

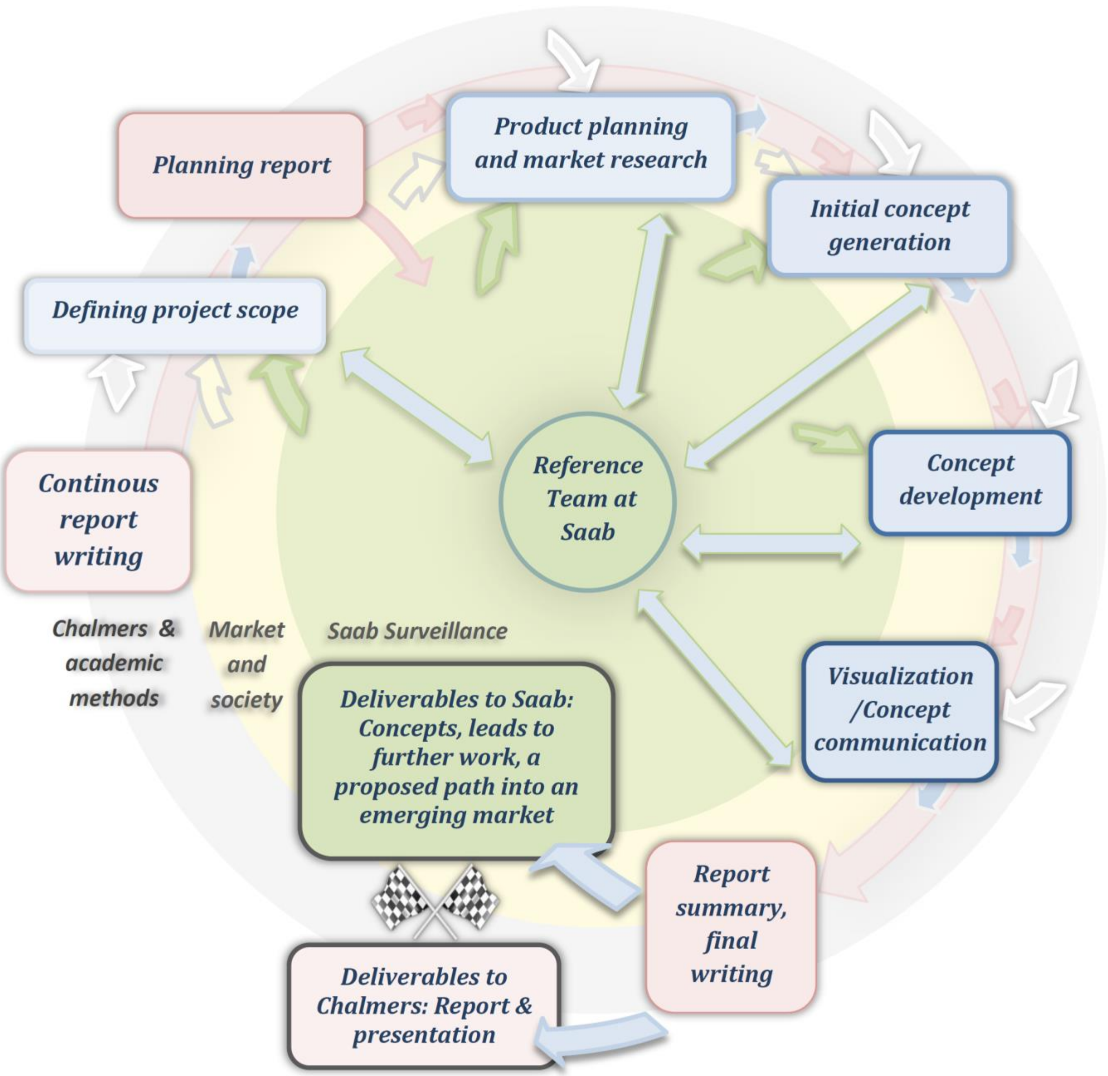


Figure 2.2 is a visual representation of the methodology.

2.4 Methods

To support the methodology of *Figure 2.2* the right choice of methods would facilitate the following:

1. *Doing the right thing.*
2. *Maintaining efficiency of work flow.*
3. *Putting in the time and effort.*
4. *Information & knowledge extraction, analysis and creation.*

Figure 2.3 show how the first three classes of methods work to enhance the forth class: Information & knowledge extraction, analysis and creation.

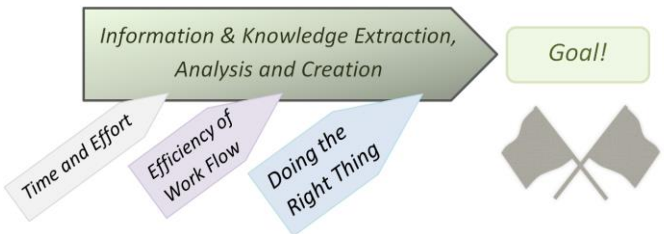


Figure 2.3 illustrates how the main methods are supported by others to reach the goal.

Agile and Lean are examples of methodologies that have been strong words buzzwords for quite some time. The binary question of "Do you know scrum?" can appear on interviews for a new job. It could be argued that a large and successful methodology perhaps is not successfully reduced to such a simple question. The urban legend-like example of Lean's 5S method being used for an office desk in England to show where the keyboard and monitor should be placed using tape stripes is an example of misunderstood Lean implementation. It highlights the importance of motivation a choice of methods and how there is a difference between small tool-like methods and a full methodology. This is the reason behind this thesis' method definition of *Figure 2.3*.

Methods to ensure number 1-3 are found in *General method for enhancing work flow* section while *4. Information & knowledge extraction, analysis and creation* consist of the large part of product development methods in this chapter. Those methods are divided by the same main activities or gates as the blue boxes in *Figure 2.2* with the addition of a section for requirements. Each method's relevance to this thesis is motivated but there is no general explanation of each method provided here.

General methods for enhancing work flow

In making sense of the fuzzy end of this project a lot of the chosen methods serve as means to quantify and making root causes visible. Establishing work environment was important.

- **Work place**: All work is conducted in an activity based work environment at the company to be as close as possible to the knowledge of the staff.
- **Log / diary:** This keeps notes about every other hour of all tasks, interviews, and events. After a conversation a reflection was written in the log as a way of following a train of thought. The log provides the following:
    - **Harvesting inspiration**: It prevents losing ideas and reflections. A flow of inspiration often comes as a result of an interview with another purpose.

    - With a mind set to **basing decisions on facts**, the log allows a person to follow an idea backwards and see what reasons were behind it and keep him or her from getting facts mixed with subjective opinions from themselves or their interviewees.
    - **Doing the right thing**: Pausing an activity and going to the log to report also promotes an evaluation to if it is the right thing to go deeper **or** instead taking a step back and looking broader.
- **Activity bank / to-do-list**: Much like the use of post-its in different popular work methodologies a breakdown of project activities into small chunks provides a list that should never be empty. Always having parallel activities enables a choice to switch tasks over the day to keep perspective and avoids getting stuck hammering a wall. In that way this method helps working towards ***maintaining efficiency of work flow.***
- **Time logging:** Keeping track of hours spent is done to ensure that ***putting in time and effort*** is done. This together with direction from *doing the right thing* and *maintaining efficiency of work flow* enables the project to move from the *starting point* to the *end point.*
- **Gantt time table:** Graphic time schedule that makes it easier to decide allowed time on each activities and setting deadlines for project gates.

Defining project scope:

Internal interviews were conducted at Saab: Extracting information of internal expectations, market, and available technologies was to a large part done through informal semi-structured or unstructured interviews. There was no available map of where to extract information and leads to find new interviewees are found in conversations/interviews.

Product planning, market research and technologies:

- The **literature review** was used to find knowledge in the following categories:
    - *Reading up on basic radar knowledge.*
    - *Internal documents connected to the project.*
    - *World trends.*
    - *Legislation on UAS.*
    - *Market size.*
    - *Available technologies.*
    - *Interesting products on or near market. Understanding what technologies can be considered.*
- **PESTEL**. The method was used to paint a picture of the world climate, in which the new market would be. Trends of technological, legislative, and political nature are underlying reasons for a need of this kind.
- **SWOT**. What were the benefits and problems for Saab Surveillance looking in to this potential market? The SWOT offers some guidance to separating internal and external positives and negatives.
- **Need classification:** The study identified three different types of need that are shown to be connected to current and future needs.
- **Kano model**: Classify requirement to understand what is absolutely necessary, what performance drivers are and what can be used as “delighters” to differentiate the product from “the rest”. Kano models are compared to the three types of needs identified in the needs classification.

- **Customer segmentation**: Is there one market or many adjacent markets that is interesting for Saab? With basis in the needs from different areas of application for a drone detection system, the segmentation provides classification and a template for sorting customers/markets. Attributes like threat, performance indicators, and market readiness are quantified for the different segments as basis for both concepts and a development plan.
- Internal **interviews**: Getting an idea of both internally and externally available technologies and available competences.
- **Technology roadmap**: If the concept product is an independent part of a larger system a technology roadmap shows what technology must be available for the development of derivative products. In the study it is presented as a list of needed technology for each conceptual building block.
- **Technology benchmark**: Strengths and weaknesses were identified in chapter five. The most prominent technologies were selected and benchmarked in extensive tables to visualize their potential over a number of important performance attributes.
- **Competitor analysis:** The competitor analysis maps general competitor trends for products on or near the market in terms of technologies used and design choices as important inputs to the concept generation phase. Input will partly consist of public information on competitors but also of expert opinions at Saab, quantifying the company's best guess.

Initial concept generation

- **Black box**: A basic way of looking at the problem as a system to get an idea of input/output to that system and also defining its borders at the highest abstraction level, far from a technical concept.
- **Flow chart**: Opening the black box and observing what is going on at a one lower level of abstraction. The flow chart is practical to use at different levels of abstraction and one block at a high level chart can contain a whole chart at a lower level.
- **Brainstorming:** Getting started and forcing inspiration to start generating concepts.

Concept development

- **Concept system overview:** Perhaps the most important part of the concept is the system overview as it is used to motivate design choices on the highest abstraction level and is needed to understand what parts of a competent system overlaps Saab's core competence and product strategy.
- **Concept benchmark**: The concepts are presented with benefits and drawbacks like the technologies in chapters five but also with a light technology mapping that that shows what underlying technological challenges lies ahead in realizing each concept. The conceptual building blocks of the drone detection system in this study are benchmarked for the needs of different customer segments.

3 Definition of the Drone

This chapter summarizes UAS terminology and classification and gives examples of commercial drones to better understand what poses a potential danger. The last section involves how future drones will evolve.

It is easy to accidentally mix some aspects of this difference shown in the image series in *Figure 3.1.* Finding large winged drones is a task that can be performed with traditional radar products. This study focus on multicopters in civil applications, but the figure illustrates that both the drone type and the threat can be similar across the civil-military border.

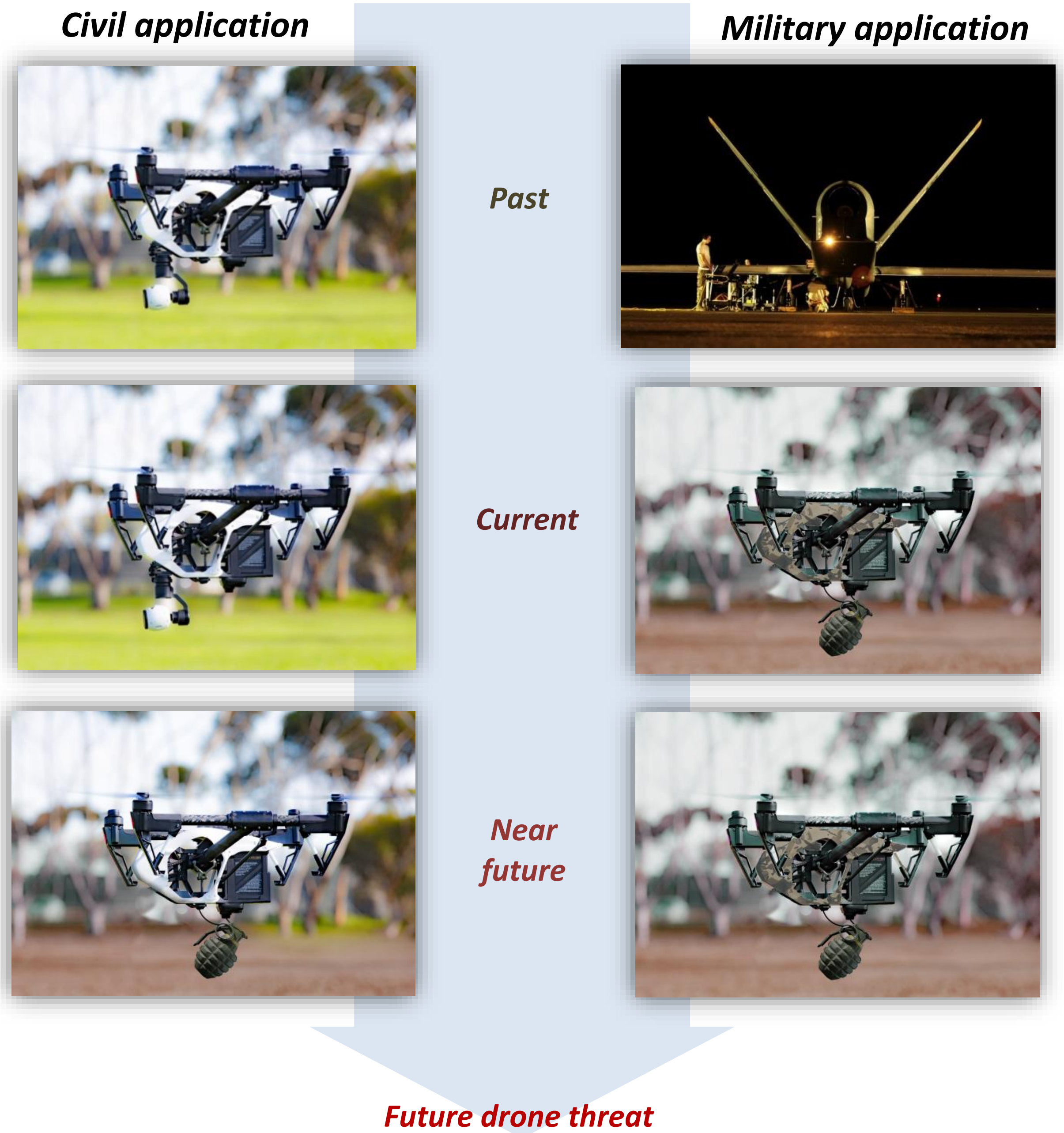


Figure 3.1 illustrates how the border between a drone threat in a civil and military application blur.

3.1 UAS, UAV and the Drone

This concept study uses all three terms to describe the same thing. To answer the question posed by the headline – There is not much of a difference when the terms are used is worth clarifying. *Image 3.2* shows a hobbyist quadcopter.

- **UAV** is the most common abbreviation in both press and journal articles for commercial multicopters, which this study focus on. The term stands for **U**nmanned **A**erial **V**ehicle, and therefore it aims to describe the aircraft itself, excluding systems like cameras, communication and command equipment. There is no restriction in size or type of Aircraft.
- **UAS** means Unmanned Aerial System and includes everything from Pilot controller equipment to aircraft and its other onboard technology like for example cameras and grappling arms. There is no restriction in size or type of system.
- **Drone** is a more dramatic and therefor popular term that can be used to describe a smaller multicopter. Ordering a UAV for recreation photography will likely mean putting a ***Drone*** in the shopping cart. In media, this term is also the most common term to describe large U.S. military unmanned aircrafts who carry out attacks on terrorists in the Middle East. These attacks are often carried out from operators within the U.S. The Drone term is often used when portraying an unmanned aircraft in a **threatening** way. There is no restriction in size or type of Aircraft. The military drones are more likely to be fixed wings planes than multicopters.
- **Multicopters** likely imply quadcopters, hexacopters or octocopters but have no limitation to number of motors. The number of motors is usually strongly connected to the size of the multicopter which can be categorized in to size classes.

Image 3.2 shows a drone, UAV, UAS or Quadcopter. All the terms are fit to describe this small aircraft.

3.2 Multicopter size classification

There are three main reasons that this classification is relevant to this study, namely:

- ***Detection****: The size of the aircraft determines how hard it is to detect.*
- ***Payload performance****: To be able to carry large payloads the multicopters will have to grow in size.*
- ***Crash danger****: The size of the aircraft is highly relevant for estimating the harm it inflicts on a person or animal on crash impact.*

(Sturdivant & Chong 2017) use a classification that is based on a NATO UAS classification report which is shown in *Table 3.3*. The nano-class is added by the authors of (Sturdivant & Chong 2017) and it is an important addition to the list as speedy competition drones can be found in that size class. The NATO classification is getting old and likely focus on plane-like aircrafts. The numbers still work for multicopters even though the range and strength has increased in commercial multicopters over the last years and might to some extent outperform the numbers in the specification table.

Table 3.3 shows size classifications of UAS according to (Sturdivant & Chong 2017).

Size class	Maximum mission range	Payload [kg]
Nano	100-500 m	>0,2
Micro	5 km	0,2 - 0,5
Mini	25 km	0,5-10
Small	50-100	5-50
Tactical	>200 km	25-200

3.3 Multicopter performance

Different multicopter classes have different potential to perform different tasks. Here, five examples of commercial multicopter products are shown as an indication of how models in different UAS classes perform.

Fast Nano-quadcopter:

In this class of drones, DIY or BIY is common to achieve attractive performance much like RC cars and planes. Even though the highest performing models are not available off the shelf, detailed instructions and second hand aircrafts are available. This model (*Figure 3.4*) is however an off-the-shelf toy product available since early 2017.

Manufacturer: *UVify*
Model: *Draco*
Weight: *About 350 g*
Speed: *160 km/h*
Range: *Likely short*
Handling: *Poor / demands user skill*
Flight time: *2-3 minutes*
Maximum payload*: About 100 g, with implications in speed*
Price: *ca 5 000 SEK*

Figure 3.4 – The Draco drone

Comment: Built for recreational and racing purpose.

Fast semi-professional camera micro-drone

An example of such drone is the DJI Phantom series and the Phantom 4 (*Figure 3.5)*. The drone is used by both hobbyist and professionals and come in different versions. The more expensive versions offer better features, especially when it comes to the camera. The DJI phantom 4 pro use a 1" photo sensor and hi speed filming in 4K which makes it usable for some professional filming. The model is restricted to 500 meters in altitude in software but earlier models do not have that limitation. Derivative products on this platform use multiple sensors to offer advanced and effective **obstacle avoidance** functions.

Figure 3.5 shows the DJI Phantom 4.

Manufacturer: *DJI*
Model: *Phantom 4*
Weight: *1 380* g
Speed: *72 km/h with standard payload in speed mode*
Range: *7 kilometers, restrictions lie in communication. 30 minutes of use in non-speed modes*
Maximum payload: *About 800 g with implications in performance*
Handling: *Excellent, easy to use*
Price: *< 10 000 SEK*

Micro/small camera drone with optical zoom

This type of drone can use its long range optical zoom for industrial inspection like for example wind turbine rotor blades which are hard optically inspect otherwise. An example of such drone is the Walkera Voyager 4 in *Figure 3.6*. 18x optical zoom and dual positioning systems (GPS & GLONASS) makes for potential in surveillance. This model is used by police forces.

Manufacturer: *Walkera*
Model: *Voyager 4*
Weight: *3200 g*
Speed: *72 km/h*
Maximum altitude: *1000 m*
Price: *35 000 SEK*
Range: Very long due to 4G connectivity

Figure 3.6 – The Walkera Voyager 4.

Small professional multi-purpose drone

This type of drone is big enough to carry payloads and example is the Japanese ProDrone PD6B-AW hexacopters (*Figure 3.7)* which can be seen on YouTube, moving chairs, catching drones and flying in heavy rain.

Figure 3.7 shows the PD6B-AW.

Manufacturer: *ProDrone*
Model: *PD6B-AW*
Weight: *19 kg*
Speed: *60 km/h*
Maximum payload: *30 kg*
Price: *Unknown, likely > 100 000 SEK*
All-weather compatibility: YES

Comment:
This multipurpose drone is aimed towards industrial use and is B2B sales only (business to business). The producer claims that it carries 11 kg for 30 minutes. There is an available version with robot arms.

Small agriculture drone

The agriculture multicopter is one step bigger than the ProDrone and specialized for its purpose where can be programmed to spray lines of crops. One example is the DJI Agras MG-1 octocopter which is no less than 1,5 meters I diameter. The drone can be hosed with water after each use for maintenance. *Image 3.8* shows the DJI Agras MG-1 spraying a field.

Image 3.8 illustrates an octocopter spraying a field.

Manufacturer: *DJI*
Model: *Agras MG-1*
Range: *1 km*
Weight: *8,8 kg*
Speed: *79 km/h*
Maximum payload: *10 kg*
Price: *80 000 SEK*

3.4 Upgrades

Commercial drones can be upgraded with OEM parts or third party components. Typical attributes that can be enhanced through upgrades are:

- ***Altitude*** *– By changing propeller rotor blades.*
- ***Noise level*** *– By changing propeller rotor blades.*
- ***Maximum air time*** *– Stronger battery pack.*
- ***Optical range*** *– Larger focal length/optical zoom and stabilizing gimbal.*
- ***Drop / release function*** *– By YouTube-tutorials.*
- ***Range:*** *Modifications to antenna. Directed antenna onboard the multicopter.*
- ***Night vision:*** *Higher ISO-sensitivity through larger optical sensor or with IR-camera.*

Except for this, various creative ideas can be found by garage-engineers on YouTube, including weapons.

3.5 Future drone threat

When developing a system to counter a threat posed by drones, one must consider that the drone technology has not nearly reached it full technical capability. A system for the future must solve a future need, not just the current.

It is assumed in this concept study that **the problem** with countering drones will grow with time. That hypothesis is based on three assumptions:

1. ***Presence:*** *Drones are likely to continue to grow in numbers.*
2. ***Automation:*** *Drones will have steadily increased performance and level of automation.*
3. ***Criminal intent:*** *Increased drone use is likely among criminals realizing the benefits of it.*

Drone identification technology

Transponder technology is used to keep track of aircrafts and enable efficient communication between aircrafts and traffic control. The same or similar technology could be used for drones and if drones would be used for transportation of goods they will have to be monitored. As of now, transponders are not really used and the transponders are expensive and large in comparison to commercial drone multicopters. Technically, they could however be slimmed down in both costs and size.

If future friendly UASs are equipped with identification technology, detection of them will be easy in comparison to drones today.

Performance

All the performance attributes of the upgrade-section will likely continue to enhance for quite some time. To enable package delivery services, drones will likely have to increase possible airtime and durability for high usage.

Control range

This attribute is worth mentioning as control range limits how freely a drone can be flown. Most drones use RF-signals directly to a controller which means range restrictions and problems with obstacles in the way of that signal. There is good potential to steer the drone via internet instead, which potentially completely removes that obstacle. 4G combines high bandwidth with low ping respond-times. The obstacle avoidance functions of DJI products enables robustness in the behavior of the drone when the signal is lost and will likely grow much stronger in the future.

Noise level

Today most drones emit a noisy mix of frequencies which resembles a large angry bee swarm. For a micro-sized drone today, the sound can reach the ground from more than 500 meters in altitude. Sideways, the sound dies out much faster. The noise level can be lowered by a number of ways:

- *Changes in propeller design lower noise level as spread the sound energy over a wider band of frequencies.*
- *Surrounding propellers by a padded protection. The largest noise print is however directly beneath the multicopter, which is a tricky direction to pad without impairing the stream of air.*
- *Put PWM (pulse wave modulation) in ultrasound spectrum.*
- *Let the propellers work at different RPMs.*
- *Use different PWM for different motors.*

There are great incentives in growing drone markets for a reduced noise level, as today's multicopters are loud and easily disturb and distract nearby people.

Automation

A level of automation is already demonstrated among commercial high volume drones. DJI phantom series is an example where obstacle avoidance and safe return to home point is used to complement the operators steering. To enable efficiency in droned delivery systems, the level of automation likely has to be high for two reasons:

1. *To reduce costs, as individual pilots for each delivery will lead to high delivery prices as drones cannot carry the same payload/amount of packages as a truck.*
2. *To enable secure air traffic and use multiple sensors and calculate a safe and efficient path.*

Drone swarm

Military drone swarms have been demonstrated with advantages in scalability and their small size being hard to detect and neutralize. The drone swarm software algorithms can be useful in air traffic flow and collision avoidance as a crucial part of automated air traffic. In construction, drone swarms can help lifting objects where it is hard to reach, with some resemblance to the dress making hummingbirds in Walt Disney's Cinderella.

Disney and Intel are two of the companies that demonstrate commercial drone swarms in LED-blinking drone lightshows with no less than 500 units in 2017. YouTube offers multiple clips on the topic.

Personal safety

To enable drone services, safety is an extremely important factor. Crashes and collision must be avoided for feasibility in that area. Drone identification is one important technology to enable safety.

Camera drone crashes have resulted in restrictions in some sports where the heavy drones risk to crash into crowds. Downhill slalom skier Marcel Hirscher was fractions of a second away of getting hit by a heavy camera drone in a competition in 2015. Correct use and better hardware will however likely minimize the danger posed by camera drones. Automation, robustness, and possibly parachutes could decrease crash danger.

In October of 2017 CNN were first as a U.S. news company to get permission to fly directly over crowds. To do so, they will use a special light weight drone, with protected propellers and safe crash de-assembly design (Loyd 2017).

Robot birds

Small robots resembling animals have been developed for years trying to find befits of their movement patterns including robotic birds and insects. Powerful and useful robots have been demonstrated with an example of a heavy humanoid performing different task including running and backflips. Robot birds of prey are already sold to airports to scare off birds to reduce bird collisions with aircrafts. When developing a system to counter drones, a robotic bird can potentially make that task more complex. Sensors that listen to loud multicopters stand chanceless against a feathered threat. Behavior analysis algorithm used to sort out drones from the many birds in a radar-covered area will have a new challenge if their movement pattern is similar. The shadow of a circulating robot surveillance eagle also has a good chance to rule out optical sensors as a counter asset.

Miniature aerial vehicles

Imitating animal shapes and propulsion is a way of increasing efficiency and force development for robots. Making the drone smaller, in the neighborhood of insect's size can be attractive in different applications in the future. With increased automation and swarm behavior this is more likely to be technically feasible and future airborne threats have the potential to continue to shrink. The smaller size has already been argued to have implications in at least range and payload size. However, optical surveillance goes hand in hand with a small size drone and small explosives could still threaten personal safety.

4 Market Analysis

As the market is rapidly emerging, the time perspective is extra important when customer needs will be prone to change for a number of reasons including market maturity, legislation, and drone technology. Understanding the needs of the customers is a key to producing any competitive product as it formulates the problem and generates the market opportunities. This chapter investigates the following:

- ***SWOT***: *What are the possibilities and difficulties, both internally and externally for Saab?*
- ***PESTEL***: *World trends relevant to the problem.*
- ***Indication of need - Areas of application***: *Who needs protection and why?*
- ***The Need***: *What are the needs of potential customers?*
- ***Customer segmentation***: *Comparing the needs, what are the similarities and differences between different areas of application?*
- ***Competitor analysis***: *What has been done by competitors and how good is it?*

4.1 SWOT analysis

The SWOT analysis sets the concept in perspective. The analysis leads to finding the required shape of the puzzle that connects the four different SWOT aspects as illustrated in *Figure 4.1* and *Figure 4.2*. *Figure 4.*1 is a graphic illustration of the SWOT analysis. The internal aspects are partly found in the introduction in company and product descriptions, but also in the mapped technologies in chapter five. The external opportunities are potential markets in this chapter and new technologies of chapter five. The external threats are of course competitors of chapter four but also changing legislation and the evolution of drones which both form the moving and potentially illusive target.

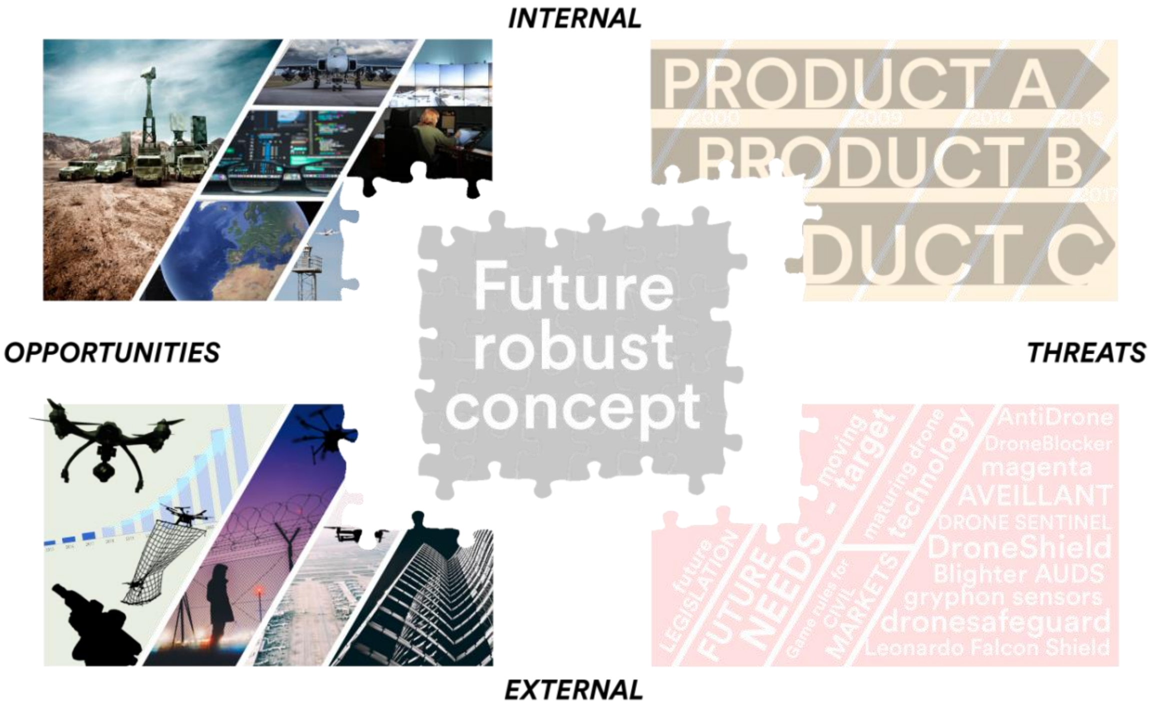


Figure 4.1 is a visual SWOT analysis.

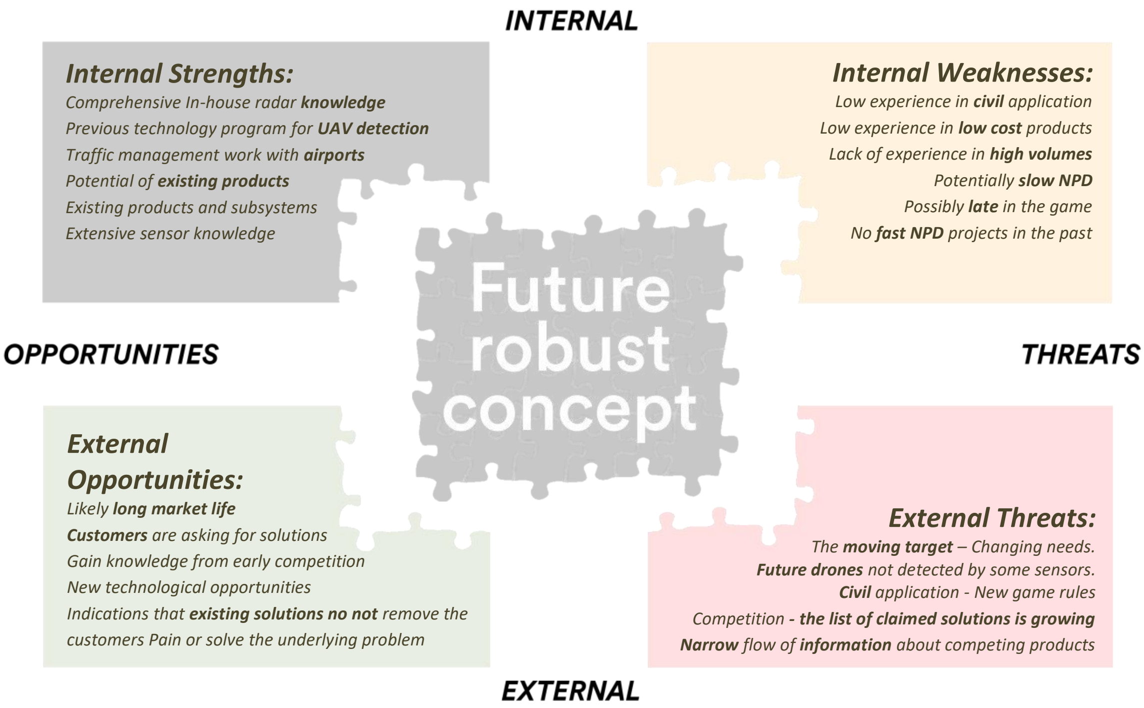


Figure 4.2 explains the SWOT of Figure 4.1 with words.

4.2 PESTEL Analysis

This analysis provides an overview of the environment in which the company would operate in a new market. That environment is divided in different categories to provide clarity and guidance. Protection against UASs is obviously connected to the presence of UASs. For that reason the larger part of this analysis maps aspects of UASs rather than drone detection equipment or radars. In that regard this PESTEL diverge from the original use of this method. *Figure 4.3* illustrates how the different trends surround a market offering.

Figure 4.3 shows the PESTEL overview and how a market offering is affected by a variety of world trends.

PESTEL – Political

Political trends and possible government market interference are found here. They are closely connected to the *Legal* trends as government and parliament decide what legislations will prevail.

Presence of UAS drive change of regulation

Commercial drones are growing in numbers and *Image 4.4* illustrates a typical hobbyist drone pilot. In March 2017, the Federal Aviation Administration (FAA) had received more than 770 000 registrations over a 15 month period in America alone according to CNN money (Yurieff 2017). 80 000 commercial and government registrations has been made during the 12 month period from August 2016 to 2017 according to (Bellamy III 2017) at aviationtoday.com. Note that hobbyist do not even have to register UASs under a certain weight, see the *Legal* part of this section for details.

Image 4.4 illustrates a hobbyist piloting a drone over a neighbor's house

Regulation concerning UASs is still changing and legislation is having a hard time catching up to the many aspects of hobbyist and commercial civil UAS usage. Relevant changes of legislation can also be read in the *Legal* part of this PESTEL analysis. Based on the rapid change of regulations, one can assume that new laws can be seen in a near future as the UAS technology has not reached it full capacity and new areas of application are still creating new markets. Future legislation will also be relevant to the need for protection against UASs.

Government trend for drone detection products

Current C-UAS solutions often use Electro/Optical (EO) sensors which in Sweden would make them likely to fall under the camera surveillance law (2013:460). A new Swedish law is proposed (2017:55) to replace the old camera surveillance law in 2018 and the proposal claims to get closer to EU directives and make the use of camera surveillance easier in preventing crimes and incidents.

Airports

An article from the pilot's union *Flygtornet* (Carlsson 2017) reports that Sweden's biggest airport Arlanda had to be shut down no less than three times during the week of the article in August on the count of non-hostile UASs entering the airport's control zone. A drone crashed into a small aircraft on landing approach at Jean Lesage International Airport in Québec City in Canada the 12th of October 2017 at about 500 meters in altitude (Howard 2017). After declaring emergency the plane landed successfully without anyone getting harmed.

In a magazine article (Warwick 2016) discuss statistics of FAA UAS sighting reports from pilots and an analysis of those reports made by Bard College. In 2015 there were no less than 1 218 reported UAS sightings from pilots of which in more than 90 % of the cases the UAS flew at an altitude above the 400 feet general limit of the time. Comparing numbers from FAA's statistic sheets from the period January to March in 2015 and 2017, the number of reported sightings has gone from 161 to 404. In a journal article (Wild et al 2016) have analyzed 152 civil drone incidents over ten years (2006-2016) and claims that their results suggest technical malfunction was a larger contributor that human factors as a reason behind the incidents. They argue that legislation and regulations should give more focus to technology that just rules for operators. In other words; regulations for UAS pilots to behave respectfully might not be enough to minimize incidents. As that report use some older data, that could imply that a larger part of those UAS's were model planes piloted by experienced users, thus having technical malfunction as a larger contributing factor. *Image 4.5* illustrates the threat drones pose to Aircrafts.

Image 4.5 illustrates the potentially devastating scenario of a drone flying into a jet engine.

Drone-watch and politicians

German Chancellor Angela Merkel had a visit from a drone landing by her podium while giving a speech in Germany in September of 2013. The incident that can be seen from different users on YouTube was non-aggressive but showed how little the security staff could do about the situation. In another incident (Shear & Smith 2015) reported that the White House had a friendly accidental crash visit from a DJI Phantom drone where the pilot allegedly had lost control and the white house radar did not see it due to its small size. According to (McCarthy 2017) the R&S Ardronis drone classification system was used during the G7 summit at Elmau Castle in Germany and for Barack Obama's visit to the Hanover Fair Trade in 2016.

PESTEL - Economical

(Keller, 2016) is one indication that existing radar system is being upgraded to be better at spotting drones. The article reports that the U.S. army orders such upgrade for Lockheed Martin's AN/TPQ-53 radar system in a $27,8 million contract. This is just an example of the interest in updating radar product with better drone detecting features and government interest though the U.S army.

Another economical trend is a comparison between the technologies of consumer UAS and drone detecting equipment. A drone for below $500 can today deliver speeds up to 160 km/h and fly at an altitude of several hundreds of meters. An existing radar solution to spot these toys over the control zone (which is well over 500 hectares in size) of a medium sized airport like Arlanda likely costs many thousands times more than such an UAS itself costs. *Figure 4.6* shows an aggressive projection of world commercial drone revenue over the coming years.

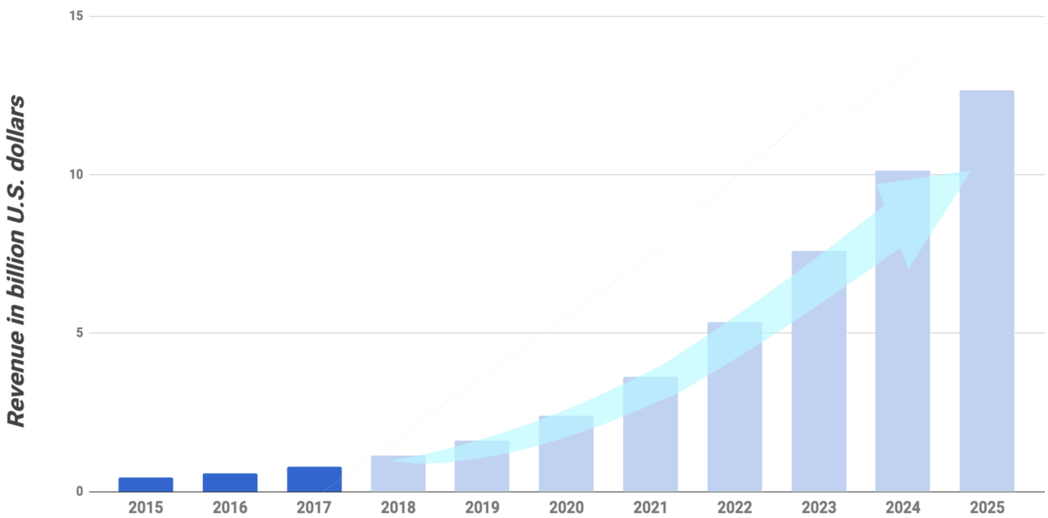


Figure 4.6 show commercial drone world market revenue projections from (Statista 2017). The graph is a reconstruction using Statista's data.

PESTEL – Social

Availability and price of UASs have generated interest and awareness of their existence among most people. As drones are perceived as a dangerous threat to personal integrity by parts of the world population, others view them as harmless toys. Other than that no relevant socio-cultural trends have been identified.

PESTEL – Technological

Both drone and counter-drone technology trends presented here.

UAS technology

Except for established uses for UASs, applications are growing with mentionable examples like the shark spotting drone reported in newspapers like (Borkhataria, C. 2017), land-mine detection concept of (Colorado et al 2017) and Amazon's plans with their PrimeAir drone delivery system. According to a report in September of 2017 (Michel 2017) at the Center for the Study of the Drone at Bard College, Amazon then had over 60 approved patents that concern their planned drone delivery service at that time. (Austin 2010) provides a thorough list of applications for UASs in his book. According to (Freeman & Freeland 2014) most commercial UAS revenue will be generated from agricultural use as illustrated in *Image 4.7.*

Image 4.7 shows how a DJI Agras MG-1 octocopter sprays crops with pesticide.

Multi sensor drone detection

C-UAS systems are being developed and include a diverse set of technologies in different concepts. In a magazine article (Larson 2016) looks at C-UAS solutions in detail to discuss a suitable solution for an airborne C-UAS system. He concludes that different technologies have its strengths and weaknesses and that strong system would use multiple technologies to combine their strengths. In their concept study of an airport drone detections system (Sturdivant & Chong 2017) also conclude that a multi sensor system is necessary.

Different technologies that can be found in mature markets and others exist within a laboratory environment. The specific use and possible combination still implicates that technological development has to progress before a dominant design can be seen on market by any manufacturer.

Large high performing existing radar systems are being upgraded with drone detection capabilities as indicated by the development contract in (Keller, 2016).

PESTEL – Environmental

Using drones instead of helicopters and cranes is more energy efficient and it is a positive technological trend following the disruptive technology swop. A future drone will also likely pose less danger and intrude less than a what a helicopter would do when performing the same task.

Looking at drone detection, radars emit possibly dangerous radiation due to the use of microwaves. A good product must consider this aspect and not harm people or animals. Energy consumption, waste disposal, and choice of materials are other factors that might be more important to keep an eye at in a civil market in comparison to a military market. The intended use of the product should work to enhance social sustainability in delivering protection to a new threat.

Ethical aspect

The defense industry has some attention of public opinion when it comes to development and manufacturing military equipment. A product that clearly only can detect and stop drones would be much preferred then methods that include generic surveillance and weapons which would encounter problems in the eyes of the public. If the product concept would be able to monitor people whilst performing its main task, that would address an ethical aspect that have to be considered with respect to personal integrity which in Sweden is currently regulated in the Personal integrity act (1998:204) and the Camera surveillance law (2013:460).

PESTEL - Legal

This section concerns laws and regulations that impact the targeted market. Regulations for the use of UASs differ over country borders. Here, Sweden and USA are used as examples to give a general indication of drone legislation. The legislation mentioned in this section does not consider the use of UAS detecting equipment but instead legislation that has impact on the presence of UASs.

Relevant laws and guidelines for UASs in Sweden

The supreme administrative court of Sweden had decided to include all camera drones to the camera surveillance law (2013:460) in 2016 which meant that individual exceptions had to be given for the use of any camera equipped UAS. In guidelines from (Datainspektionen 2016) to county administrations reasons for exceptions were primarily prevention of crimes and accidents which meant a great obstacle for both hobbyist and professional UAS users. This prohibiting law was only applicable to drone use for less than a year but had been a hot topic in media and allegedly caused damage to industries using camera drones.

According to (Veckans Affärer 2017) it was with large majority the Swedish parliament in 2017 voted to make an exception in the camera surveillance law to exclude UASs with proposition (2016/17:182). The difference for the drone user is essential as there is no longer need for a camera surveillance permit for hobbyists and instead just guidelines in place to consider the implications of the drone.

Guidelines are provided by the Swedish transport agency (Transportstyrelsen 2017) and include the following main points:

- *Fly within reach of sight, and a maximum of 500 m distance.*
- *Maximum flying altitude of 120 m.*
- *Keep distance to people and animals. Do not fly over people.*
- *Mind the control zones around airports. Special permit is needed to fly there.*
- *Mind restricted areas including locations as prisons, power plants, and military areas.*

In addition to (Transportstyrelsen 2017) spreading film and video taken from the air can still conflict with PUL (1998:204) looking after personal integrity and if the data could be considered within the Geographic Information Act (2016:319), it would be sensitive to Swedish armed forces. Commercial use of drones still needs permits from the Swedish transport agency.

New legislation in 2018

A new camera surveillance law (2017:55) is proposed to at least partially include drones from 25th of May 2018 and to more closely follow EU-directives. It is safe to say that legislation is still trying to catch up with the disruptive technology of UAVs.

Drone map

Figure 4.8 illustrates Air Navigation Services of Sweden's (Luftfartsverket - LFV) "drone map" and show an example of no-fly zones in the Gothenburg area. Note that for example Säve city airport, Skogome correctional institution, Gothenburg city harbor and docks, Preemraff oil refinery and Saab Surveillance are not represented in the map. Since 2015 Säve Airport no longer have commercial air traffic but it is still used for ambulance, police, and training traffic.

Figure 4.8 is a reconstruction of LFV's "drone map" of the Gothenburg area.

UAV rules in the U.S.

Rules for UASs in the USA can be found with the Federal Aviation Administration (FAA 2017) and have been in place since 2015. They are similar to Swedish rules with some exceptions:

- *The aircraft must be registered with the FAA database if it weights over 0.55 lbs.*
- *No restriction for height of flight.*

For commercial use there are additional restrictions including:

- *Must fly under 400 feet.*
- *Must fly during the day.*
- *Must fly at or below 100 mph.*
- *Must not fly over people.*

These rules are subject to waiver that can be applied to the FAA for exceptions. Except for typical protected areas, the FAA recognized a threat to stadiums and defined areas around them as national defense airspace, making it a criminal offence to fly there from 2014 according to a Forbes contributor article (McNeal 2014). The permission for CNN to fly over crows in October of 2017 (Loyd 2017) will likely be followed by others.

4.3 Indications of need

This section presents different application areas for an UAS detecting system and a source of indication to each need. Some extra emphasis is put into the airports section for the following reasons:

- *Saab already has business with airports in Saab Sensis which provides ground radars for larger airports.*
- *Saab's Traffic management business area develops a system for remote Traffic control of airports.*
- *Articles indicate a need for drone detection at airports today.*
- *Indications directly from many airports.*

Airports

As argued in the *PESTEL* section, the FAA pilot reports (Warwick 2016) and the article about Arlanda's frequency of UAS visits (Carlsson 2017) indicate that there is a need for monitoring UASs at airports in general. After multiple interviews with airport employees, the authors of a journal article claim that:

> The first is that it is very clear that airports are well aware of the threat posed by drones and they are actively working with local groups, private industry, and federal agencies to understand the threat and to develop ways to respond. (Sturdivant & Chong 2017).

As part of The Federal Aviation Administration's (FAA's) Pathfinder program, the FAA started cooperative research with Liteye Systems Incorporated, Gryphon sensors, and Sensofusion in Juli of 2016 (FAA 2016). The FAA also says the research program aims to test and evaluate technologies and procedures for detecting UASs near airports.

Saab is already supplying airports with radar systems and according to (Saab Sensis 2017), 36 of the busiest airport in the US now uses Saab Sensis' ASDE-X radar for local ground traffic management. (Sturdivant & Chong 2017) use this specific radar system in suggesting a multi sensor system for airports, a SoS (system of systems). They also state that, while covering a 12 000 feet of land the radar only has about 200 feet altitude coverage. Even if the radar has dire restrictions in possible UAS detection use, the product still put Saab radars at airports and opens up to possible integration of existing technology.

Prisons

Commercial drones have high potential for illegal smuggling of contraband to prisons. Multiple newspaper articles report how drugs, phones, and other contraband are carried in to prisons without security even noticing that they are there. *Image 4.9* is a digitally constructed image how an octocopter smuggle contraband in to a prison yard in the dark.

Image 4.9 is a constructed image of an octocopter drone entering a prison with ease.

According to a contributor article for Forbes (Goglia 2015), the Prisons Bureau made a public request for information on counter-drone technology. The prisons Bureau is part of the American Department of Justice and according to the article responsible for about 205 000 federal inmates.

One interviewee argued that there is an urgent need for protection at prisons and that even a solution that catch only part of trespassing drones. He also claims that a C-UAS system is preferred for such a customer. Multiple newspaper articles report that the drone problem is real and how an English prison installed a drone jamming system called Sky Fence can be read in a Telegraph newspaper article by (Mogg 2017).

Power plants

Power plants are an important part of a country's infrastructure and make them sensitive to sabotage. According to a magazine article by (Larson 2016) many power plants have high security standards and a manufacturer of a radar drone detecting system, SpotterRF claims to have a number of both power generation and transmission customers. At the same time an interviewee from marketing at Surveillance believes that this is not an interesting market area and that a terror threat would be the only event that needs to be prevented. He argues that a UAS is not likely to be an effective tool in an act of terror.

Stadiums

Sport events and concert gather large amount of people to a stadium. There is a great danger for one or a few people associated with a friendly but malfunctioning drone visit. The UAS can be heavy and can seriously hurt people crashing in the stadium. The concentration of people also makes them a possible target for terror attacks.

According to an article in the Wall Street Journal (Robinson & Landauro 2015) at least one of the bombers in the Paris bombings in 2015 had a ticket to a Football game at Stade de France stadium and tried to get in. The guard fortunately found his suicide vest and thereby stopped a horrifying attack but the bomb still detonated outside the stadium and killed a person. *Image 4.10* shows a large and crowded baseball stadium.

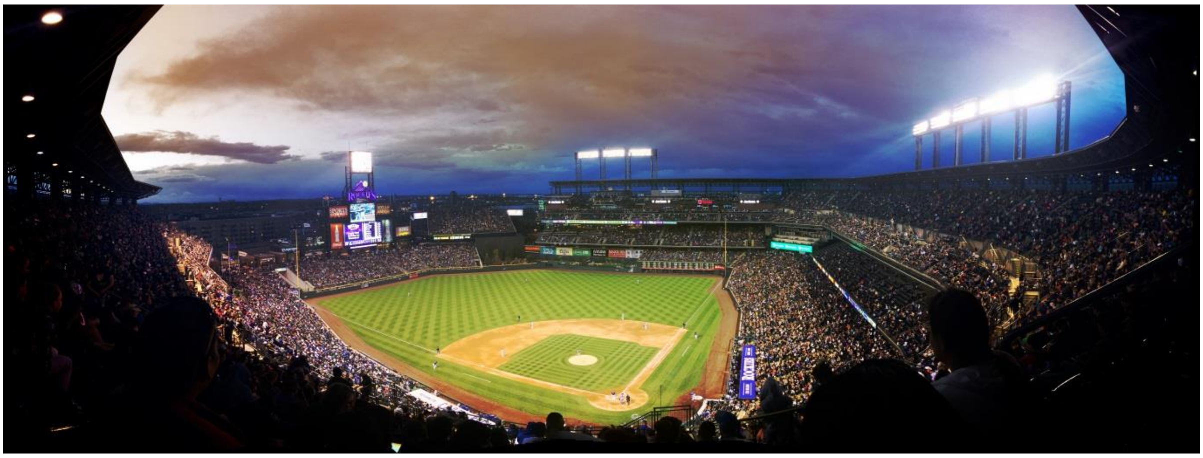


Image 4.10 shows a crowded stadium during a baseball game.

Police

All over the world the Police look for ways of dealing with illegal drones. Examples of mobile drone disabling technology are net guns (Atherton 2016), various RF jammer guns (Hodgkins 2015), drone-catching drones (Mail Online 2017), and Dutch drone catching eagles (The Guardian 2017). The police in different countries need a mobile C-UAS system where neutralization step can be done by for example the mentioned technologies. It is assumed that the police use such a system in crowded areas, which makes the neutralization step hard; not putting people at risk when disabling, taking down a drone. *Image 4.11* is a montage of a drone flying over a crowd.

Image 4.11 is a constructed image of a commercial drone over a crowd.

Military ground forces - Long range optical espionage

There are recent examples of how countries manage to get good footage of other countries ground forces and there is a military need for countermeasures according to an interviewee at marketing. This customer is well aware of their needs but existing solutions does not solve the problem.

Company espionage

Some indications can be found where UASs spy through windows in offices, use its mobility to enable hacking of secured networks and also prototype espionage. One example of prototype espionage is how drone paparazzi's know test location and manage to get images of car prototypes. There is a high level of secrecy in automotive industry's product development as they are complex products in the most competitive markets.

Drone corridors

Future development of drone delivery systems is indicated by Amazon's *PrimeAir* program. (Michael 2017) show 65 awarded patents for Amazon. If this kind of delivery system will be part of the future, a need of traffic management for the transportation UASs will come with it. Managing these drone corridors could be an interesting market for derivative products after establishment on other markets.

4.4 The Need

The *4.6 customer segmentation* section of this study summarizes the needs presented in depth in this section. Three dimensions of the needs were identified and presented here, namely:

1. ***Type of need**: Ease of Pain, solving of underlying problem or efficiency improvement.*
2. ***Performance aspects**: Which attributes are most relevant for each application and how much of that attribute is needed or wanted?*
3. *What are the **long term aspects** relevant to a certain applications?*

The type of need is important to understand and there is a Pain factor for potential customers in all the areas of application identified in this study. The Pain of the customer tells us what they are ready to pay for. As in this case where no good solutions exist, the customer in Pain will try whatever medicine or Pain relief is available. A customer might even buy them all to see if anything works. Looking a few years into the future, this might however change. Instead of being medicated, the underlying problem must be attended and solved in order to ensure a happy customer. These different product offerings are illustrated in *Figure 4.12*.

1 - Offering a sound investment / Efficiency improvement

3 – Solving the underlying problem

2 - Offering Pain relief

Figure 4.12 illustrates different types of product offerings to a customer.

Current and future needs

The current situation for any application area with a Pain factor is that no solution exists that really solve the problem. It is likely that early products on the market only need to ease or take away those Pain factors to some degree without offering great performance. This will however change with time, as the customers realize that the underlying problem has to be solved as competitors grow in numbers. Long term aspects will likely follow the high performing need and aspects of use, durability, and lifecycle aspects will eventually become equally important factors.

The KANO model

The model is a simple graphic way of categorizing product attributes into three categories, which corresponds to the same category of needs:

1. *Basic attributes*
2. *Performance attributes*
3. *Delighters*

The basic attributes is necessary to solve the problem, while performance attributes enable doing that effectively. The delighters are not necessary to solve the main problem but still attractive attributes and they are an increasingly important way of standing out among competitors. Carefully identified and implemented delighter attributes can motivate a higher product price, thus increasing a profit margin. As markets mature and get saturated, the delighters tend to descend into the basic needs.

Trying to understand delighter needs is therefore necessary in developing a future robust concept.

Airports

The airport needs are based on internal interviews, a literature study and calculations. *Image 4.13* is a constructed image that illustrates how a commercial popular micro-drone enters air space above an airport. The drone model has a software restriction limiting the drone to fly under 120 meters in altitude. Without that restriction, this model could fly in the altitude range of kilometers. For this application the following threats posed by drones have been identified:

- ***Threat***: Collision with planes cause damages and could leads to accidents.
- ***Threat***: Sudden drone detections with little position information cause delayed landings.

The Pain

Drones constitute a great Pain to most airports as friendly UAS fly into airports' airspace and accidently force them to close all traffic for 30 minutes or longer. The airport needs a solution just to be able to operate as they have done in the past. Removing the Pain means not having to temporarily close down the airport and spend time on locating drones and their operators. This suggests a solution that prevents drones from entering the airspace. Adjacent Pain points are:

- *Potentially dangerous **bird** flocks.*
- *Ground surveillance of the **runway**.*

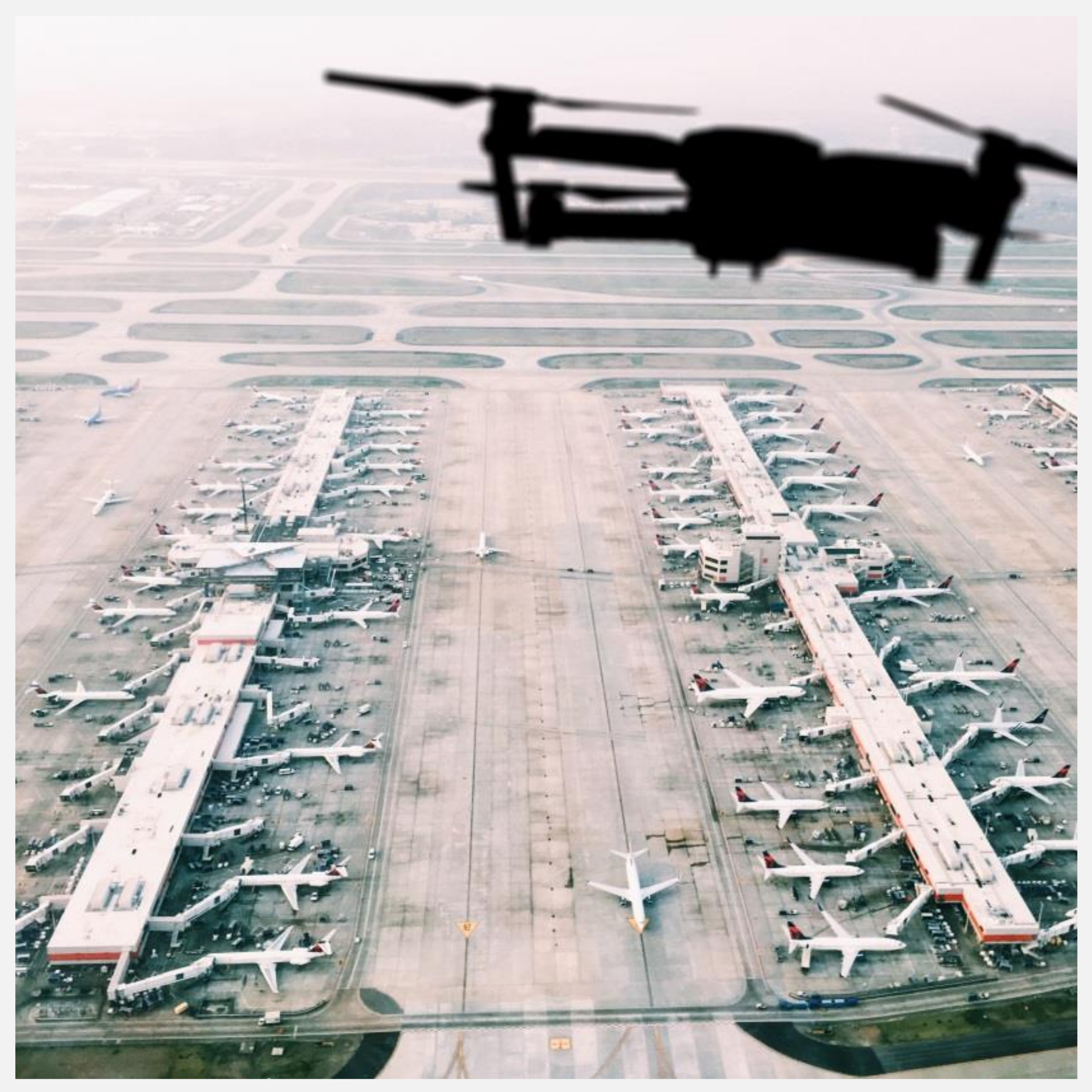


Image 4.13 is a constructed image of a drone flying over an airport at about 100 meters in altitude.

Solving the underlying problem

Solving the actual problem at airports, a solution partly lies in legislation, knowledge of drone operators, and technological restrictions. Suggestions in both academic reports and press can be found to use transponders for all drones to be able to communicate with them. This can also solve a large part of the problem with friendly drone visits. During 2017, drone manufacturer DJI has updated many of their newer products to require internet connection before take-off. If they are within protected areas of their database, the UAS refuse to start. It is for example impossible to take off with a new DJI drone within the control space of Landvetter in Gothenburg.

Efficiency

Having comprehensive, accurate, and reliable information about what is moving around airports enables efficiency for traffic control. The drone Pain can easily be translated into monetary issues as there is a great price tag on closing down a large airport. A drone detection product could help the airport in this which implies a financially sound investment.

Performance

Users of a drone detection system are possibly traffic control and airport security. According to one interviewee at Traffic management who work with remote towers, the traffic control is busy and adding work to them would not be preferred. A fully automated system would likely be most welcome to all stakeholders. According to (Sturdivant & Chong 2017) a drone detection system must have high accuracy of drone detection which also means low rate of false detection, which correlates with what the interviewee at Traffic management said.

Range

To demonstrate the range need at an airport, examples are given from that size up to 11 km radius sensors in the following steps:

1. *Multiple 500 m radius range sensors.*
2. *Single 3 km radius sensor.*
3. *Double 3 km radius sensor.*
4. *Single 11 km sensor.*
5. *Double 11 km sensor.*

The reason for showing different sensors here is that some drone detections sensors marketed at airports have very limited range (a few hundred meters). About 3 km is also an occurring range among existing drone detection sensors.

Figure 4.14 illustrates how the seventh largest airport in the world (measured by number of passengers per year) would use multiple relatively short range sensors (500 m radius with 360° view) to cover a larger part of an airport. The illustration shows three UASs visible to the sensors and one fast commercial micro-drone outside the sensors reach that is flying towards the airport.

Figure 4.14 shows a number of multicopters flying over a large airport.

Figure 4.15 show how a larger sensor with a 3 km radius range would capture the same micro-drones as in *Figure 4.14*. The time it would take the UAS to reach the runway would roughfly double compared to the short range sensors in *Figure 4.14,* which illustrates how little help the short range sensors offer on their own. Note that a large centrally placed sensor like this would likely have coverage shadows behind buildings and planes.

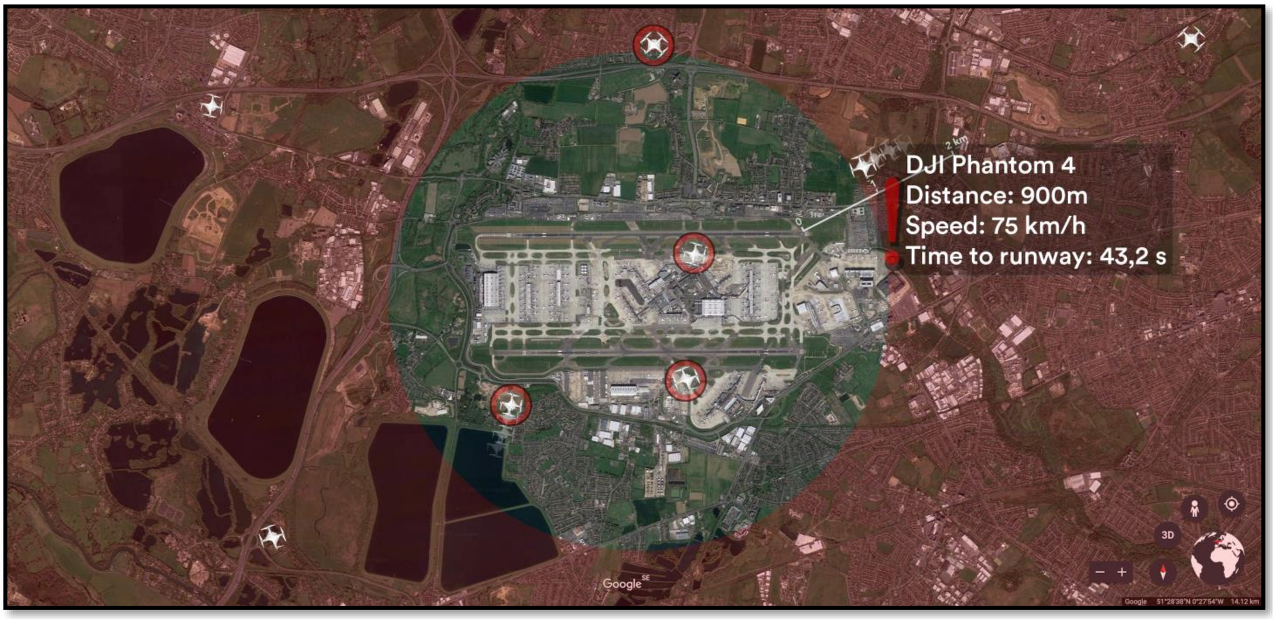


Figure 4.15 illustrates a centrally placed large sensor with a three kilometer radius range.

Scale of need at different at different size of airports

Moving down the list of busiest passenger traffic airports from the seventh largest in the world to the 259th (according to projection calculations of 4.5 Market size), *Figure 4.16* show the same example of drone placement and sensor size and placement as in *Figure 4.15.* This highlights that relevant size aspects of an airport in this case is the size and length of a runway. The range and coverage need is roughly the same for the two examples.

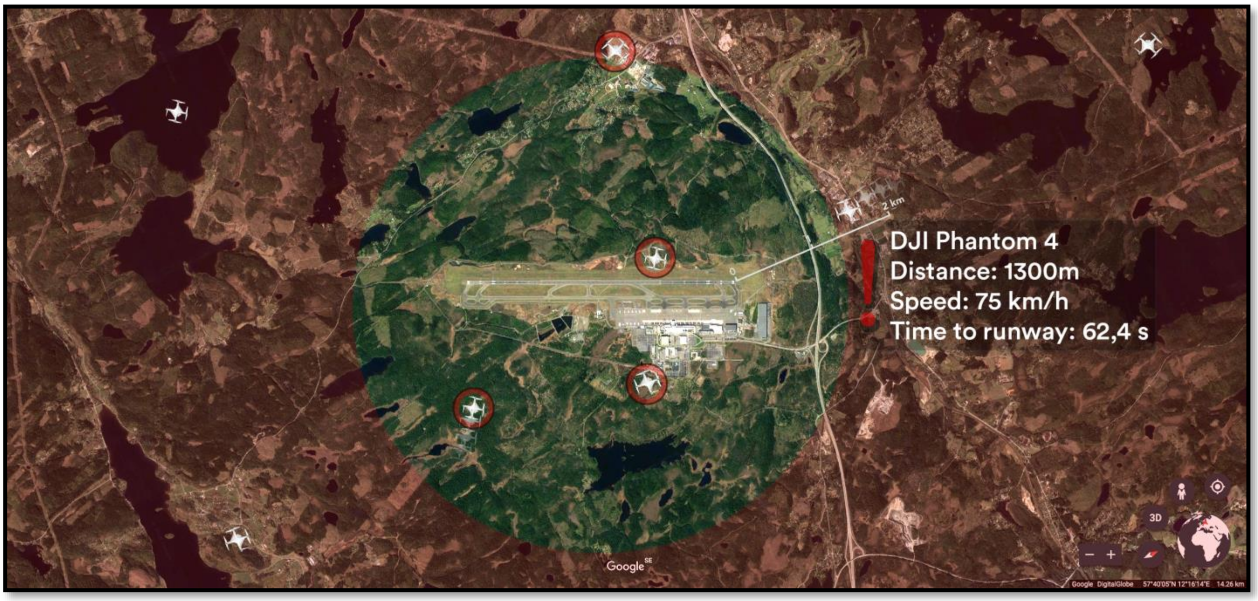


Figure 4.16 illustrates the same (as Figure 4.15) centrally placed large sensor with three kilometer radius of range.

Altitude coverage

Before illustrating longer range sensors, the altitude coverage is examined as it shown to be an input to the range need.

In the FAA pilot UAS sightings reports, qualified estimations are often given of altitude of the UAS. Looking at the 82 sightings of January of 2017, 74,4 % of the reports have altitude estimations. With a lowest drone altitude of about 5 meters and a highest reported altitude of 3 kilometers of those sightings, the median altitude is 510 meters and an average is 726 meters. *Figure 4.17* shows the sighted drones' altitude over an x-axis of dates in January of 2017.

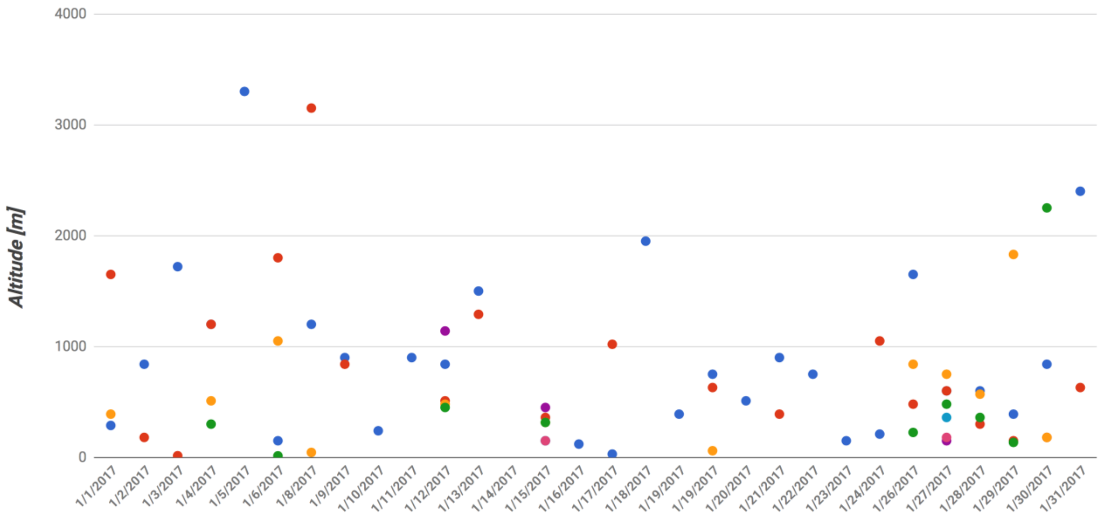


Figure 4.17 shows altitude data from FAA reports of UAS sightings in January of 2017.

The data shown that sighted drone mostly fly high compared to legal and recommended altitudes:

1. *91 % exceed 120 meters.*
2. *57 % exceed 400 meters.*
3. *42 % exceed 600 meters.*

!

The control zone of an airport reaches 2000 feet in altitude which roughly translates to 600 meters. This data strongly indicates that a detection system must have the ability to include high altitudes. A large part of these reports are made by pilots and it could be argued that some of the low flying UASs are not as likely to be discovered by them meaning that low altitude drone should not be neglected.

According to an interviewee at Surveillance, a pilot of commercial and fighter jet aircrafts, a commercial jet approaches the runway with a 3° angle with a speed between 120-150 knots. That translates to an aircraft descending into the control zone at a distance of about 11,5 km from the runway as the control zone reaches 2000 feet into the air on a landing as shown by:

$$600/\tan(3°) \approx 11{,}5\ km.$$

The statistics in *Figure 4.17* however suggest that the control zone's altitude reach is not enough as almost half of sighted UASs had an altitude above the control zone. To cover for example 95% of the drones' altitude's in that data, altitude threshold would have to be set at 2000 m which for a landing aircraft with a 3° angle. That means that the ground equivalent range of such a system would have to be

$$2000/\tan(3°) \approx 38{,}1 \text{ km.}$$

If that range and altitude should be covered and assume that an aircraft should not have to abort its landing in that time the landing time in the case of 120 knots would through conversion to m/s be:

$$\frac{38\ 100}{\left(120 \cdot \frac{1{,}852}{3{,}6}\right)} \approx 618 \text{ s.}$$

A DJI phantom 4 in speed mode, travelling at a constant speed of 20 m/s straight towards that runway would be at 12,3 km distance from the runway at the time that the aircraft descends into the control zone by:

$$20 * 618 \approx 12{,}3 \text{ km.}$$

Control zone

The control zone of Landvetter is relative to the size of the runway and thereby capability for large Aircrafts. Except for the areal coverage of the control zone shown in *Figure 4.18* it also extends to an altitude of 2000 feet, roughly translating to 600 meters. *Figure 4.18* shows the range requirement without sensor examples and is followed by different range sensors' effectiveness in *Figure 4.19, 4.20, 4.21 and 4.22*.

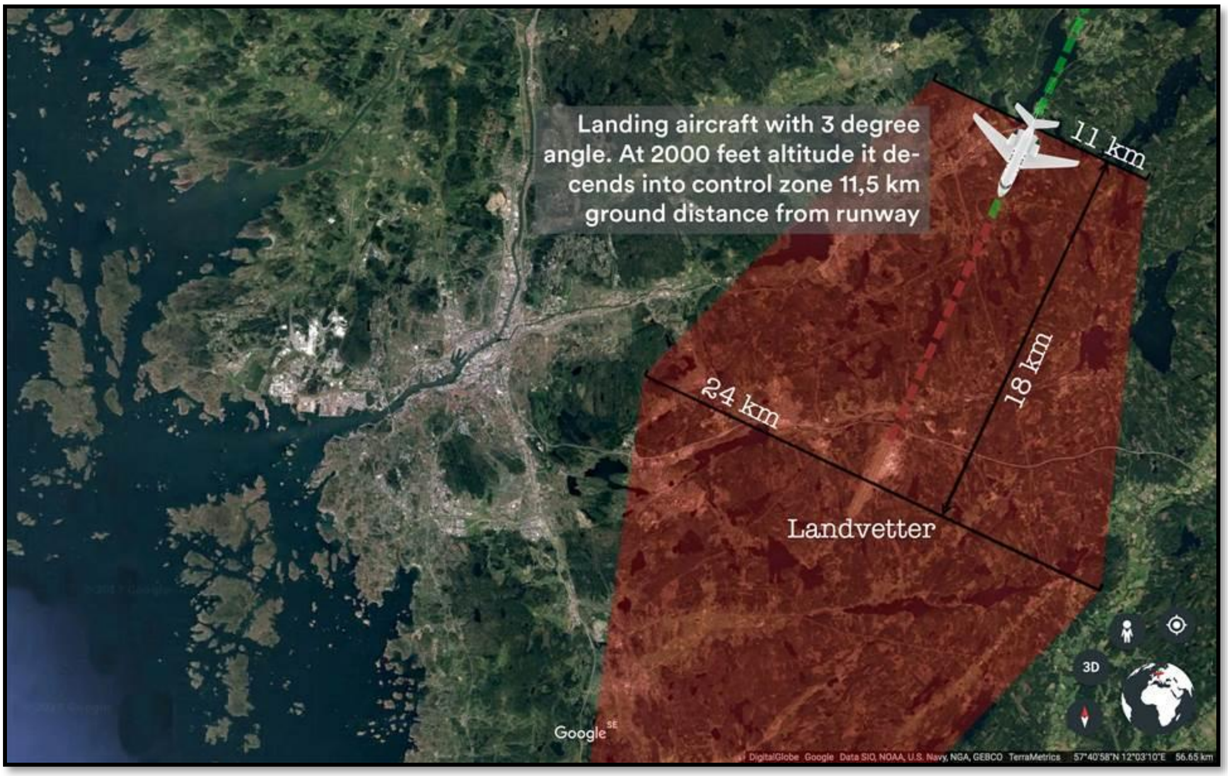


Figure 4.18 - Landing aircraft at Landvetter, Gothenburg.

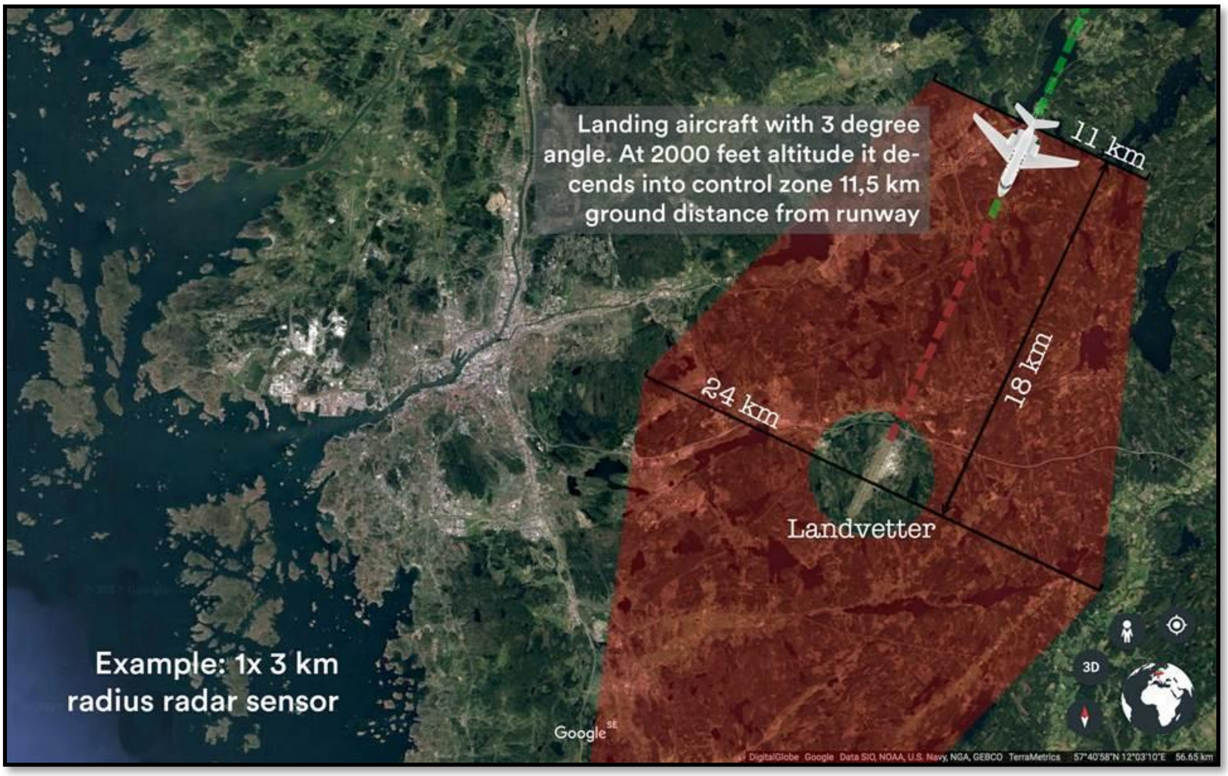


Figure 4.19 illustrates how a centrally placed 3 km radius sensor does not cover the critical path (red line) of a landing aircraft.

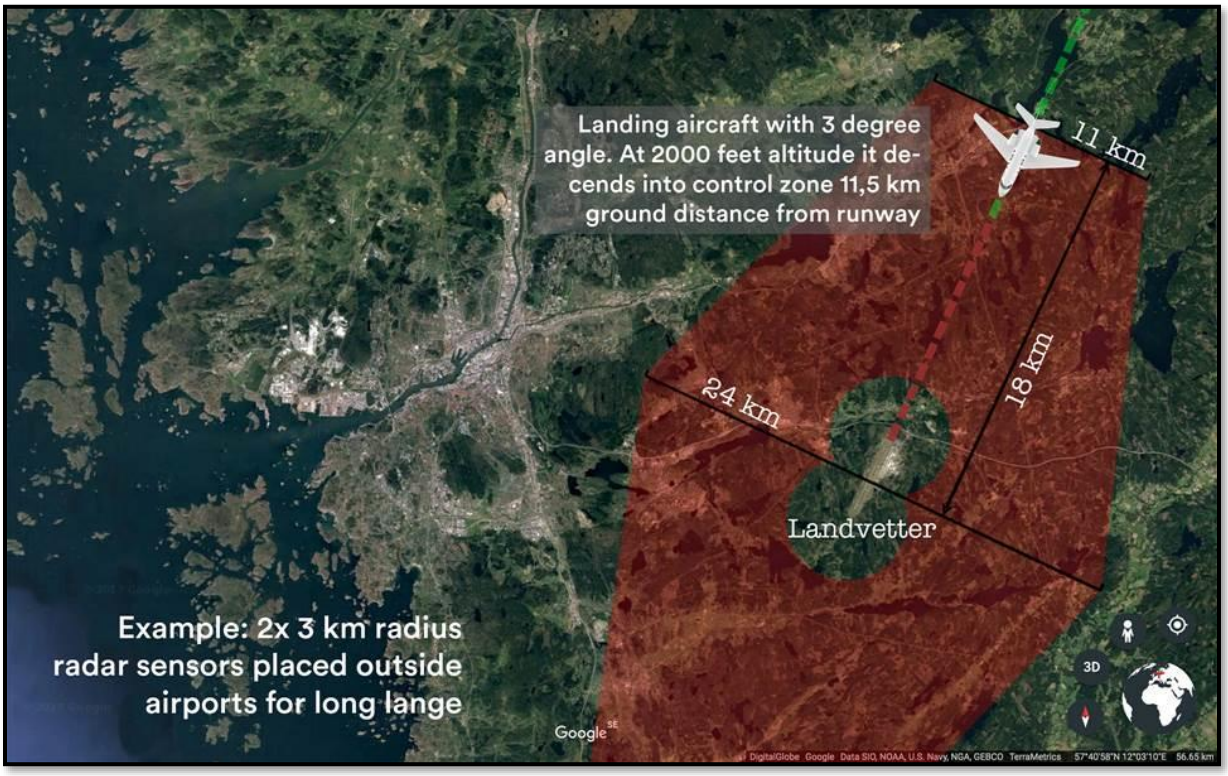


Figure 4.20 illustrates how two 3 km radius sensors far from covers the critical path of a landing aircraft.

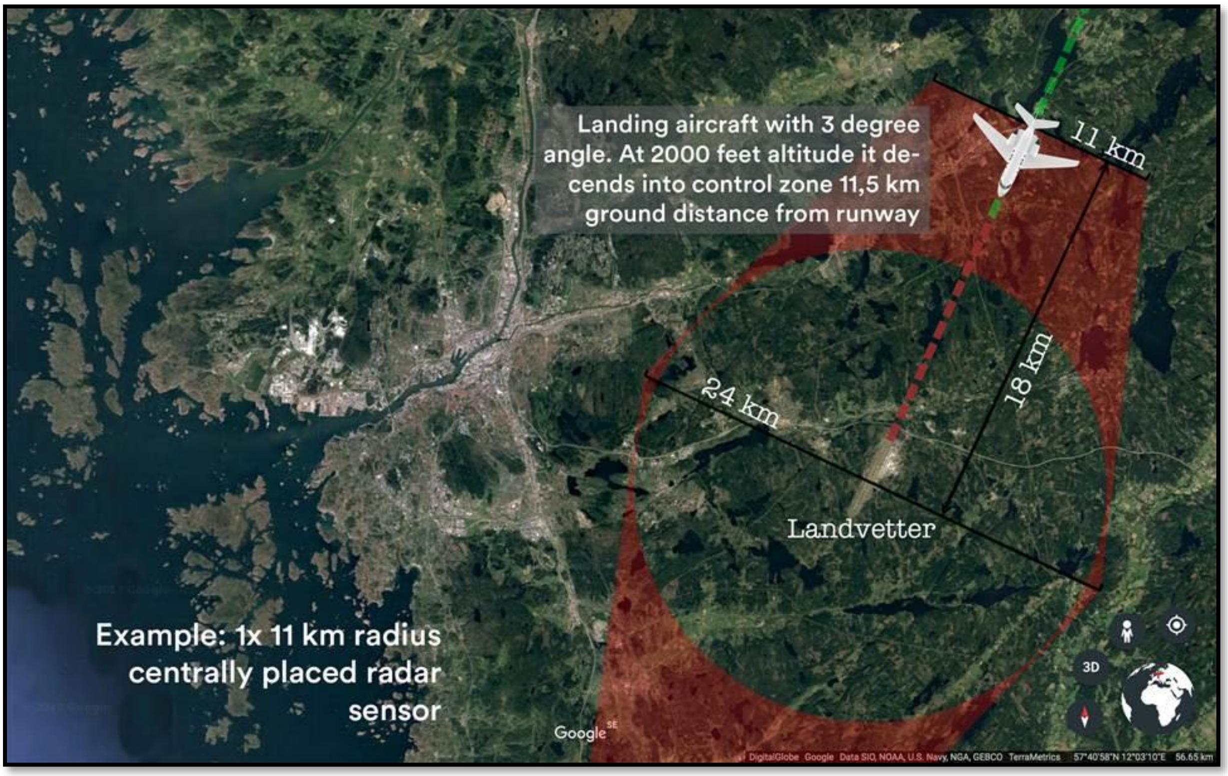


Figure 4.21 illustrates how a single centrally placed 11 km radius sensor almost covers the critical path of a landing aircraft.

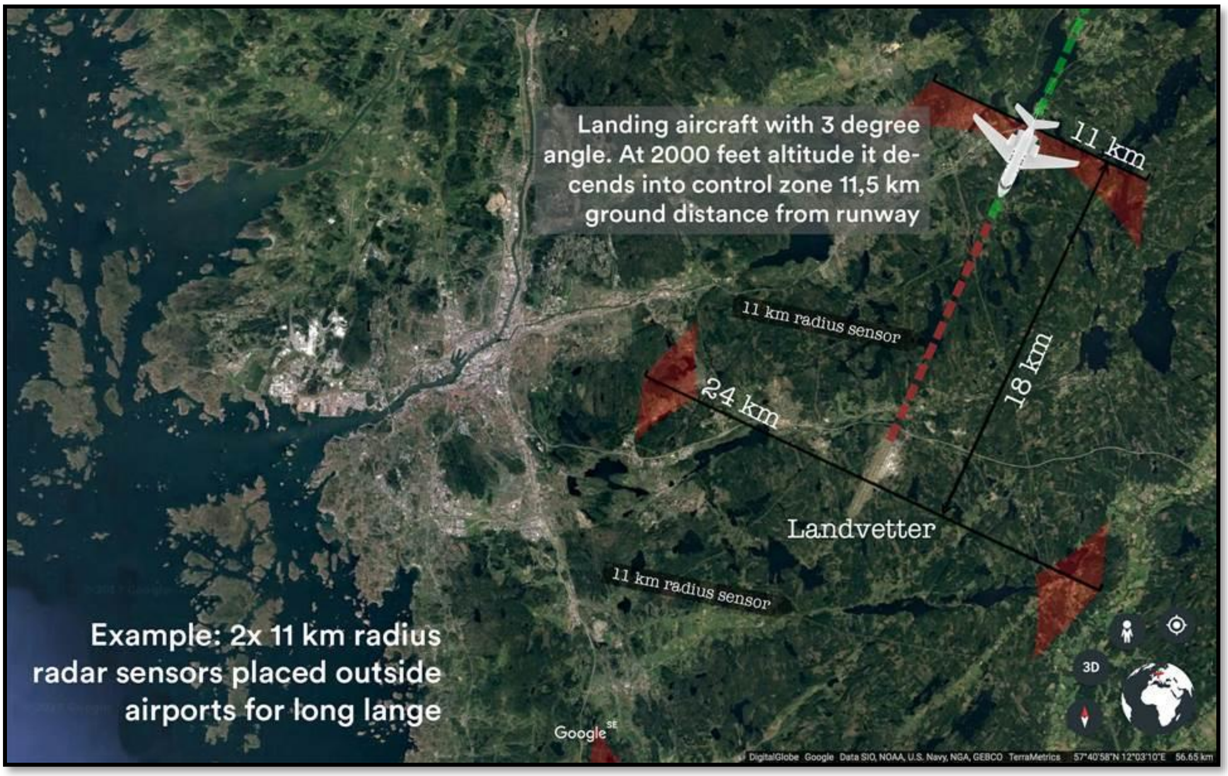


Figure 4.22 illustrates how two 11 km radius sensors more than covers the critical path of a landing aircraft in two directions.

Dynamic coverage

Range is a highly important factor which has great impact on suitble technologies for a detection concept. For most sensors topographical aspects, objects, buildings, and weather could have negative influence on the range. Traffic control, groundradars, lights, and more are placed on towers at the airports to get range. Another important factor here is that the aircrafts themselfes can be of substatial size and cover a sensor's sight to a heigth of about fifteen meters.

Delighters - Secondary tasks

According to Traffic management there is also an outspoken need for a radar system that can monitor the runways for smaller airports where Saab Sensis ground radars are two expensive. One of the interviewees at Traffic management believes that ground radars at airports are being replaced with transponder systems but it leaves an airport potentially blind to vehicles that are not equipped with such a transponder. As the interviewee claims that installation costs are high it suggests that it could be interesting to offer runway ground surveillance in the same product offering. The interviewee also acknowledged that some larger airports use bird radars to avoid bird collisions like the emergency landing on the Hudson in 2009 (National Transportation Safety Board 2009). *Image 4.23* shows a mid-sized birdflock that is both potentially dangerous and expensive in collisions with aircrafts.

Image 4.23 illustrates a peaceful flying flock of birds that would face certain death in a jet engine and cause damage to the aircraft and in the worst case even hurt or kill passengers.

Life cycle aspects

(Sturdivant & Chong 2017) identified the following long term needs at an airport application:

- *Ability to adapt system over time.*
- *Sustainable delivery of value to the customer over time.*
- *Work as a SoS (System of systems): Ability to integrate existing assets such as ground radar, cameras, and human observations.*
- *Operate within current regulatory situation.*

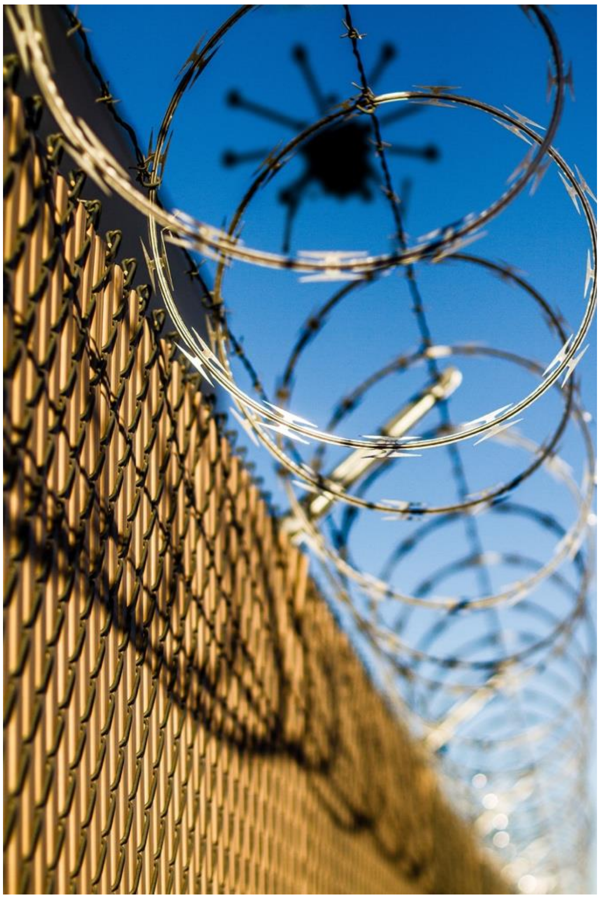
Generic life cycle aspects that apply to all areas of applications presented later in this Needs-section.

Prisons

Image *4.24* show a montage of a Small-class UAV octocopter flying over a prison fence. The model is a meter in size and has performance suitable to carry packages, in this case contraband.

For this application the following threats were identified:

- ***Threat**: Larger then micro-type drones providing inmates with contraband.*
- ***Threat**: Drones (possibly micro-drones) providing network coverage to avoid prisons' signal blocking equipment.*
- ***Threat**: Contraband being weapons and explosives.*



4.24 shows how hexacopters is used to transport contraband into a prison yard. The image is a montage.

The Pain

The Pain for a prison is that drones carry contraband efficiently into the prisons and security cannot stop it. Manually guarding airspace in all directions for the security is both costly and hard to maintain sufficient precision. Hovering drones have been used to establish a cellular link to inmates with contraband phones to get around signal blocking technology at the prison according to an interviewee in sales and marketing. The prison security has no way of stopping it and do not even notice when deliveries are being dropped unless the drone crashes.

Easing the Pain

Easing the Pain could mean surveillance with alarms of trespassing UASs. A system that stops some of the drones would potentially still be attractive for the customer according to the interviewee at marketing.

Solving the underlying problem

In this case means the underlying problem translate to the drone operators which have to be identified to stop further contraband traffic. As long as the drone operators are free to continue their work, easing the Pain will not be enough for prisons in the long run - The drone operators need to be stopped.

Performance

Prisons unfortunately have no uniform design and therefore offer a variety of challenges of coverage for a detection system. Putting for example one large detection sensor at the large English Dartmoor Prison would likely implicate poor coverage due to the layout of building and surrounding topography. The last is visualized by *Image 4.25* but the high buildings are not obvious in a 2D map. In a comparison, the terrain near the Swedish maximum security prison in Kumla (*Image 4.26*) has fewer objects and shadows and would be easier to protect against drones.

Image 4.25 shows the Dartmoor prison.

Image 4.26 shows the Swedish maximum security prison in Kumla.

Power plants

No Pain factors are identified for this application area. The indications of need are weak and based on speculations and the competitor SpotterRF having customers in the U.S. If there is a need, it is assumed that detection only is sufficient, much like the functionality of surveillance cameras – knowing what is going on. It could be argued that if the threat is terror, a multicopter is not the most likely way of sabotaging.

Wind turbines

Wind turbines, like in *Image 4.27*, killing rare birds have been a topic in media. A small detection system for birds could be useful for statistics. If multicopters pose a danger to the wind mills rotor blades, a combined detections system could be useful. Audio sensors for bat detection are sold for use in wind turbines.

Image 4.27 shows multiple wind turbines on the country side.

Stadiums

This is a strong example of crowded events as many stadiums support tens of thousands of visitors at once. They are often open without possibility of roof, leaving all or parts of the crowd unprotected from aerial objects. Adjacent applications are other sports and music events that do not take place in a stadium but still gathers large crowds.

The threats identified in this application are:

- ***Threat***: Crash danger.
- ***Threat***: Terrorist actions.

The Pain

When a drone visits a concert or a sports game at or near a stadium, there is little anyone can do about it today which is a similarity for all applications. The Pain at a stadium is that they cannot do anything but watch if a drone flies over the stadium.

Easing the Pain

Temporary solving the issue for the drones at stadiums would be stopping some or all drones to fly over stadium crowds, inside or outside of the stadium during events.

Solving the underlying problem

Solving the problem of friendly drone operators would probably most effectively be done with information, legislation and technical restrictions in drones which all means looking at a higher abstraction level. It could still leave a problem of semi-friendly (mischievous) drone operators who still likes to get a peek of what is going on inside the stadium. That means that those operators would have to be found to be stopped, which would likely be done by the police. Drone manufacturer DJI's no-fly update also include stadiums like for example Ullevi in Gothenburg.

Terrorist actions at such location are hopefully found before the plan is carried out. Except for stopping a plan in motion, solving the real problem would mean finding the operators and catching them.

Performance

Stadiums are often surrounded by dynamic city environments with plenty of coverage for low altitude drones as illustrated by *Image 4.28*, *Image 4.29*, and *Image 4.30.* Parc de France has a 48 000 spectator capacity and Stade De France provides no less than 81 000 seats. The needed range is determined by what has to be done when a drone is detected but the dynamic coverage factor is very strong in this application due to the city environment. A large sensor with long range does not necessarily get coverage between buildings and any drone that wants to get through, can often do so (likelihood differs between sites).

If a drone has to be neutralized in any way, the crash danger has a very high influence on how that must be done. If the scenario is terror threat, the neutralization step has to be robust and high performing as there is virtually impossible to move the crowd to safety when a threat has been identified.

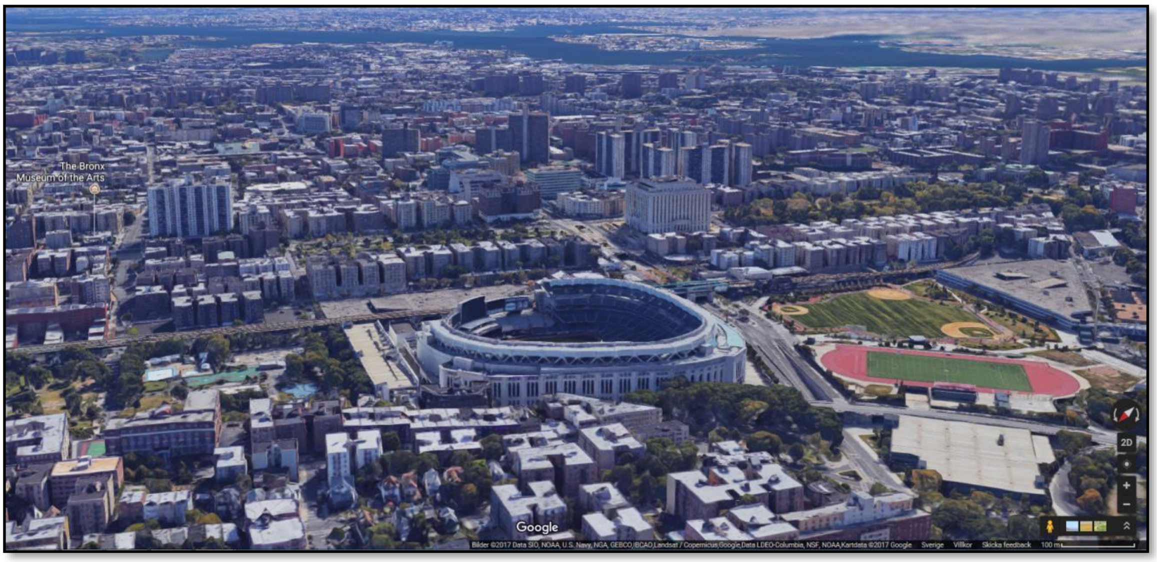


Image 4.28 shows the Yankee baseball stadium.

4.29 shows a google earth view of Parc des Princes in Paris.

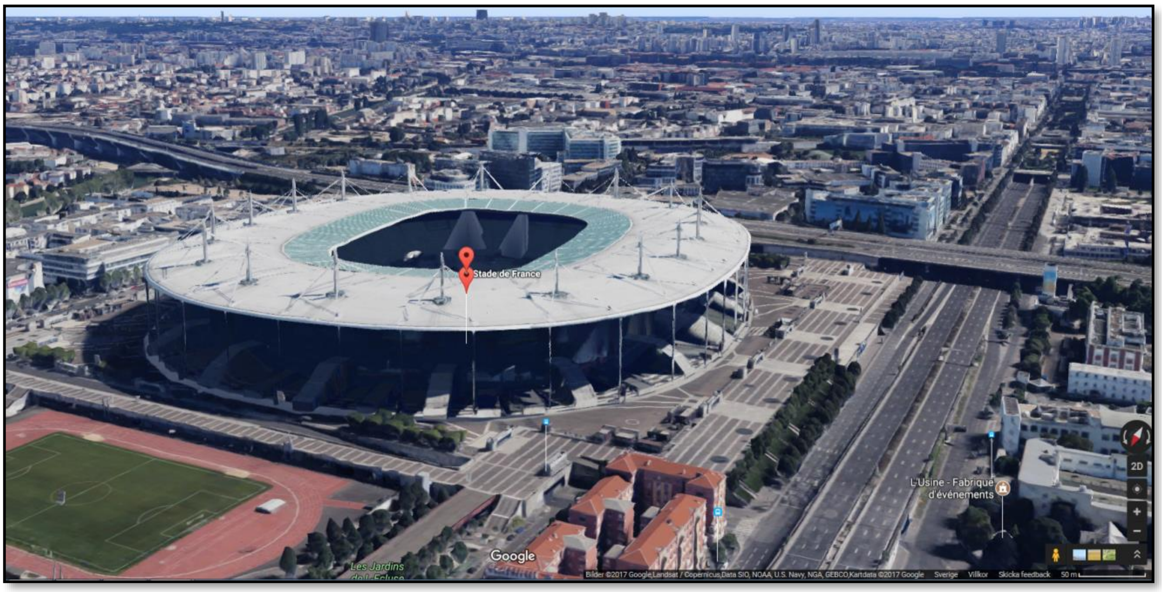


Image 4.30 shows Stade de france football stadium in Paris.

Police

The police needs to have an ability to protect temporary gatherings of crowd and to effectively deal with drones that break laws and regulation. To some extent a handheld anti-drone gun can solve some of the need for the police. The biggest limitation in that is a highly restricted range of operation. The police will likely be involved in many different temporary scenarios where a drone threat is present.

The Pain

The Pain for the police is their lack of ability to deal with unwanted drones. Shooting them down with a normal firearm is very hard as a result of:

1. *The movement of the drone.*
2. *Its small size.*
3. *Distance to the drone.*

In all crowd situations, using a firearm is of course also highly inappropriate as can be understood when looking at *Image 4.31* where the police are tasked to observe and avoid any type of dangerous situations to arise. The various buildings types impair observation range and serves as a good hiding ground for malicious drones. Damaging a drone in the air can easily lead to compromised personal safety.

Image 4.31 illustrates a crowded demonstration in a German city.

Not being able to deal with drones undercuts their authority and YouTube provide examples of drones mocking police officers in what resembles a game of cat and mouse. Being able to take down the drone offers some ease of Pain but not much. The real problem needs to be solved.

Solving the underlying problem

For the police it is highly relevant to catch the perpetrator which is the drone operator. Prosecuting perpetrators is the most obvious way of measuring results for the police. This problem is not likely to be solved with regulations, legislation, and technological restraints as in the case of the airport as a perpetrator per definition does not care much for rules. The police must have a technical ability to catch the perpetrator.

Military scenario

This application is outside the general scope of the study and is included for comparison. It stands out from the other identified applications in:

1. *Military use.*
2. *Very long range for drone neutralization and therefore even longer detection.*
3. *More likely able to stop drone by destruction.*
4. *Winged drones more likely that multicopter drones.*
5. *Army users with extensive training.*

The identified threats in this application are:

- ***Threat**: Enemy spy drones getting footage of friendly forces.*
- ***Threat**: Likely larger drone class that other segments which implies high speed and larger payload possibilities*.

Need - Performance

The biggest cost driver in this application is the extreme range of detection. Solutions exist in long range ground radars from different manufacturers but in what could be called an extreme price range. Neutralization could has bigger potential be allowed to be solved by destruction in a military scenario than in the civil applications and can accordingly be solved with existing weapons. Existing weapons are however expensive and not streamlined for the task with implications possibly including personal safety. Non-destructive counter measures would be safer and therefore attractive.

Company office espionage

The Pain factor is argued to be a motivator for customers in this application as well, although indications in media are relatively few. That does not mean that the Pain does not exist no or in the future. *Image 4.32* shows a large city office building with large windows that provide a good view for any multicopter camera drone that wants to have a look inside. The two threats identified in this application are:

- ***Threat**: Unfriendly drones photograph into offices.*
- ***Threat**: Unfriendly drones or hover in reach of company secure Wi-Fi.*

Performance

Office buildings would likely use a permanent installation that warns on intrusion, giving office personnel time to prepare for the threat. False alarms at an office would likely be highly unwanted. Since no counter-action is needed, the need of range is considered to be low. Depending on the situation, coverage can be an important factor if other buildings and trees block the line of sight.

Image 4.32 shows an office building in a city.

Prototype espionage

Car prototypes are tested to some extent near the manufacturer's manufacturing or development facilities. They also needs to be taken to different kinds of test tracks for real life testing, which makes them vulnerable to industrial espionage, likely performed with camera drones. The one threat of this application is:

- ***Threat***: Unfriendly drones photograph prototypes.

Performance

A system for this application only needs to warn the user to give them time to cover or hide the prototype. The need of range is depending on the optics of the spy drone. In this study a camera drone is estimated to get relevant footage of a prototype from a few hundred meters away, using compact zoom lenses with roughly 20x zoom starting at a focal length correspondent to 50 mm in a 135 film (or Full Frame digital camera). At full zoom in this example the focal length will be 1000 mm which implies a horizontal angular coverage of 2,06° using:

$$AHC = 2 \cdot \arctan\left(\frac{D}{2 \cdot f}\right),$$

where AHC is angular horizontal coverage, D is the horizontal width of the sensor and f is the focal length. At 300 meters, the image cover 10,8 m in width which means that a car will cover about 45% and is assumed to be roughly the maximum range for medium to small optics due to difficulties in optical performance and gimbal stabilization. Heavier optics will however likely perform better. *Image 4.33* illustrates a curvy Mediterranean road that can be used to stress different attributes that needs testing in a car prototype. Different car brands also test their prototypes in Nordic countries to stress weather robustness factors on drivability and durability.

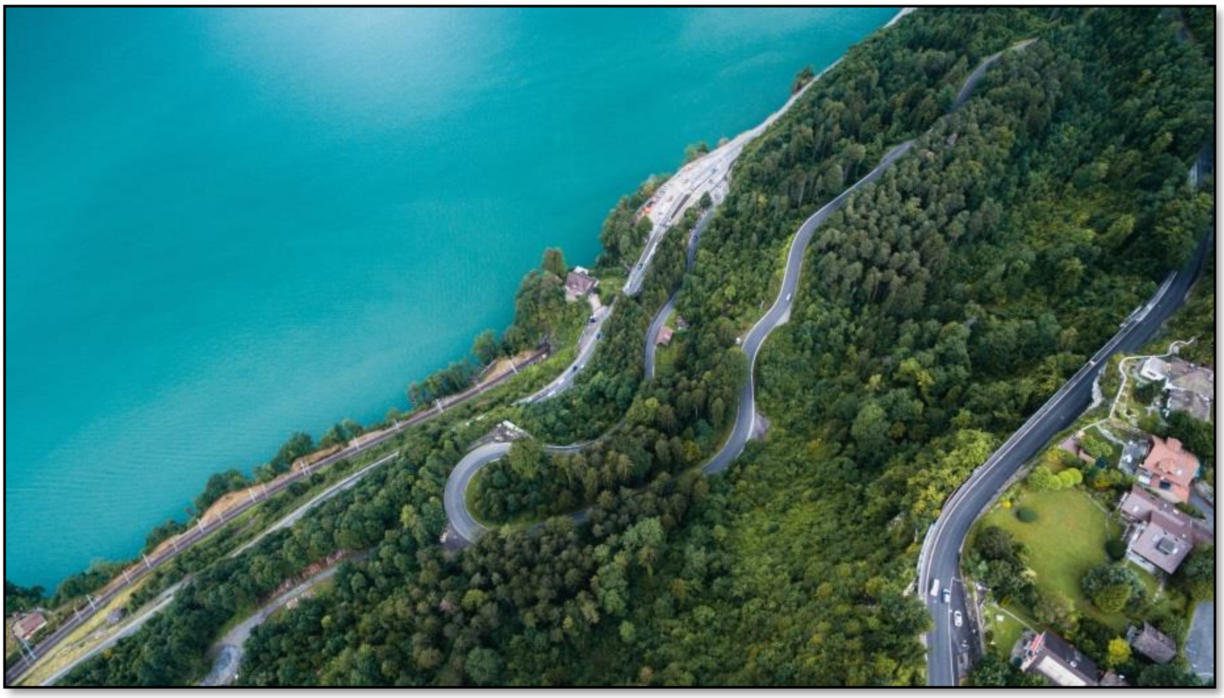


Image 4.33 illustrates a curve road suitable to test new cars' drivability.

Life cycle aspects

The main categories of life cycle aspects and stakeholders identified in this study are shown in *Table 4.34*. The table illustrates how the different aspects affect different stakeholders.

Table 4.34 shows what stakeholder is interested in what sustainability aspect.

sustainability aspect / Stakeholder	Robustness to future needs	Product support	Customer relationsship	Cost of operation	Ability to solve problem	Stay up to date from a customer's viewpoint	Maintenance	Environment profile	Recyclability
Saab surveillance	High	Low	High	Low	High	High	Low	Medium	Medium
The public	Low	Low	Low	Low	High	Low	Low	Medium	Medium
Customer	High	High	Medium	High	High	High	High	Medium	Medium
End user	Low	High	Low	Low	High	Medium	High	Low	Low
The environment	Medium	Low	Low	Low	Low	Low	Medium	High	High

Future proof

Few products in the world could be entitled future proof. Even living candidates like the pencil or a deck of cards took quite a beating in the 90's. Maintaining market relevance is however still a highly important factor for a new product and a slightly increased market life can be the difference between profit and loss for product.

Robustness to future needs is considered to be the most important factor of *Table 4.34* in this concept study. This being as drone technology will change and the identification of Pain factors indicates that the underlying problem must be solved to satisfy future customers.

4.5 Market size

This section presents an idea of market size for four areas of application. The police seek a mobile solution and this study does not estimate how many systems there is need for. Drone corridors is an interesting market, but further in the future and does not have a size calculation as even a best guess of the need depends on how far in the future one looks.

Airports

According to (Chartsbin 2011) there were about 44 000 airports in 2010 of which about one third was paved airports. According to those statistics there were in Sweden 152 paved airports and 97 unpaved. Tightening the scope to larger airports, in *Table 4.35* statistics are given of numbers of passengers for the top five airports in Sweden in comparison to the top five airports in the world when it comes to number of passengers per year.

Table 4.35 shows passenger per year data for ten airports comparing Sweden's to the World's largest.

YEAR	AIRPORT	COUNTRY	passengers per year [milion people]	Increase since 2011
2016	Hartsfield-Jackson Atlanta International Airport	USA	104,2	12,80%
2016	Los Angeles International Airport	USA	80,9	30,80%
2016	Beijing Capital International Airport	China	94,4	22,00%
2016	Dubai International Airport	UAE	83,7	63,30%
2016	Tokyo International (Haneda) Airport	Japan	79,7	28,40%
2016	Stockholm Arlanda	Sweden	24,70	29,50%
2016	Bromma Stockholm	Sweden	2,51	15%
2016	Gothenburg Landvetter	Sweden	6,38	30%
2016	Malmö	Sweden	2,22	14,40%
2015	Stockholm Skavsta	Sweden	1,81	-29,80%

In 2011 according to the so called DATABLOG (theguardian.com 2012) Stockholm Arlanda was ranked as number 75 on a top 100 list in that regard. Note that the data is stated to be preliminary data from the Airport Council International who every year publish top 30 airports. Growth in numbers of passengers since 2011 is given for each airport in *Table 4.36* to get a general idea of the growth rate. In the list from 2011, the 100th place airport had 14,0 million passengers during 2011. Data of Swedish airports are taken from their owners (Swedavia 2017) and the Swedish Transport agency (Transportstyrelsen 2017). The 2016 data from the top five airports is taken from an annual air traffic report by (The port authority of NY & NJ 2017).

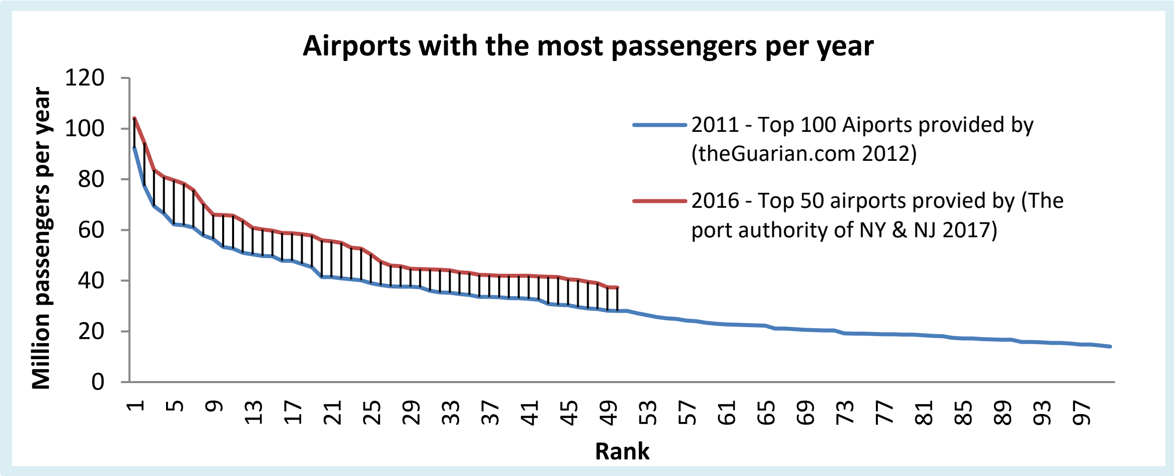


Figure 4.36 shows the airports with the most passengers in the world in 2011 and 2016 according to (the Guardian 2012) and (The port authority of NY & NJ 2017).

Projection of smaller airports using trend function

Figure 4.36 visualizes data from (theguardian.com 2012) and (The port authority of NY & NJ 2017) and the increase in air traffic can be seen in the difference between the two lines. To be able to predict a market for airports additional data would be needed and a logarithmic trend line was iterated and added to the 2011 data and raised with an offset to be similar to fit the 2016 data. The result can be seen in *Figure 4.37.* In this projection Landvetter would rank at a 259th place among the biggest airports in the world in terms of passengers per year.

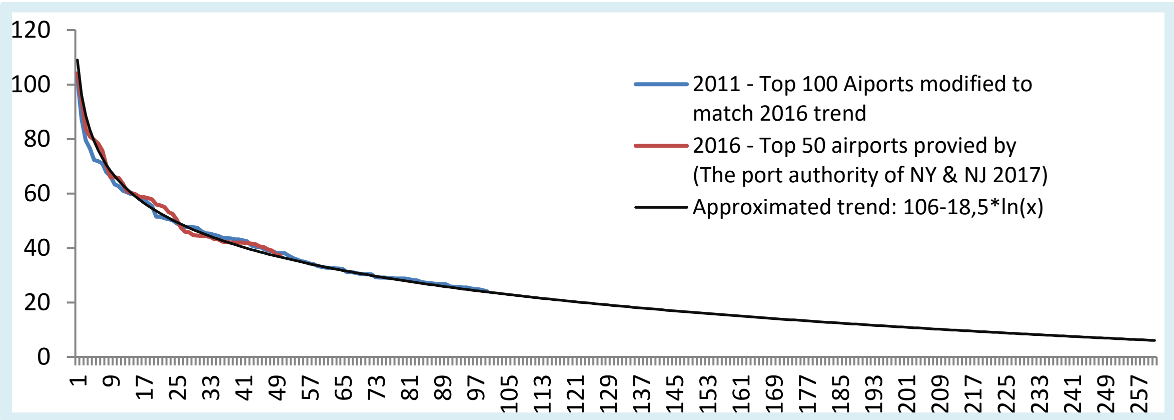


Figure 4.37 show data from 2011 2016 along with a logarithmic projection trend line.

Cargo traffic

Too see a relation between passenger traffic and cargo traffic data of largest airports in each regard is visualized in *Figure 4.38*. Cargo traffic statistics use tons per year as a measurement and the numbers are therefore recalculated to a passenger per year equivalent where a passenger is estimated to weight an average of 75 kg and has a 12 kg luggage.

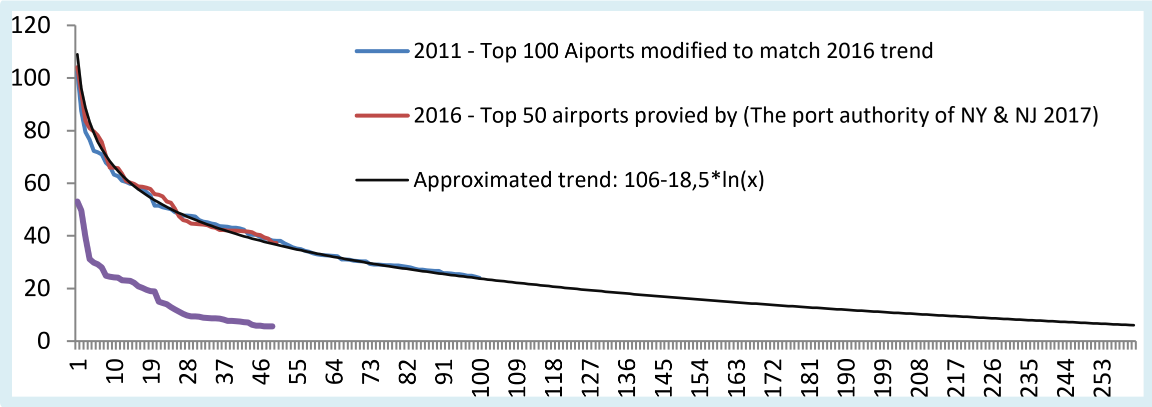


Figure 4.38 shows cargo traffic in relation to passenger traffic.

The cargo trend is steep and does not add much information except that a few airports might be added.

Prisons

In Sweden, 48 prisons hold about 4200 people, where only 7 of the prisons have “Safety classification 1” which is the highest of three degrees of safety (Kriminalvården 2017). According to an article in the New York Post (Ingraham 2015). There are 1800 state and federal prisons but also 3200 local and county jails where arrested people spend their time before a trial and possible conviction. Prisonstudies.org is a free access database for information on prisons over the entire world and is supported by The Prison Brief, Institute for Criminal Policy Research and Birkbeck University of London. With their statistics, different countries part all the worlds prisoners can be calculated and the ten largest are presented in *Table 4.39*. Sweden is shown in comparison and is not the 11th country on a list.

Table 4.39 presents data on where the worlds prisoners are found.

1.	***USA***	***20,5 %***
2.	*China*	*15,7 %*
3.	*Brazil*	*6,3 %*
4.	*Russia*	*5,9 %*
5.	*India*	*4,0 %*
6.	*Thailand*	*2,9 %*
7.	*Mexico*	*2,2 %*
8.	*Iran*	*2,15 %*
9.	*Indonesia*	*2,15 %*
10.	*Turkey*	*2,11 %*
	Sweden	*0,05 %*

The list gives an idea of markets by country. It can also be combined with the numbers of prisons in Sweden and in the U.S. to give a hint on how many prisons a country on the list is likely to have.

Power plants

In a report for General Electrics (Evans & Annunziata 2012) state that there were 62 500 operating power plants with a capacity of 30 MW or more in 2012. The report also shows a map of where those plants are located. According to (Nuclear Energy Institute 2017) there were in 449 operating reactors and 60 more of the way.

Stadiums

There is no credible and easily accessible place for finding comprehensive information on stadiums in the world. According to (Worldstadiums.com 2017) there are 4910 stadiums in the world and looking at the stadium in Sweden, the data seems to be correct but there are some credibility issues with the webpage Worldstadium.com. It is anonymous, has no references and no information about who owns the webpage. Looking at the "List of stadiums by capacity" article on (Wikipedia 2017) it has 147 references and test samples seams correct. According to that article, there are 527 stadiums with a capacity of 40 000 visitors or more.

4.6 Customer segmentation

The market segmentation is a way of looking for similarities and differences in the need for different areas of application. Similarities in the needs allow the same or a similar product to solve the problem which enables a larger need in volume for a certain product. A danger with segmentation is trying too hard to find similarities and thus producing a product not solving the needs in any application. The most interesting market segments are here proposed as:

- *Airports.*
- *Urban crowd situations: Police, Stadiums and other crowd situations.*
- *Prisons.*
- *Military scenario.*
- *Company office espionage.*
- *Prototype espionage.*

Each of these segments is here listed with type of threats, performance indicators, levels of market readiness, and what specific tasks should be performed in each application. *Figure 4.40 – 4.45* illustrate the segment applications.

Airports

- ***Threat***: Collision with planes cause damages and possible leads to accidents.
- ***Threat***: Sudden drone detections with little position information cause planes to delay landings.

- ***Performance***: Very long range.
- ***Performance***: Detection only according to Traffic Management.
- ***Performance*****:** Possibility of solving a large part of a dangerous and costly bird problem at many airports.
- ***Performance*****:** Possibility of solving problems usually solved by costly ground surveillance radars.

- ***Market readiness: HIGH.*** Large airports have large economical gains in solving the problem. Most airports have a large Pain factor in dealing with drones. Clear indications of customers being ready to buy solution. **Primary and secondary markets** would be divided by the number of passengers for an airport as it translates to revenue and monetary losses in drone shut downs. The need is the same, but might need delighters to attract secondary market customers – Birds and Ground surveillance.
- ***Market life***: The problem could decrease by with future laws and regulations.

1. ***Primary task:*** Monitor mainly friendly drone visits that could lead to Collison.
2. ***Secondary task:*** Identify operator.
3. ***Secondary task:*** Remove drones.

Figure 4.40 shows an airport.

Urban crowd situations (including Police & Stadiums)

- ***Threat***: Crash danger.
- ***Threat***: Terrorist actions.

- ***Performance***: Urban environment with structures preventing detection **coverage**.
- ***Performance***: Hard to take down drones in a safe way.
- ***Performance:*** Likely mobile solution.
- ***Performance***: Detection is helpful, but a full C-UAS is likely needed.
- ***Performance:*** Range depends on countermeasure.

- ***Market readiness***: MEDIUM. Police are looking for solutions but more information is needed.

Figure 4.41 shows a large mass of people between high buildings.

1. ***Primary tasks****:*
   a. Detect drones.
   b. Determine threat level.
   c. Identify operators in ill-willing cases.
   d. Stop drone.

Prisons

- ***Threat***: Larger then micro-type drones providing inmates with contraband.
- ***Threat***: Drones (possibly micro-drones) providing network coverage to avoid prison's signal blocking technology.
- ***Threat***: Contraband being weapons and explosives.

- ***Market readiness:*** MEDIUM/HIGH.

- ***Performance***: Often easier surrounding environment than a typical urban environment.
- ***Performance:*** Full C-UAS system is likely preferred but detection could help.
- ***Performance:*** Range has full dependency on countermeasure.

Figure 4.42 shows an American prison yard.

1. ***Primary task****:*
   a. Stop contraband flow.
   b. Identify contraband drop locations and find evidence for prosecution.
2. ***Secondary task****:*
   a. Identify operator.

Military scenario

- ***Threat***: Enemy spy drones getting footage of friendly forces.
- ***Threat***: Likely larger drone class that other segments which implies high speed and larger payload possibilities.

- ***Market readiness:*** HIGH.

- ***Performance***: Extreme range detection.
- ***Performance:*** Strong need of neutralization.
- ***Performance:*** Neutralization at long distance.

  1. ***Primary task***:
     a. Stop enemy drone at long range.

Figure 4.43 illustrates the military scenario.

Company office espionage

- ***Threat***: Unfriendly drones photograph into offices.
- ***Threat***: Unfriendly drones or hover in reach of company secure Wi-Fi.

- ***Market readiness:*** LOW.

- ***Performance***: Short range detection.
- ***Performance:*** Detection only.
- ***Performance:*** Relatively easy to solve technically compared to other segments.

  1. ***Primary tasks:***
     a. Detect drones.
     b. Inform / alarm.
  2. ***Secondary tasks:***
     a. Identify operator.

Figure 4.44 shows a glass facade office building.

Prototype espionage

- ***Threat***: Unfriendly drones photograph prototypes.

- ***Market readiness:*** MEDIUM.

- ***Performance***: Range unknown.
- ***Performance:*** Detection only.

  1. ***Primary tasks:***
     a. Detect drones.
     b. Inform / alarm.

Figure 4.45 illustrates a car prototype.

Summary

Table 4.46 shows an overview of the threats and tasks for the different segments. The table shows that the threats for different segments do not overlap. Looking at the tasks that should be solved by the concept system, some but few similarities exists at that level of abstraction. Looking closer at the tasks at a lower level of abstraction, there are however more similarities.

Table 4.46 shows the threats and tasks of the different customer segments.

SEGMENT	Threat	Task
Airports		
	Collision w. plane	*Detect drone*
	Not knowing where drones are leads to unnessecary traffic haults	*Monitor drone visits*
		Warn about unfriendly visits, possibly terror
Urban Crowd Scenario		
	Crash danger	*Detect drones*
	Terrorist actions	*Detemine threat level*
		Stop drone
		Identify operators in ill-willing cases
Prisons		
	Contraband smuggling	*Detect drone*
	Drones providing network to avoid blockage	*Stop contraband*
	Contraband being weapons	*Identify operators*
Military scenario		
	Enemy spy drones getting strategical footage	*Detect drone*
		Stop enemy spy drone at very long range
Company office espionage		
	Drones takes fotos into office	*Detect drone*
	Drones hover in reach of WiFi to hack secure network.	*Inform / alarm*
Prototype espionage		
	Drones photograph prototypes	*Detect drone*
		Inform / alarm

Even though strong needs indications for company office espionage are not found it is still attractive in that is potentially easy to solve technically.

Table 4.47 compares the needs of the different segments.

Table 4.47 shows how much of performance attributes that are needed in each identified application area.

Segment / Application — system Attributes	Range of detection	Dynamic coverage	Low level of false alarm	Need of mobility	Ok to destroy	Ok to transmit disruption	Identify birds	Need of operator identification	Determine threat level	Ease of installation	Low maintenance	Stopping drones
Airports												
Small civil airports	Long	Medium	High	None	No	No	Delighter	Delighter	No	Low	Yes	Low
Medium civil airports	Long	Medium	High	None	No	No	Delighter	Delighter	No	Low	Yes	Low
Large civil airports	Long	Medium	High	None	No	No	Delighter	Delighter	No	Low	Yes	Medium
Military airports	Long	Medium	Medium	None	Yes	No	Delighter	Delighter	No	Low	Yes	High
Urban Crowd Scenario												
Police	Medium	High	Low	High	Yes	Yes	No	Yes	Medium	Mobile	Medium	High
Stadiums	Medium	High	Medium	Low	No	Medium	No	Yes	High	Medium	Yes	High
Demonstrations	Medium	High	Low	High	No	Medium	No	Yes	High	High	Low	High
Sports events and concerts	Medium	Medium	Low	Medium	No	No	No	Yes	High	High	Low	High
Prisons												
Small prisons	Short	Low	Medium	None	Medium	No	No	Yes	Medium	Medium	Yes	Medium
Large prisons	Medium	Low	Medium	None	Medium	No	No	Yes	Medium	Medium	Medium	High
Prisons in city environment	Medium	High	Medium	None	No	No	No	Yes	Medium	Medium	Medium	High
Military scenario												
Optical airborne espionage	Long	Low	Low	High	Yes	Yes	No	No	Medium	Mobile	Low	High
Short range multicopter look-out	Short	Medium	Low	High	Yes	Yes	No	No	Medium	Mobile	Low	High
Company office espionage												
Office buildings	Short	Medium	High	None	No	No	No	Medium	Low	Medium	Yes	Low
Enclosed areas	Short	Low	Medium	None	No	No	No	Medium	Low	Medium	Yes	Low
Prototype espionage												
Test track car prototype	Short	Medium	Low	Medium	No	No	No	Medium	Low	Medium	Medium	Low

4.7 Competitor analysis

Alternatives of UAS detection systems are aggressively growing in numbers and a summary of available options from September of 2017 can be found at (Unmanned Airspace 2017). General trends for competing products, competitors and market are shown in this section.

Military hush hush

The level of market readiness of each product/concept in (Unmanned Airspace 2017) is hard to estimate but some of the products claim to have customers. Many of the actors that provide these alternatives have their main focus in development of military systems. According to multiple interviewees at Saab Surveillance, specifications of products in the military sector are usually shy as no manufacturer wants to give away to many leads to competitors. Even though the market scope of this study aims at a civil market, other actors are used to military customers, just like Saab Surveillance. This being as the task is most similar to a military scenario of detection and neutralization.

Beware of game rules at a civil market. Developing a completely new product far away from competitors and customers in a functional organization with innovation driven manner could easily lead to great distance between the aim of the scope and a moving target.

Performance indicators

Some of the competitor products provide numbers for detection range, power consumption and other usable information. The problem is the definition of identification is vague. For example, a product can claim to have a detection range of ten kilometers but not mention that it is not able to separate the multicopter from 200 birds on radar until it is within 800 meters of range. Some concepts have demonstration clips on YouTube but circumstances of background, geographical and topological aspects give sparse information on robustness and actual coverage.

Interesting performance indicators to know about competitors are:

- ***Range****: Per habit the number one performance indicator.*
- ***Dynamic coverage****: In the shadow of the main selling point Range, coverage indicates of how well area within range is actually covered and is very important for a drone detections system as small size is an advantage in a game of* ***hide and seek****.*
- ***Altitude coverage****: How low and how high can a drone fly and still be detected? It also indicates if a solution is looking to stop friendly or unfriendly UAS.*
- ***Mobility****: Is it suitable for mobile use, and how easy is it to move and work in a new environment*
- ***Price:*** *If price was not an issue, at least detection would to a large degree already be covered.*
- ***Technologies used****: In combination to what a product claim to perform, the used tech-nologies provide useful information.*
- ***Ready for market****: If a product seems to actually sell and get customers, it can be an indication of a strong choice of technologies but also provide clues of market and customer segmentation.*
- ***Type of developer****: Is the developer a large military equipment manufacturer usually developing in silence or a PR-boosted commercial manufacturer or even a master's thesis concept study?*

Competitor trends

In an analysis of competitors on or near the market, the following trends were identified:

- *They use multiple sensor types.*
- *They strive towards being scalable.*
- *They are land based.*
- *There are few rotating radars.*
- *Reuse of surveillance technology meant for other applications is common.*
- *Most competitors give an appearance of low market readiness.*

Competitor – Blighter AUDS

This C-UAS-system uses multiple radar panels with 90 degree horizontal coverage in combination with RF detection and an electro-optical IR sensor to detect drones. For its countermeasure it uses signal jamming to disrupt the drone's communication with its operator.

The strengths of this product are relatively long range and robustness due to three different detection sensors. The defeat stage using signal jamming is also claimed to have a few kilometers in range. Downsides with this product are its size and low mobility. Detection sensors are not likely to find drones behind obstacles. The drone jamming is likely to disrupt all kinds of Wi-Fi and cellular traffic. Some GHz frequencies that are open in the U.S. are reserved for military use in Sweden. Disrupting signals in those frequencies without permission are illegal and has lifetime in prison as a possible outcome.

Competitor – Rafael Drone Dome

This product uses radar and EO sensors, including an EO-IR sensor for detection and is thereby similar in detection method to the Blighter AUDS system. For defeat it also uses signal jamming but also a scaled down industrial LASER, used as a gun to shoot down drones at long range. Many of the mentioned performance indicators are similar to the previous example with the two most obvious differences being the Rafael Drone Dome being slightly more mobile due to smaller size and the ability to actually shoot down drones which in civil use often seems inappropriate.

5 Underlying Technologies

To understand the detection need, one must understand what the surveillance information is going to be used for. Even though the drone detection comes before the countermeasure in a drone handling procedure, they constitute a system where the requirements for the detection part are partly generated from the choice of countermeasure. For example, if the countermeasure is fast and safe, the need of detection range is likely low. If a detected drone leads to a time-consuming process of stopping it before it reaches the danger zone, the stop zone is large and push away the closest allowed line of detection. The need of long detection range drives cost, size, and complexity of the detection system. *Figure 5.1* illustrates how the countermeasures set requirements for detection range.

This chapter maps available technology for finding the drone and countermeasure separated by sub-chapters.

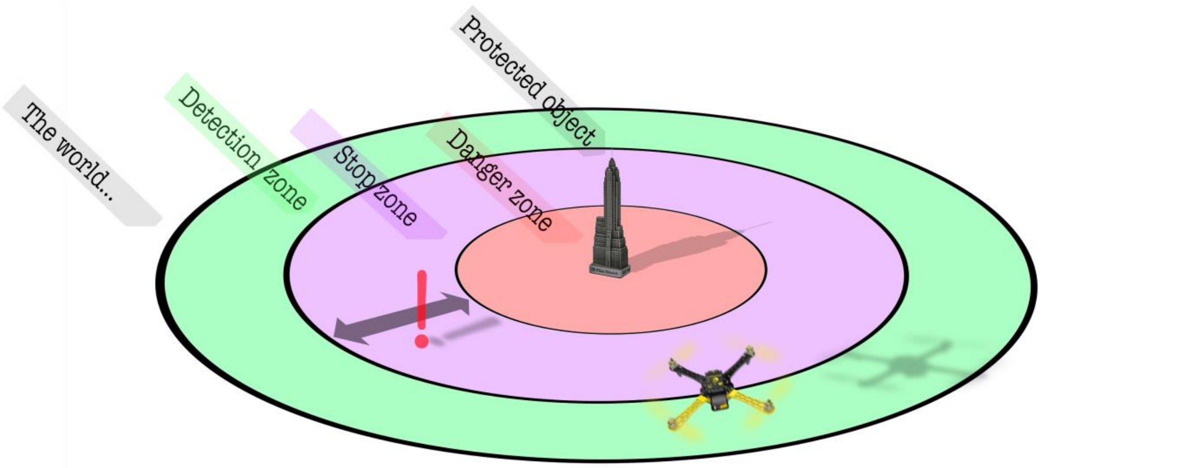


Figure 5.1 illustrates a drone scenario with different zones.

5.1 Finding the drone

To get attractive range and coverage, understanding usable technology is necessary. This section maps what underlying technologies there are to help solving the problem. The technologies have been analyzed with reports of previous work and expert opinions at Saab Surveillance for technologies where expertise was available. Each technology is analyzed and rated for different aspects and finally a selected number of sensors are benchmarked against each other over a number of important drone detection attributes.

Radar

Radar technology has been used for a long time for military air, ground, and naval surveillance as well as for civil applications ranging from weather radars to speedometers in cars. Most available radar surveillance systems are built to detect large cross-section objects compared to the very small signatures given by micro- and nano-drones. Saab's specialty lays mainly in large military surveillance systems with exceptions in for example civil surface radars. A radar signal travels at the speed of light which enables possibility for good performance at long distances.

Expensive range

The simplified radar equation indicates that doubling range R results in having to multiply transmission effect P_S with a factor 16 to achieve the same received effect P_e:

$$P_e = \frac{P_S \cdot G^2 \lambda^2 \cdot \sigma}{(4\pi)^3 \cdot R^4}$$

This relation is a reminder that it is crucial to determine what range is needed to not let price, weight, and complexity of the radar derail. The difference between one and ten kilometers of distance to the same target theoretically translates to a need of 10 000 times stronger signal to achieve the same result.

Benefits

- *Proof of concept for long range.*
- *Possibility to separate drones from birds, although being a technical challenge.*
- *Detect rogue drones: YES. (A rogue drone does not emit signals).*
- *High weather robustness in performance.*
- *Full performance also in low or no light situations.*

Drawbacks

- *All materials do not reflect a radar signal. The ones that do: Reflects it differently.*
- *Still a challenge to effectively and efficiently separate drones from birds.*
- *Saab's (and equivalent competitor's) systems are over-scaled for some civil drone detection applications.*
- *High power radars often emit unhealthy radiation.*
- *Cannot see behind obstacles.*

Knowledge within the company: Extensive.

Monostatic pulse radar

Monostatic pulse radar typically uses the same antenna to both transmit and receive. It sends a strong pulse, then switch to listening mode and listens to the echo. Benefits of this type of radar include that the receiver gets no disturbance from the transmitter as they do not operate simultaneously and shared used of components for send and receive.

The downside of switching between send and listen is that you will get an inner blind spot. If a pulse is for example 1 µs in duration the pulse travels 300 meters in that time. A target at 140 meter away means 280 meters for the signal to get both ways. In the case of 1 ms pulse, the radar is still transmitting and will not listen to the echo of that target. There is also inertia in the physical system to switch between send and receive which limits how short distance the pulse radar can achieve. *Image 5.2* illustrates how a large monostatic pulse radar sensor is blind to close objects.

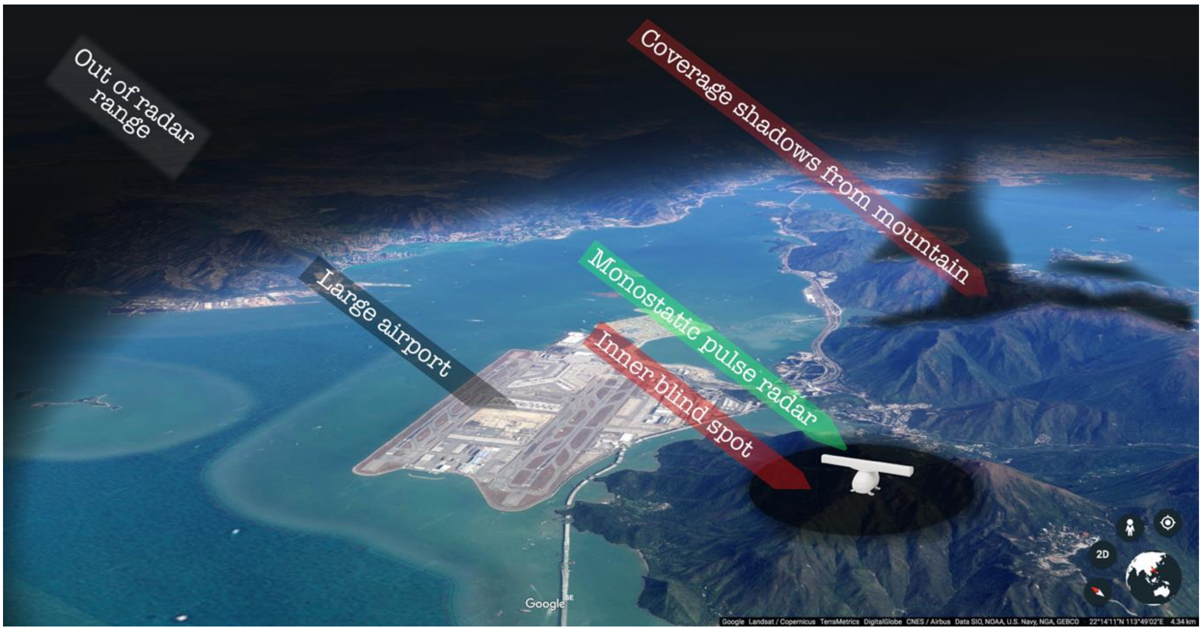


Image 5.2 illustrates the inner blind spot close to the radar

Benefits

- *All radar benefits.*
- *Long range possible as receiver do not get disturbance from the transmitter.*

Drawbacks

- *All radar drawbacks.*
- *Inner blind spot for pulse radars.*

Knowledge within the company: Extensive.

Frequency modulated continuous wave radar (FMCW)

The FMCW radar sends and listens simultaneously which leads to not having the inner blind spot of the pulse radar. The transmission frequency can be changed to best illuminate the target as different frequencies produce different radar returns.

Benefits

- *All radar benefits.*
- *No inner blind spot.*
- *Low peak power due to continuous transmission.*

Drawbacks

- *All radar drawbacks.*
- Signal leakage from simultaneous send and receive leads to a restriction in range.

Knowledge within the company: High

High frequency FMCW radar

This type of radar that operates on a high frequency has advantages in its high level of detail. The high frequency leads to this technology being sensitive to atmospheric attenuation, limiting range of this technology. An example of application is radars in cars mapping surrounding cars and environment.

Benefits

- *All radar and FMCW benefits.*
- *High level of detail.*

Drawbacks

- *All radar and FMCW drawbacks.*
- *High atmospheric attenuation compared to lower frequency radar bands leads to limitations in range.*
- *Existing components are expensive for most frequencies with exceptions for components used in for example car radars. This could limit the choice of frequency for a low cost radar sensor.*

Knowledge within the company: High

Micro-Doppler UAS radar return

This considers how to analyze radar return data and can to be applied to various radar technologies.

Micro Doppler is used to detect objects with a small cross-section. High performance radars have the ability to detect micro drone as shown by for example (Jahangir & Baker 2016) but with two major drawbacks. The first is generating extreme data-streams. Apart from that the Doppler looks at speeds for an object and a quadcopter can hover and travel at speeds up to 40 m/s. This can make the radar blind to hovering or slow moving objects. A possibility is to instead look at the Micro-Doppler signature generated from the rotor blades which give a velocity spectrum of 0 (in the middle of the blade) to the velocity of the blade's tip and is typically presented within the frequency domain. This means not only detecting a small target with radar, but also distinguishing it from other object with similar properties and thus also creating basis for classification. *Figure 5.3* shows frequency micro Doppler radar return for a quadcopter over a time axis ms. The wave formation of the figure comes from the speed of each rotor blade giving a high Doppler speed return when it:

1. *Rotates towards the radar (approximately 135 m/s at the tip for a DJI phantom 4)*
2. *Slowing down and momentarily standing still from the radar's view point as the tip moves sideways and does not produce much Doppler signature.*
3. *Moving from the radar thus generating a negative frequency in the figure.*
4. *Slowing down and momentarily standing still at the other side.*

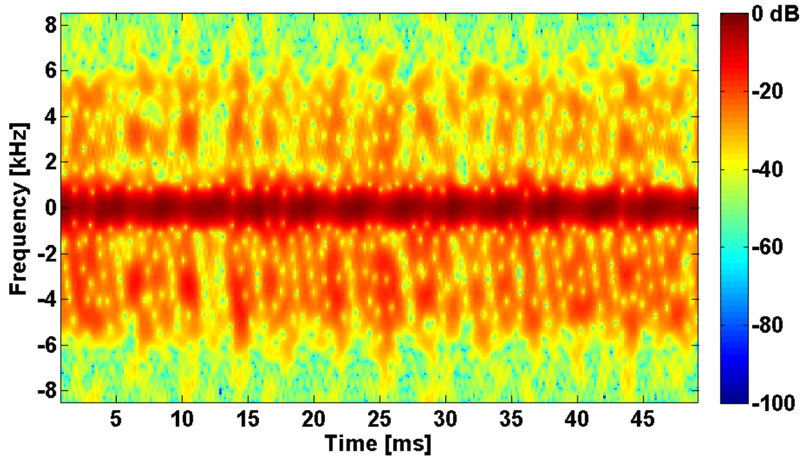


Figure 5.3 show a micro-Doppler frequency radar return (© Saab AB 2017:1).

The figure shows a quadcopter which means it shows four rotor blades simultaneously. To get an idea of rotation speed one should look at every fourth positive (or negative) frequency spike which in this case would be roughly 5 ms.

Benefits

- *All radar benefits.*
- *Possibility to get a unique drone signature on a radar sensor.*
- *Possibility to separate drones from birds.*
- *Extensive Doppler radar knowledge at Saab.*
- *No clear proof of concept from competitors.*
- *Detect rogue drones: YES.*

Drawbacks

- *All radar drawbacks.*
- *Looking in the micro Doppler range means that birds and other objects will appear on radar.*
- *Risk of generating large data sets to process when searching the micro Doppler range.*
- *No proof of concept except for in laboratory environment.*

Knowledge within the company: High

Passive radar using commercial signals

This is a form of bi-static radar which means that the transmission and receiver mechanism is separated. The passive radar takes this separation a step further and uses existing commercial signals in the air as transmission. This leads to potential gains in some aspects, but also major drawbacks in others.

Benefits

- *Passive sensor leads to low power consumption and lighter construction than active radar.*
- *Signals like digital TV-signals are widely broadcasted and transmit around the clock.*
- *Proof of concept by (Liu et al 2017).*
- *Detect rogue drones: YES.*

Drawbacks

- *Knowledge of feasibility is low.*
- *Dependency on transmitter locations.*
- *Dependency on transmitter frequency which potentially makes it harder to analyze radar return information.*

Knowledge within the company: Low / Medium

WLAN/RF detection

Most UASs continuously send WLAN data to the operators receiver in the 2,4 or 5 frequency bands. This is an uncontrolled band where most wireless internet and other WLAN can be found. There is a possibility to detect the signal that is being broadcasted by the drone by signal surveillance. This technology is used for some C-UAS systems on or near the market. The video feed typically use 5,8 GHz band for analog TV-signals. *Image 5.4* illustrates the connection between a drone and a controller.

Image 5.4 illustrates the operating signal between the drone and the operator's controller.

Benefits

- *No send signal needed - Only requires passive sensors which could implicate a simple construction.*
- *Most commercial UAS send transmission data to its operator.*
- *Proof of concept has been made by other companies.*
- *Proof of concept has been made within the company.*
- *Potential to locate operator.*

Drawbacks

- *Detect rogue drones: NO.*
- *Extensive traffic on 2.4, 5 and 5,8 GHz bands which could implicate difficulties in finding drones in the background noise. This is illustrated in Figure 5.5.*
- *Directed antennas on commercial drones make it virtually undetectable from the wrong direction.*

Knowledge within the company: High

Figure 5.5 illustrates the heavy traffic on WLAN and cellular frequencies in a city environment.

Audio sensors

Special microphones can be used to detect UASs through finding a specific high-pitch signature from multicopter rotor blades and motors and can be found in competitor products. The range for competitors varies and some have a range as low as 50 meters. This technology is assumed to have a range potential of a few hundred meters.

An implementation of drone detection sensors is the cluster audio sensor that uses multiple ultrasound microphones mounted close enough to each other so that the same period in the audio sinusoid signal reach all the microphones simultaneously. A comparison of time-of-arrival for the soundwave is used to calculate direction of the source.

Benefits

- *Proof of concept within the company.*
- *Sound travel past some obstacles.*
- *Detect rogue drones: YES.*
- *Potential to implement low cost version with less performance.*

Drawbacks

- *Current technology limited in range.*
- *Limited by physics: **Speed of sound**. At 500 meters, there is about 1,5 seconds of delay allowing in a DJI phantom 4 to travel about 30 meters before soundwaves reach sensors.*

- *Available hardware is expensive.*
- *Sensitive to rain and especially wind.*
- *Extensive background sounds in an urban environment below 20 KHz.*
- *Atmospheric damping of ultrasound frequencies limits range.*
- *Cannot show speed or distance unless triangulation is used.*
- *Drones will likely be less noisy in the future.*

Knowledge within the company: Medium

EO sensors – Digital camera sensors

Digital cameras, surveillance cameras and face recognition are some areas that contribute to this technology being widely used in many technological areas. With optical zoom, high resolution sensors and image stabilization the technology offers long range for detection and through recognition software also good basis for classification of targets. Availability of low price components due to economy of scale and detection algorithms for other applications like for example face detection auto focus, smile detection and such features. *Image 5.6* shows a typical ground surveillance system of digital video cameras.

Image 5.6 shows a camera surveillance system.

Benefits

- *Possibly low weight.*
- *High availability of off-the-shelf products.*
- *Long range.*
- *Potential for classification and detection in software.*
- *Proof of concept by other companies: Drone detection with few pixels is demonstrated.*
- *Proof of concept: Advanced image processing is widely used in other applications.*
- *Night vision possible with IR.*

Drawbacks

- *Performance in poor weather conditions: Poor, as illustrated in Image 5.7.*
- *Low potential as only technology for detection in a concept as it takes many pixels to cover a wide angle and still have long range.*
- *Maintenance: Lens likely has to stay clean to maintain functionality.*
- *Must be fast to maintain long range.*
- *Must have sufficient stabilization to maintain long range.*
- *Non-IR small photo sensors have poor sight in low light conditions.*
- *Not likely to effectively estimate speed and distance if the drone travels towards the sensor.*

Knowledge within the company: Medium / Low

Image 5.7 illustrates how sensitive an optical sensor can be to weather conditions.

Robust multi sensor fusion engine

In a system that uses multiple inputs to increase resolution, coverage and overall performance a fusion capacity is needed. Saab has such a system that is used in other products and to make different products cooperate to product data of higher quality. If a system is scalable and mobile, this fusion platform must be robust and general to easily adapt to different solutions.

Historically and presently this task fits a human operator but the information flow is getting larger.

Benefits

- *Benefits of using different sensors with different strengths.*
- *Enables scalable solution.*

Drawbacks

- *Risk of adding high complexity and computation power if it is not streamlined for a specific purpose.*

Knowledge within the company: High

Software classification algorithm

A decision tree algorithm can be used to determine the movement pattern of the moving object on radar to separate a drone from a bird or other objects. This is based on an idea that movement pattern of a bird and a drone differ. A problem is that different birds have different movement patterns and clear unnatural behavior like a hovering drone is hardly relevant as the drone has to be moving to pose a threat. A drone going in a straight line is not unlike a swan or a similar bird.

Benefits

- *Exists for Saab products.*
- *It is software and therefore upgradeable.*
- *Can be used with multiple detection technologies.*

Drawbacks

- *Possible heavy computing power.*
- *Similarities between some birds' and drones' behavior pattern.*
- *The computing need growths exponentially with area.*

Knowledge within the company: High

Available products

Existing products that can be fully or partly used for detection are shown here.

Mass produced consumer sea radar

There are a number of boat radars on the market that could be categories in to main categories: Those with a large visual antenna and those with hidden smaller antenna. The consumer sea radar analyzes clutter widely different from that in a land environment. What is interesting about the boat radar is that is a highly durable radar product with a very friendly price tag. Economy of scale for all components of this products help raise the question: **How much of this product could be used in a drone detecting radar system?**

Benefits

- *Very low price for a radar product.*
- *High durability in demanding environment (saltwater and vibrations).*
- *Potentially sufficient range.*
- *Built for civil application with large manufacturing volumes.*
- *Passive cooling.*
- *Warming and ice-removal achieved with energy from hardware.*
- *Possibility to reverse engineer mechanical sub-solutions.*

Drawbacks

- *Lack of feasibility knowledge.*
- *Only 2D mapping of area.*
- *Likely too low performance.*
- *Narrow angle in elevation.*

Knowledge within the company: LOW

Giraffe 1X

The newly developed G1X radar system shown in *Figure 5.8* offers the ability to detect micro UASs at a long range in comparison to existing C-UAS systems. Detection of a target in the size range of a micro-UAVs can be achieved in more than 10 km according to simulations. Identification requires about 60 meters in range and separation from other objects in that size will be done in a closer range. The product is not developed to only be a drone detector with the implication that it is not streamline to do so. On the other hand, if it performs the task well it could enable a low time-to-market, much lower than for a completely new product. It has a software upgradeable platform and is in that way functionally modular or at least upgradeable.

Figure 5.8 shows the G1X on a rooftop. (©Saab AB 2017:2).

Benefits

- *Long range.*
- *Military grade durability in tough physical conditions.*
- *All radar benefits.*
- *Good potential to perform drone detection without further development.*
- *Lightweight and small for a military radar, but also compared to a civil SMR ground radar.*
- *Existing classification software.*
- *Possibility to solve adjacent problems at airports.*

Drawbacks

- *Only potential in some areas of application.*
- *Possibly not streamlined for drone detection purpose with implication in price and size.*
- *Limited mobility for some applications.*
- *Moving parts.*
- *High power consumption.*
- *Unhealthy radar emissions due to radar-band and high peak power results in safety distance of up to five meters.*

Knowledge within the company:* *Full

Airport surface movement radar (SMR)

This is an air traffic ground radar system that keeps track of ground objects as small as humans. The leading manufacturer in the world is Danish Terma but Saab Sensis provides the Sr-3 radar in the ASDE-X system which can be found at major airports in the U.S. The radar itself has a 6,5 meter diameter rotating antenna and can detect a cross-section of about 0,5 m^2 at several kilometers of range in poor weather conditions. (Sturdivant & Chong 2017) argue that the SMR, specifically Saab's Sr3 could work as a base in a larger SoS, system of systems at an airport. According to Interviewee four, the radar is not at all built for drone purpose and does not work for the purpose.

The minimal cross-section of 0,5 m^2 is not at all small enough for UAS detection and as it is designed for ground purpose, it looks down at runways for its location. The location is a robust tower often placed at a nearby hill. The altitude of 200 feet mentioned in (Sturdivant & Chong 2017) does not reach much except the runways. In other words: **It cannot be used to spot drones**.

SMR tower as infrastructure

Although the SMR cannot be used in its current state, there is still potential of existing infrastructure. According to an Interviewee at Traffic Management, the installation of such radar is a costly procedure as it is expensive to:

- *Plan a good spot for a SMR at a high location, most often outside the airport.*
- *Prepare area; for example remove trees.*
- *Build foundation for tower.*
- *Build a robust tower that safely supports the large SMR-radar.*
- *Cable ducting to Traffic Control.*

Detection technology benchmark

The most promising sensors were compared over a number of performance attributes to visualize strengths and weaknesses of them and can be seen in *Table 5.9*.

Table 5.9 compares selected sensors over a range of performance indicators.

	Long Range RADAR	Long Range RADAR with µ-Doppler	Short Range high frequency RADAR with µ-Doppler	RF - direction finder	RF - triangulation	Single Audio Sensors	Cluster Audio Sensors	EO sensor	EO-IR sensor	Air Borne EO-sensor	Air Borne EO-IR sensor	Air Borne short range radar RADAR	
Range	Extreme	Extreme	Medium	Good	Good	Short	Short	Medium	Medium	Medium	Medium	Medium	Range
Dynamic environment coverage	Bad	Bad	Bad	Good	Good	Good	Good	Bad	Bad	Good	Good	Good	Dynamic environment coverage
Detect in city environment	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Bad	Bad	Good	Good	Medium	Detect in city environment
Detect in darkness	Good	Good	Good	Good	Good	Good	Good	Bad	Good	Bad	Good	Good	Detect in darkness
Determine distance to target	Good	Good	Good	Bad	Good	Bad	Bad	Bad	Bad	Bad	Bad	Good	Determine distance to target
Determine Speed of target	Good	Good	Good	Bad	Good	Bad	Bad	Bad	Bad	Good	Good	Good	Determine Speed of target
Mobility	Bad	Bad	Medium	Medium	Bad	Medium	Medium	Good	Good	Good	Good	Good	Mobility
Detect in fog	Good	Good	Good	Good	Good	Good	Good	Bad	Bad	Bad	Bad	Good	Detect in fog
Detect in rain	Good	Good	Good	Good	Good	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Detect in rain
Weight	High	High	Medium	High	High	Low	Medium	Low	Low	Low	Low	Low	Weight
Proof of concept	High	Medium	Medium	High	High	High	High	High	High	High	High	High	Proof of concept
Detect rogue drones	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Detect rogue drones
Detect robotic birds	Medium	Medium	Medium	Good	Good	Bad	Bad	Medium	Medium	Medium	Good	Good	Detect robotic birds
Detect drone swarms	Medium	Medium	Medium	Good	Good	Good	Good	Medium	Good	Medium	Good	Good	Detect drone swarms
Health implications	Yes	Yes	No	No	No	No	No	No	No	Medium	Medium	Medium	Health implications
Inner blind spot	Yes	Yes	No	No	No	No	No	No	No	No	No	No	Inner blind spot
Knowledge at Saab	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Knowledge at Saab
Local processing	High	High	High	Medium	Medium	Low	Medium	Good	Good	Good	Good	Medium	Remote processing
Processing power	High	High	High	High	High	Low	Low	Medium	Medium	Medium	Medium	High	Processing power
Power consumption	High	High	Low	Medium	Medium	Low	Medium	Low	Low	Low	Low	Low	Power consumption
Feasibility	Good	Medium	Medium	Good	Good	Good	Good	Good	Good	Good	Good	Good	Feasibility
Detect drones with low speed	Medium	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Detect drones with low speed
Future proof	Good	Good	Good	Bad	Bad	Bad	Bad	Good	Good	Good	Good	Good	Future proof
Low cost potential	Bad	Bad	Medium	Medium	Medium	Good	Medium	Good	Good	Good	Good	Medium	Low cost potential
Need of development	Low	High	High	Medium	Medium	Medium	Medium	Low	Low	Medium	Medium	Medium	Need of development
Maintanance	Good	Good	Good	Good	Good	Good	Medium	Medium	Medium	Bad	Bad	Bad	Maintanance
Ease of installation	Bad	Bad	Medium	Medium	Medium	Good	Medium	Medium	Medium	Good	Good	Good	Ease of installation

5.2 Stopping the drone

Curious drone operators around the world have pushed both companies and individual various countermeasure equipment dealing with the uninvited UAVs. Police and military forces nave had to use regular weapons to some extent which have proven quite a challenge as long range and small target size require high angular precision. Looking at existing or near-the-market C-UAS systems the most common countermeasures are signal jamming and different kinds of destruction.

Classification of counteractions

The definitions of C-UAS system derives from the U.S. army and looking at the fourth step of neutralization it is also referred to as Destroy. Shooting down the drones is however not the only option for stopping them, especially not for a civil application. If the countermeasure still needs to be destruction, a warning would likely be in order before a shot is fired. In this concept study, four classes of countermeasures have been identified:

1. ***Inform***
   a. *The gentle countermeasure of informing the operators that they need to stop.*
2. ***Disrupt***
   a. *Disrupting communication between the remotely steered drone and its operator.*
3. ***Catch***
   a. *When reasoning does not work, physically catching the drone is still more civilized than destruction.*
4. ***Destroy***
   a. *Scaled down military Anti-air capabilities or innovative ways of destroying the drone.*

Inform-class

Preventive information to reduce misuse of drones has been shown in the PESTEL analysis in the form of laws and regulation. LFV's drone map in Sweden is one example of that even though there are large gaps in the information it provides today. Beyond these passive ways of informing operators, active information actions can be used in a trespassing scenario. This implicates getting the operators' attention through the use of technology.

General benefits

- *Perceived as a friendly countermeasure by all stakeholders.*
- *Easy to comply with regulations.*
- *No damage to operators' equipment.*
- *Safest way of stopping drone if it is successful.*

General drawbacks

- *Only works for the friendliest type of drone operators.*
- *Technical restrictions to reaching the operator with information.*
- *No existing solutions have been identified.*

Future transponders

Transponders are mentioned in Chapter 3 and are technology for aircraft identification. In a future with many drones in the air at any time, a technology like this is likely to be implemented. The term transponder usually refers to the specific technology, but here it is assumed that the same functionality can be achieved by different technical solutions.

When a UAV has been identified by transponder communication the operator needs to be identified. That could be solved by an online registry of drone operators with contact information or by enabling direct communication with the operator via the drone. Using the later or possibly both alternatives would imply higher performance. An example of such system is shown in *Figure 5.10* which illustrates a future transponder conversation between the automated security and automated drone. The transponder system also enables a communication channel between the security staff and the drone operator to facilitate extensive threat evaluation.

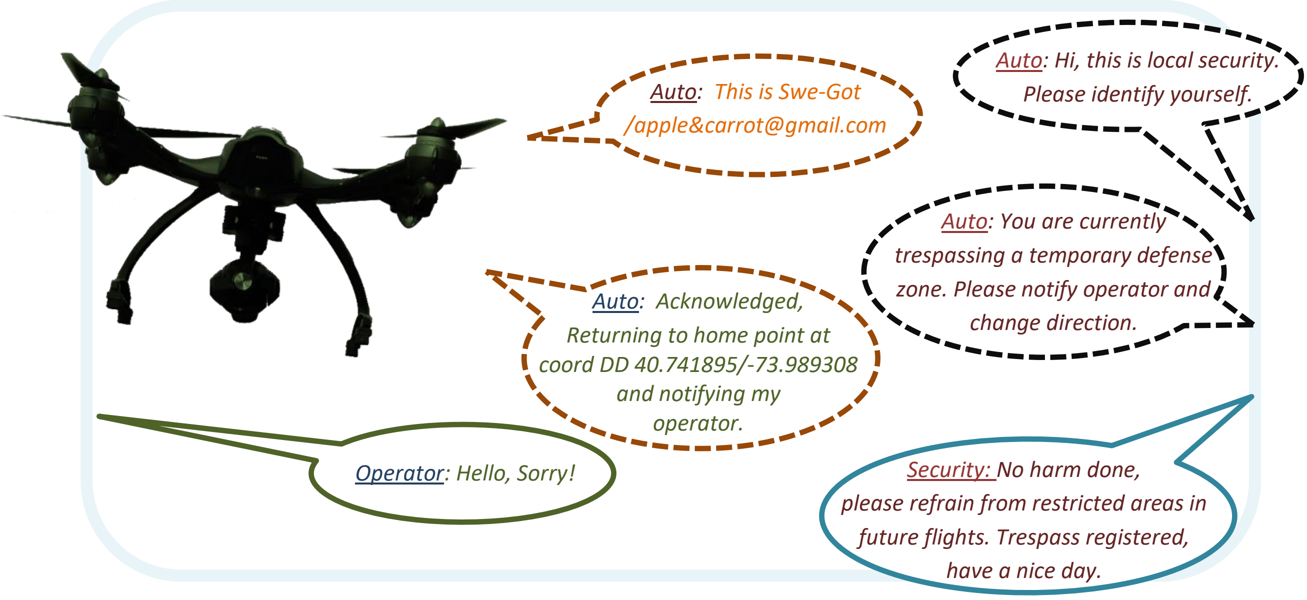


Figure 5.10 illustrates how a future drone transponder could function.

Benefits

- *Inherited benefits from the Information class.*
- *Efficient way of identifying aircrafts quickly with good range.*
- *Considered friendly by drone operator and the public.*
- *Does not require advanced technology.*

Drawbacks

- *Inherited drawbacks from the Information class.*
- *Low incentives for operators to use transponders if not regulated by law.*
- *Low incentives for drone manufacturers to use transponders if not regulated by law.*
- *Requires online registry for drones if used as today's transponders.*
- *Today's transponders are built for regular aircrafts with implications in size and price.*

Disrupt-class

The disruption-class actions break communication between the UAV and its operator and works with different levels of success depending on how the drone operates. A completely manually controlled drone will not be able to continue with planned movement when the operator's communication feed is broken but commercial drones often have automated fallback routines for when the connection is down. This usually means going to a defined home-point or just landing where it is. Technically, the drone could however continue on its mission without connection using automated routines and it is likely that future drones use a steadily increased level of automation. *Figure 5.11* illustrates how a hostile drone's mission has been disrupted and the operator link no longer reaches the drone.

Figure 5.11 illustrates a disrupted and confused drone without contact with its operator.

General benefits

- *Perceived as a semi-friendly countermeasure by operator and the public.*
- *Potentially no damage to operators' equipment, but the disrupt action can easily lead to the drone crashing if it lacks proper automation capabilities.*
- *Easy to measure result of this action. Does the drone stop/return to its home point?*
- *Commercial drones today rarely offers disruption proof auto pilot functions other than return to home point or immediate landing.*

General drawbacks

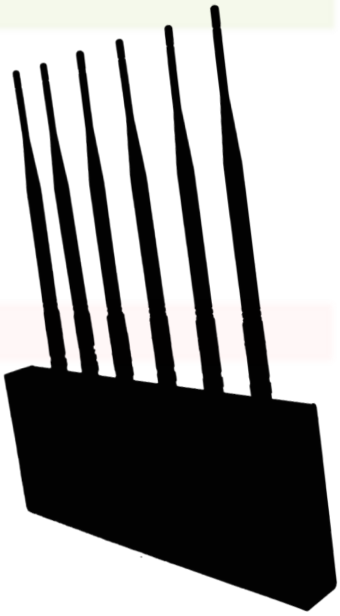
- *Most technologies* ***do not work against rogue drones*** *- Automated drones that do not require operator connection except if the navigation sensors' data feed is disrupted.*

Jammer technology

Signal jamming means disrupting someone else's communication by sending out a stronger signal on the same frequency. Signal jamming can be used to disrupt all wireless signals like for example radio, Wi-Fi, phones, and radar. Some prisons broadcast a jammer signal to disable contraband cell-phones smuggled into the prison. Hobby jamming equipment can be purchased online and broadcasts on a wide range of frequencies with implications for a variety of applications. Signal jamming is however a destructive action and is often illegal to perform depending on frequency and signal strength.

Benefits

- *Inherits benefits of the Disrupt class.*
- *Current use in other applications works as strong proof of concept.*
- *Use in competitor products indicates functionality.*
- *Existing components and low price.*
- *Low power consumption enables mobility.*
- *Easy to implement.*



Drawbacks

- *Inherits drawbacks of the Disrupt class.*
- *High risk of disrupting signals that are not targeted, like most wireless internet and phone signals.*
- *Technical challenge for narrow frequency disruption – targeting a specific drone's communication.*
- ***Laws and regulation** restrict the use of jammers.*

Coordinate spoofing

Most drones (excluding toy class drones) use GPS to navigate. Some also use other coordinate systems, and there is also a possibility of using multiple systems for redundancy. Sending false coordinates with a stronger signal enables a possibility to infect the drone with a false map which makes it follow a new path. This is illustrated in *Figure 5.12* where a drone is given fake indications of where it is.

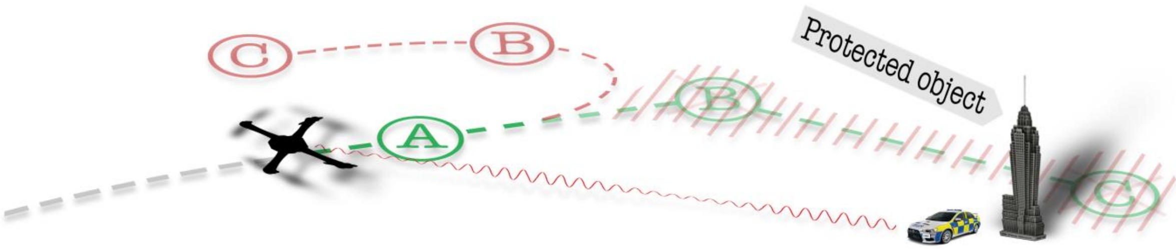


Figure 5.12 illustrates how a drone threat is countered using coordinate spoofing.

Benefits

- *Inherits benefits of the Disrupt class.*
- *Knowing the frequency of coordinate satellites makes the technical challenge to perform this action highly manageable.*
- *Widely available technology and knowhow.*

Drawbacks

- *Does not work for UAVs that navigate through manual guidance or alternative sensor inputs.*
- *Hostile drones could be built with robustness for false coordinates.*
- *Needs good information or guess on where a hostile drone is planning to go to be able to use false coordinates to guide it to a safe place.*

Hi-jacking

This action means taking over control of the drone and has been demonstrated to work for a number of commercial drones of today.

Benefits

- *Inherits benefits of the Disrupt class.*
- *Proof of concept on a variety of today's commercial drones.*
- *Controlling the trespassing drone's landing procedure enables a safe way of stopping it.*

Drawbacks

- *Inherits drawbacks of the Disrupt class.*
- *Not likely to work on custom drones with secure wireless protocols.*
- *Not likely to be future proof.*

Catch-class

This is likely a mechanical way of stopping the trespassing drone and potentially generates clear feedback on whether the action was successful or not. There are countermeasures on the border of being either catch or destroy. The definition in this concept study is that a catch-class countermeasure is likely managed to catch the drone without it crashing. The reason behind that definition is that as a crashing drone poses a clear danger to personal safety.

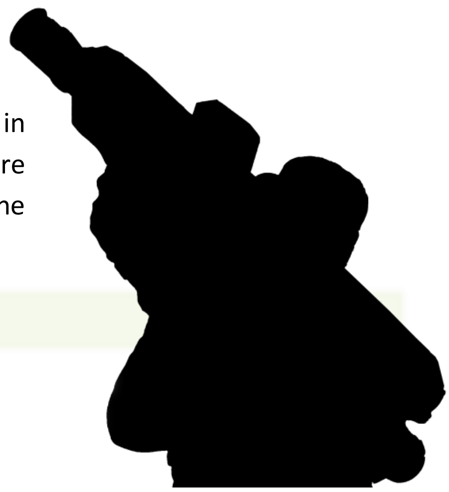
General Benefits

- *Robust way of stopping the drone. Mission complete when the drone is caught.*
- *Personal safety: A catch action should not lead to drones falling from the sky.*
- *Proof of concept with different solutions.*

General Drawbacks

- *Limited range for most demonstrated solutions.*
- *High technical challenge to catch fast and agile drones.*

Handheld net-guns



Existing or near-the-market products have been demonstrated where a bazooka-like weapon shoots a net-grenade that catches the drone in the air with different success in the personal safety aspect. One or more demonstrations use parachutes to avoid the drone crashing. To fit the Catch class, a crash-safe solution like that is considered here.

Benefits

- *Inherits general benefits of the Catch class.*
- *Mobility.*

Drawbacks

- *Strong limitation in range.*
- *Highly unlikely able to catch fast and agile drones.*

Trained eagle

Eagle versus drone videos on YouTube show how fierce attacks from wild Eagle couples protect their territory and provide a swift end for hobbyist UAVs.

With a slightly fictional ring to it, trained eagles has been demonstrated to successfully remove micro drone targets from the air on command. YouTube provides demonstrations from both the French army and the Dutch Police force. The French army shows how the Eagle chickens have small drones to play with and pick on while growing up. Whether a trained eagle catch or destroy a targeted drone can be debated. In this study it is argued fall under the Catch category as the drone is not shot but, but carried to a safe location.

Benefits

- *Highly competent platform for drone removal.*
- *Proof of concept.*
- *Classification and removal of drones.*

Drawbacks

- *Having large Eagles hunt in crowded areas is not likely perceived as a friendly method.*
- *A trained predator requires both extensive training and maintenance.*
- *Risk of hurting the animal itself.*
- *The drone is likely to be damaged.*
- *The eagle sometimes drops the drone, making it a pure case of destructive action with the drawbacks of that class.*

Airborne net-guns

Different concepts and products have been demonstrated where hexacopters hunt and catch drones in the air, resulting in the targeted drone hanging disabled in the net from the hunting drone.

Benefits

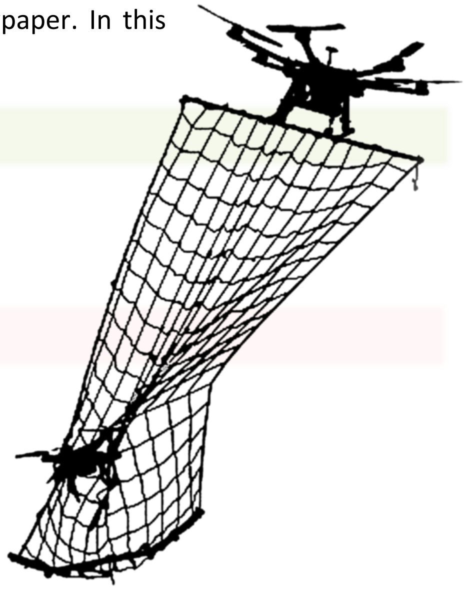
- *Inherits general benefits of the Catch class.*
- *No limit in range due to the mobility of the aircraft carrying the net-gun.*
- *The possibility of getting close to the targeted drone enables a low fail rate.*

Drawbacks

- *Technical implications of having a large hunting drone in the air.*
- *Demonstrated solutions only have one net which means one chance of catching the target.*
- *Demonstrated solutions only catch micro-class multicopters.*

Airborne net

This implements an idea of catching aerial annoyances with flypaper. In this solution, the flypaper consists of a net.



Benefits

- *Inherits benefits from airborne net-guns*
- *Possibility of catching multiple drones with one net, like flypaper.*

Drawbacks

- *Inherits drawbacks from airborne net-guns.*
- *Demonstrated solutions are not as agile as airborne net-guns.*

Destroy-class

This aggressive way of stopping the drone has restricted potential for use in civil applications due to personal safety when drones fall from the sky. On the other hand, it includes more technologies and widens the possibility of effectively stopping the drone.

General Benefits

- *Good potential range.*
- *Definite result.*

General Drawbacks

- *Unsuitable to perform destruction in most civil applications.*
- *Perceived as a hostile action by drone operator and the public.*
- *Personal safety risk being compromised by falling drones.*

Handguns

This method has been used by the police in lack of other methods when a drone has to be removed from the air. Shooting a gun in the air in a city environment can neither be considered safe or effective.

Benefits

- *Proof of concept*
- *Availability.*

Drawbacks

- *All drawbacks of Destroy class.*
- *Short range.*
- *Very hard to hit a small moving target with a handgun.*
- *A loud fired gun is perceived as a very hostile action.*
- *Additional personal safety risk from falling bullets.*

Rifles

This is basically the same as using handguns but with a clear difference in performance potential, making a rifle at least usable against drones. The range is still argued to be short even though it is better than handguns.

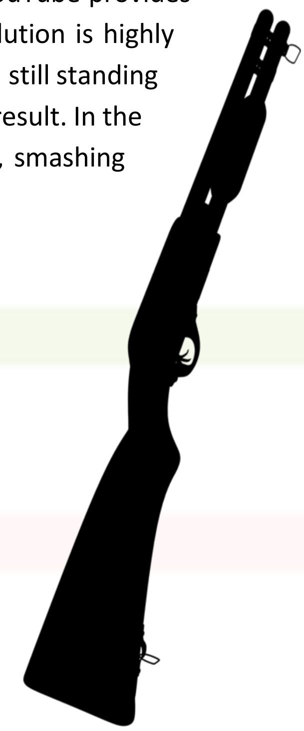
Benefits

- *Proof of concept*
- *Availability of existing technology and methodology.*
- *Better range than handgun.*

Drawbacks

- *All drawbacks of Handguns and Destroy class.*

Net ammunition



Drone catching net ammunition for shotguns is being sold in the U.S and YouTube provides various demonstrations of users trying it out. In the current state, this solution is highly limited in range, usability, and success rate. In demonstration videos, even a still standing drone with short distance proves to be a challenge with a high fail rate as a result. In the cases it does hit the target it functions more like destructive ammunition, smashing parts of the drone to pieces rather than catching it.

Benefits

- *Proof of concept, although it serves as weak proof.*
- *Availability of existing technology and methodology.*
- *Possibility of future products having better performance.*

Drawbacks

- *Very short range.*
- *High fail rate of existing product.*
- *Poor performance against moving drones.*

Airburst munition

This ammunition is set to explode near the target thus increasing the target area and lowering the need for precision or extending the range. The weapon use laser aim to determine distance to target and program munition to burst at the right time.

Benefits

- *Increased range against drones (compared to ordinary rifles) due to increased target area.*
- *Proof of concept by competitors.*
- *Not as harmful to people as regular ballistic ammunition.*

Drawbacks

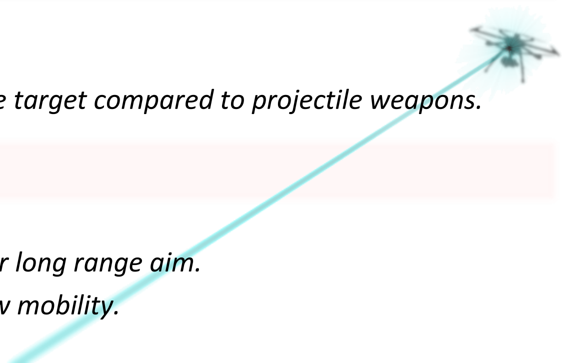
- *All drawbacks of Destroy class.*
- *Similar to ballistic weapon approaches of drone destruction.*
- *Concept is based on U.S. army XM25 CDTE rifle which after a long development is still not ready in 2017.*

Laser canon

The laser canon is a high power industrial laser that can send a concentrated laser strong enough to set fire to a small aircraft. Demonstrations from different manufacturers have been made with examples in the U.S. navy and the Rafael drone dome C-UAS system.

Benefits

- *Very long range*
- *Proof of concept*
- *Low risk of damaging untargeted object than the target compared to projectile weapons.*



Drawbacks

- *All drawbacks of Destroy class.*
- *Require a highly competent stabilizing system for long range aim.*
- *Very high power consumption likely results in low mobility.*

Suicide drones

This can be considered to be a guided missile of some sort, but with potential of using more or less RC toy-grade components. The drone can target and destroy rotor blades of the target with its own body as ammunition or carry explosives.

Benefits

- *Possibly long range.*
- *Good potential for low fail rate.*
- *The concept enables multiple derivative solutions.*
- *Possibly modular solution with mass produced platform.*
- *Good potential to hit fast and agile targets, given that the solution itself uses a platform with those attributes.*

Drawbacks

- *Slow compared to laser and ballistic weapons.*
- *No proof of concept.*

EMP granade

An electromagnetic pulse grenade disables electronics by sending a short high peak power pulse on impact. As it targets electronics it can be perceived as a slightly friendlier method of killing drones than weapons with higher potential to harm people.

Benefits

- *Potentially perceived as friendlier than weapons that can harm people.*
- *Does not necessarily need to hit target directly.*

Drawbacks

- *Proof of concept not demonstrated.*
- *Risk of destroying untargeted electronics.*

Countermeasure technology benchmark

The most promising countermeasure technologies were compared over a number of performance attributes to visualize strengths and weaknesses of them which can be seen in table *5.13*.

Table 5.13 compares different drone countermeasures over a range of performance attributes.

	Transponder	Visual guidance	Jammer	Cordinate spoofing	Hijacking	Handheld netgun	Airborne net-launcher	Airborne net	Trained eagle	Rifle	Net-ammunition	Airburst munition	Laser canon	Suicide drones	EMP granade	
Range	Long	Long	Med.	Med.	Med.	Short	Long	Long	Med.	Short	Short	Med.	Long	Long	Med.	Range
Stopping time	Short	Med.	Short	Short	Med.	Short	Med.	Med.	Med.	Short	Short	Short	Short	Med.	Short	Stopping time
Dynamic enviroment coverage	Good	Med.	Med.	Med.	Med.	Med.	Good	Good	Good	Poor	Poor	Poor	Poor	Good	Med.	Dynamic enviroment coverage
Suitability for city environment	High	High	Poor	Poor	High	Med.	Med.	Med.	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Suitability for city environment
Ability in darkness	Good	Good	Good	Good	Good	Poor	Med.	Med.	Poor	Poor	Poor	Poor	Med.	Good	Poor	Ability in darkness
Speedy and agile target	Good	Med.	Med.	Med.	Good	Poor	Good	Med.	Med.	Poor	Poor	Med.	Med.	Good	Poor	Speedy and agile target
Mobility	Good	Good	Good	Good	Good	Med.	Good	Good	Med.	Good	Good	Good	Poor	Good	Good	Mobility
Performance in fog	Good	Med.	Good	Good	Good	Poor	Good	Good	Poor	Poor	Med.	Poor	Poor	Med.	Good	Performance in fog
Performance in rain	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Med.	Good	Good	Performance in rain
Proof of concept	High	Med.	High	High	High	Med.	High	High	High	High	Med.	High	High	Low	Low	Proof of concept
Rogue drones	Poor	Poor	Poor	Med.	Poor	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Rogue drones
Drone swarms	Good	Good	Good	Good	Good	Med.	Med.	Good	Poor	Poor	Poor	Good	Poor	Good	Good	Drone swarms
Robotic birds	Good	Good	Good	Good	Good	Good	Good	Good	Med.	Good	Med.	Good	Good	Good	Good	Robotic birds
Personal safety	High	High	Med.	High	High	Med.	Med.	Med.	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Personal safety
Power consumption	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	High	Low	Low	Power consumption
Feasibility	Med.	High	Laws	Laws	High	Med.	High	High	Med.	Med.	Low	Med.	Med.	High	Med.	Feasibility
Future proof	Yes	Yes	No	Med.	No	Yes	Yes	Yes	Med.	Yes	Yes	Yes	Yes	Yes	Yes	Future proof
Low cost potential	High	High	High	High	Low	High	High	High	Low	High	High	Med.	Low	Med.	Low	Low cost potential
Need of development	High	Med.	Low	Med.	High	Low	Med.	Med.	High	Low	Low	Low	Med.	Med.	High	Need of development
Maintanance	Low	Med.	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Med.	Med.	Low	Maintanance
Ease of installation	High	High	High	High	High	High	High	High	High	High	High	High	Low	High	High	Ease of installation

6 Discussion

This chapter follows the structure of the report, highlighting the findings of different sections and methods.

6.1 Methodology

The methodology was planned to facilitate early concepts for a product in a new market. A few potential customers and applications where drones pose a problem had been discussed at the company to some extent but little structured work was done there. The methodology in *Figure 2.2* was made in the planning stage but held up during the study. Due to the hot topic of the subject and early findings in the study, an interest was generated at the company which led to early communication of market analysis and initial concept work. This can be described with two way communication arrows in *Figure 2.2* which was meant to serve as iterative early feedback.

Due to the complexity of the problem and differing needs in different applications, this study was very wide in its scope. The consequence of that was the more work could have been beneficial in each step of the project. The benefit of keeping the scope wide was that a lack over overview and relevant mapping of all the ingredients of a SWOT analysis led to a great need both at Saab but as it seemed also among competitors. A lot of technical ideas, fractions of problem descriptions, and indications of customer needs was more or less corridor talk at the company but also in media, but an overview and structure of all mentioned ingredients was missing. It could be viewed as many different problems bundled into one bag of drone detection problems, but for a strong market and product strategy that would also be necessary.

6.2 Definition of the Drone

The definitions used in this study are getting old and comes from military drones which imply that for example a micro-drone can carry something as large as a hand-gun. What are future smaller drones going to be called when the small prefix-names are taken? Better classification should be used!

The drone definition is closely connected with the growing markets that use drones as a disruptive technology. Chinese DJI is a very strong player in many different drone classes and their assortment of drones gives a very strong idea of what the different classes are. The classes differ a lot in physical attributes but to a large extent they can all share developed navigation, communication and automation capabilities which is highly favorable for the drone company. This implies that they have had the possibility to develop automation and robust navigation and that technically enables self-flying drones in a near future. For an automated drone (called rogue drone in a hostile situation) some technologies for both finding and stopping the drone are rendered useless.

Upgradable features shown in the beginning of chapter three and the presence of robotic birds, drone swarms and miniature UAVs also heavily damages the ability of some underlying technologies for both detecting and stopping drones. Being up to date and looking into the future for drone definition is crucial to developing a future robust anti-drone system.

6.3 Market analysis

The market analysis includes all external aspects of the study except for technologies.

PESTEL analysis

The PESTEL analysis indicated that the drone market will continue to grow and it could be argued to be in the lower part of a technological s-curve projection and that many markets driving drone development have not yet matured. Except for that, new markets are also likely to keep popping up. With a growing presence of drones comes a growing need for protection which does not benefit from the disruptive development of drone technology – unless they are included in counter-drone systems. This is illustrated in *Figure 6.1* which is a modification of the projection in *Figure 4.6*.

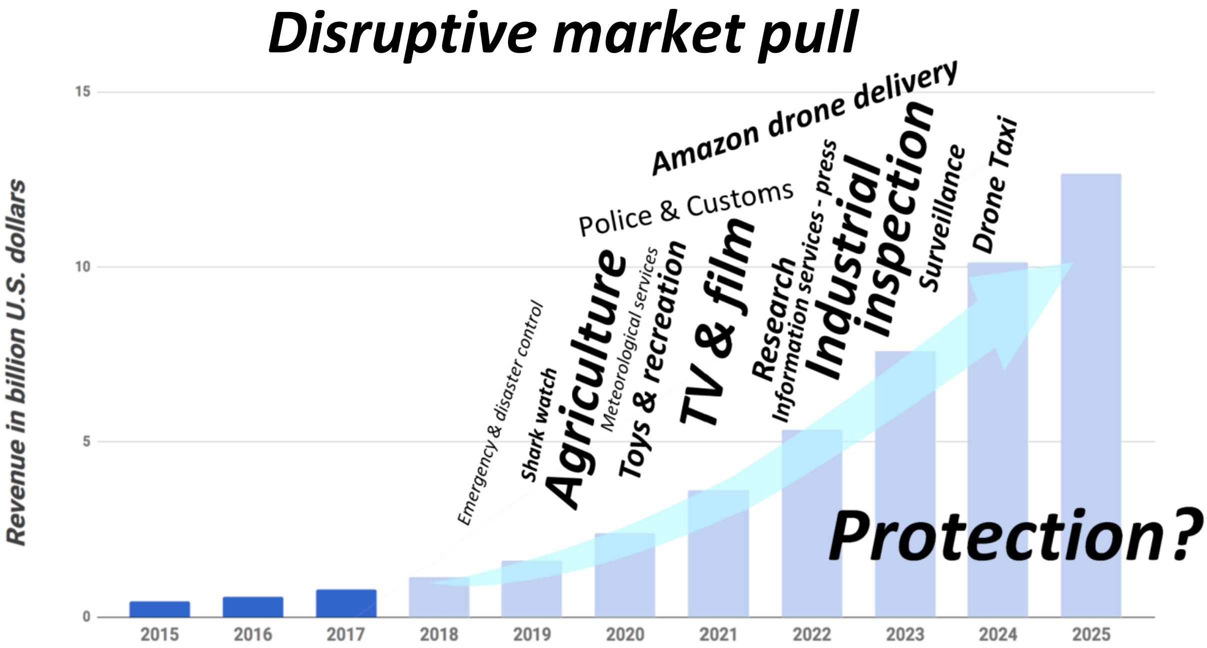


Figure 6.1 illustrates a disruptive market pull for drone development.

The second and most valuable finding of the PESTEL was rapidly changing laws and regulation to try and manage the many implications on personal integrity, airspace, and personal safety. This will be closely connected to the technical need of several applications as more or less all problems concerning non-hostile drone-encounters could be solved with laws, technology like transponders and technological restrictions from the manufacturers like DJI do with limited use in restricted areas. This study does not estimate if and when those technologies will fully be used but it would be valuable information in future development.

The SWOT analysis

In its simplicity the SWOT was very useful to illustrate the task in this study and highlight the importance of understanding the surroundings to produce a relevant concept.

Needs

As this concepts study was done without any direct contact with potential customers, indications of needs from media along with indications to the company was basis for the choice of scenarios. More and different applications not covered in this study likely exist but those can be added and analyzed with the structure in this report.

Needs classification was an important topic on understanding to help identify the time factor in a market offering. The moving target is a common concept in product development literature it is illustrated in this study, where the drones themselves are changing in presence and appearance now and for some time into the future. The changing drone drive technical needs but the Pain factor is a very important part to understand in making the right market offering. It is already argued in the needs chapter that desperate customers looking for Pain medication with willingness of buying them will get tired of temporary Pain easing medicine as the market matures. The changing needs are illustrated as part of a changing product offer over time in *Figure 6.2.* If future aspects has not been considered the road will be closed for the current product portfolio.

Figure 6.2 illustrates what factors drives a change in the product offer over time.

Maps

Surfing Google Earth and Apple maps especially in 3D-mode was a very rewarding way of getting to understand the problem and technical needs of the system. Like personas are used to understand the users of a product, relevant drone scenarios are often based on the environment. All or most of the world airports can be located through the maps services where for example the placement and sometimes even the brand of their SMR ground radar can be identified. Whether the airports are surrounded by dynamic environments like buildings and terrain can most often be found in the maps without any contact with the airport. The same goes with most applications including stadiums, crowd situations in cities. This method can also be used for specific planning a multi asset system and presenting it to potential customers.

Market size

The market size estimations are limited in this study but there are important findings which are highly relevant to a product plan.

Company internal indications point to Landvetter being the smallest sized airport that would consider drone detection system of a certain price today. Five employees at Saab with different backgrounds were asked where they thought that Landvetter would rank in the world, looking at passengers per year. Everyone responded with answers between 2000-3000th place. The trend calculation in *Figure 4.37* projected a rank of 259th place for that airport which indicates a much smaller market than internal projections pointed to. That led to the conclusion that development for a modified, airport specific version of the G1X radar might not be a sound development project. The number of airports that are likely to purchase an expensive drone detection system will likely grow with time, especially if there are more drone incidents.

The prisons in Sweden do not constitute a strong market and the same can be assumed for adjacent countries. USA on the other hand hold about one fifth of the worlds prisoners in over 5 000 prisons and have extensive national problems with guns and drugs. That is definitely a market worth noticing but it likely attracts other players, some of which are more likely to produce low price solutions than Saab Surveillance.

Regardless of what application is analyzed in market size, the number of customers interested in having an anti-drone system will continue to grow for some time.

Customer segments

At first look, a reader might wonder why separating areas of application and customer segments. The main reason is the mission to identify potential markets. The application areas mainly looks at who needs help while the segments is used to classify different scenarios that are, for different reasons, similar. It is not only a way of looking for similarities that create juicy markets but also to highlight differences that especially generate different technical needs. When new areas of applications are identified, they can likely be placed into one of the identified segments of this study.

The segments' differences are demonstrated through a comparison of threats (shown in *Table 4.46*), as they are different for all of them. To a large part, the threat defines the problem a customer experience and it is a driver for a customer to buy an anti-drone system. In other words, understanding the different threats is crucial in developing protection against the drones.

6.4 Competitors

There are quite a few potential competitors for the identified segments and the number is growing. Finding accurate technical specifications for the different systems are quite the challenge. In many cases they have presented specs, but how they have chosen to grade their own solution includes larges playroom for error and perception.

The general trends among competitors served as one of several inputs to system design choices especially when it comes to multi sensors detection which almost all competitor systems have. Other strong trends are that most competitors partly or solely use RF detection and almost exclusively use signal jamming as countermeasure. It is argued that RF detection has a crucial weak spot against rogue drones and that competitors jamming equipment are illegal to use in all applications due to the high potential of disturbing untargeted communication signals. This indicates that most of what is seen on market today is not future robust and does not even solve today's problems. It is likely put there as time stalling while developing real countermeasures that can actually be used.

6.5 Underlying technologies

The chapter begins with motivating why the counteraction cannot be neglected when planning a drone detection system. The reason for this clarification is that the company were asking for the concept for a detection system only, but no realizing that the requirements for the detection parts is highly effected on what the information is going to be used for. A slow countermeasure calls for an early detection as argued illustrated in that chapter.

Finding the drone - Benchmark

The detection technology benchmark contains a high density of information on the selected sensors. For that reason, the worst candidates from the detection technology chapter are not presented in it. The performance indications of *Table 5.9* are a wide set of attributes that is relevant for the different drone detection applications. The table clearly demonstrates that even the large and expensive radars have their drawbacks and would hardly represent a complete drone detection system – for most applications.

Looking only on the amount of green, an airborne EO-sensor looks to be stronger than a large radar system, but the difference in range is a highly important and expensive one. An "extreme range radar" might cover more area than 50 air-borne EO-sensors and the later could be blind in poor weather conditions. From this benchmark the conclusion was drawn that combined sensors clearly has the potential to complete each other and together produce a greener total score.

Stopping the drone

Alternatives of stopping the drone that were found in existing solutions were often destructive ones. It was concluded that a destructive way of stopping the way is rarely feasible. A non-destructive countermeasure found on competitors was jamming. In fact, most competitors claim that they use jamming as a countermeasure which does not at all comply with regulations as the technology can easily do more damage that good. That also makes the jamming action destructive.

Mentioning the word countermeasure often drew interviewees to think of destructive ways of stopping the drone and consequently also led some of them to saying that it is not possible – A system should therefor only detect. A classification of countermeasures was made in this study. This was important to show that the difficulties of destruction are being considered and show that there are other ways to stop the drones. The destructive action is only one of four categories of stopping the drone, a way that should be avoided. The first and most gentle way, information does not include many options. That does however not say that it has low potential and finding effective way of performing the information action could lead to innovation with competitive potential.

Among the countermeasure technologies, future transponder technology is represented with a very good score. However, the two red flags have potential to render it completely useless. The first red attribute: no ability to stop rogue drones means that it only works for drone operators who play nice. The second implicates that this technology will only be used if countries' future drone laws state that drones must be equipped with transponders.

6.6 Research questions

The research questions from chapter 1.5 are shown again with a following discussion on them.

1. ***Problem:*** *What do we need protection against?*
2. ***Need****: What are the needs of the customer, and how do they rank?*
3. ***Market research****: What is the new market, and how should that be segmented?*
4. ***Company analysis****: How do the company's competences match the need of the customer?*
5. ***Concept****: How could Saab create a market offering that puts them in a leading market position? How can they reach a wide market?*
6. ***Moving target****: What is changing in the near future?*
7. ***Development plan****: What would be the first step, a way in to a new market?*

The problem

The drone threat is defined in chapter three and it is argued that the problem varies in different segments in chapter four. The problem will change over time for a number of reasons and calls for a future robust solution.

Need

The needs are not the same in different segments and they are also argued to change over time with regards to the Kano model and the needs classification in chapter four.

Market research

The new market looks more like different markets at a closer look with the segment need analysis of chapter four. The segments could easily be divided into sub-segments (which they are in *Table 4.47*) but the threat and tasks are the most important aspects in the segmentation. To have a competitive product, it is highly attractive to be able to solve a scenario indifferent of threat type or performance needs.

Company analysis

The company profile does not match high volume low price products and trying to be cheapest is not the way in. There seems to be a gap for systems that really solve the drone problem over time and the need of high performance systems matches the company's strengths. On that note, understanding the needs best among competitors is highly important. The airport is the most obvious fit to the company's ground radars as the range need is extensive.

Concept

A strong concept solves the given problems and is the way to a strong position. Aiming at markets where a low price tag is expected can be problematic, but the segments cannot predict how much specific customers can pay – There might be customers that fit a low price segment profile that are willing to invest in a high performance system. The concepts are presented in the following chapters.

Moving target

Upgrades and the future drone threat of chapter three is part of a changing problem and chapter four provides examples of changing legislation and need. The moving target is illustrated in the SWOT analysis in *Figure 4.1* and chapter four in general. It is summarized in *Figure 6.2*.

Development plan

That research question is best answered in chapter ten.

7 Application System Analysis

Closing into the system concept of Chapter 8, further system analysis of each segment is presented here. Via black box-models and flowcharts, a clear difference in complexity between different scenarios is highlighted.

7.1 System Black Box analysis

A Black boxes analysis of each customer segment is given here to clarify what a system must do at the highest level of abstraction.

Airports

Figure 7.1 presents three Black Box-models for an airport drone detection system. Black box a) and b) are detection-only-systems as Traffic management claim that that is all an airport customer wishes to have. There is a higher level of automation in model b as the operator does not need position information as an effect of the system determining the risk itself. Box a) and b) would both mean easing the Pain factors but would not regard the underlying problem. As argued before, an interest in solving the underlying problem will likely follow with maturity in this market. Black box c) do not only detect, but also remove the drone and is presented in case laws, legislation and technological restrictions do not solve the underlying problem to a high enough degree.

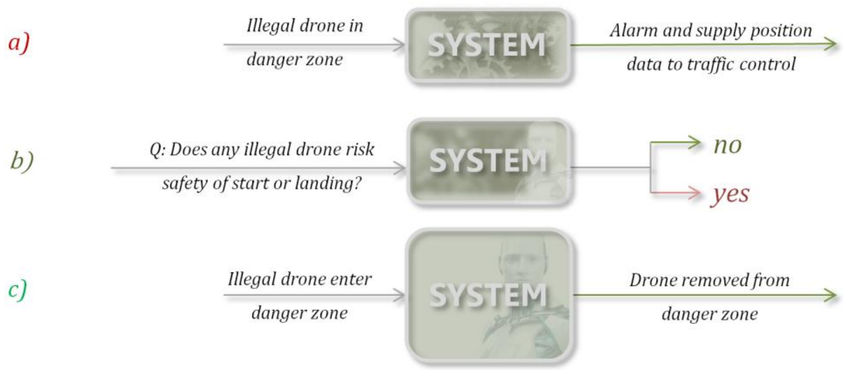


Figure 7.1 shows three versions of the system with difference in level of automation.

Urban crowd scenario

Figure 7.2 presents a Black Box model for this application area to visualize input and outputs of such a system. Three simultaneous outputs indicate a higher complexity as a result of more demanding needs than at an airport.

Figure 7.2 presents a Black Box analysis of the system in an urban crowd scenario.

Prisons

Figure 7.3 shows a Black Box model for a prison drone detections system. Stopping the contraband is the obvious task that is the great Pain for prisons. Identifying the operator could be necessary as a drone competent operator outside a prison will likely not stop sending contraband as one of his or her drones had been confiscated or destroyed. With experience and know-how, putting another drone together is easy.

Figure 7.3 shows a Black Box for a system at an airport.

Military scenario

In the military scenario the systems input and output can be described as in *Figure 7.4*. A big difference to police use is that there is no need to catch drone or identify operators here.

Figure 7.4 is a Black Box model of the military scenario.

Company office espionage

A Black Box model of the office espionage scenario can be viewed in *Figure 7.5*. The idea is to warn if the is danger. If the protected office is large, position information might be needed to delimit the alarm to the right area.

Figure 7.5 illustrates a Black Box of the office scenario.

Prototype espionage

Figure 7.6 shows a Black Box for this application. The simplicity of the model makes it similar to that of an automatic doorbell in a cloths store.

Figure 7.6 is a Black Box of the Prototype application.

7.2 Flowcharts

Opening and looking into the Black Boxes from the previous section, flowcharts describe more in detail how a system produces the outputs of the Black Box models. The blocks' color in the flowchart relate to the coming system overview in *Figure 8.1* where blue, red, and green color represent Perceive, Do, and Operations tasks.

Urban crowd scenario: Police & Stadiums

Multiple Black Box outputs in *Figure 7.2* hint that this is a more complex system than that of an airport. The Flowchart in *Figure 7.7* clearly demonstrates the complexity of the system. The *Detection loop*-function visually constitutes a very small part of the flowchart while functions enabling the three outputs of the black-box system constitute the major part.

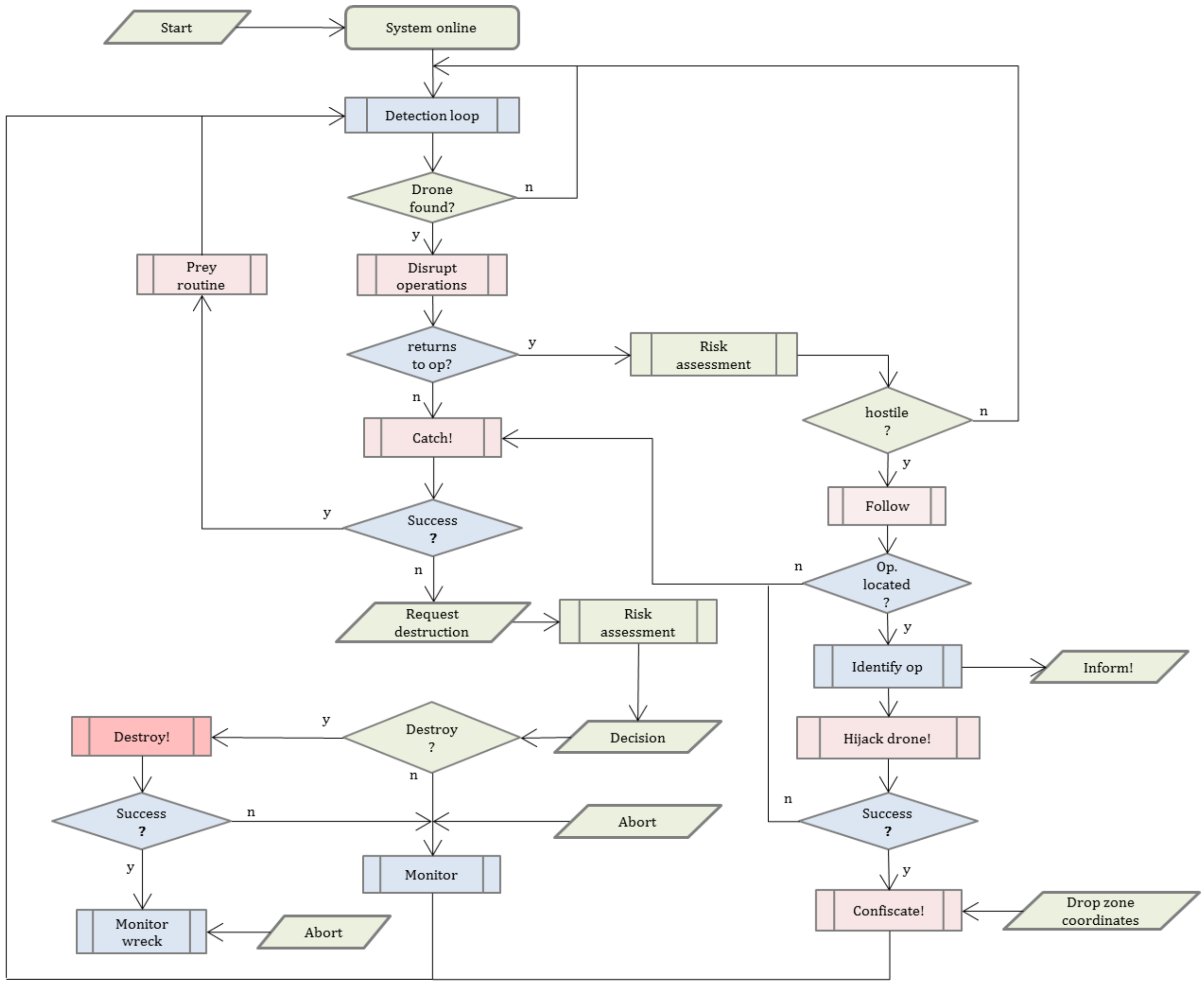


Figure 7.7 is a flowchart for a system in the Urban Crowd Scenario.

Airports

Black Box model a) from Fig*ure 7.1* best fits Traffic management's description of the need and is therefore describes further in a flowchart in *Figure 7.8*. At this level of abstraction the flowchart is very simple and contains a *Detection loop*-function and a *Monitor*-function in which continuous data is delivered to Traffic control.

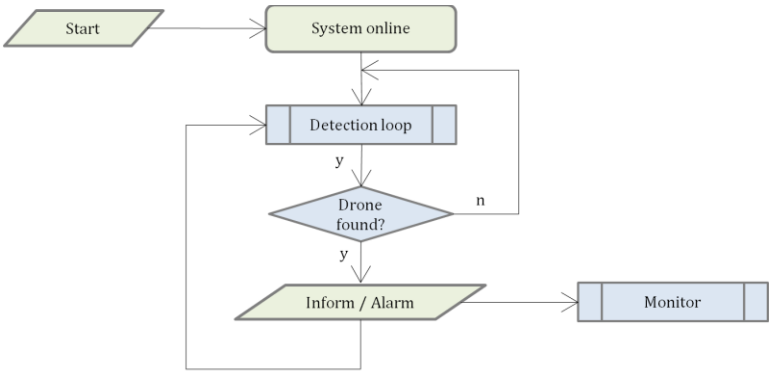


Figure 7.8 is a flowchart for a detect-only system with low level of automation.

Prisons

The flow chart for the prison Black Box is the same as for an urban crowd scenario in *Figure 7.7*. The drone classification of the flowchart is not represented in the prison Black Box as there is a possibility that all drones should be classified as hostile.

Military scenario

For this application two flowcharts are presented. The first one in *Figure 7.9* only visualize that the drone has to be detected and removed and the second one in *Figure 7.10* looks at a slightly lower level of abstraction and the *Remove drone*-function has been unraveled.

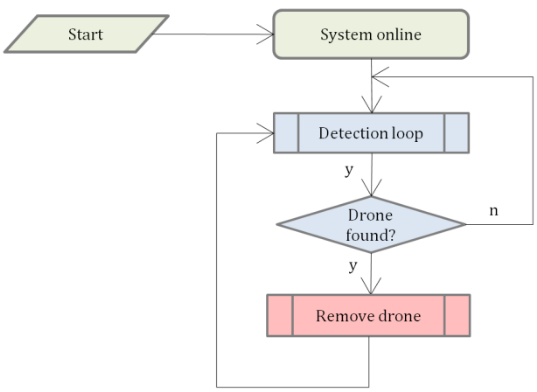


Figure 7.9 shows a simple flowchart with high abstraction level including Detect and Remove drone-functions.

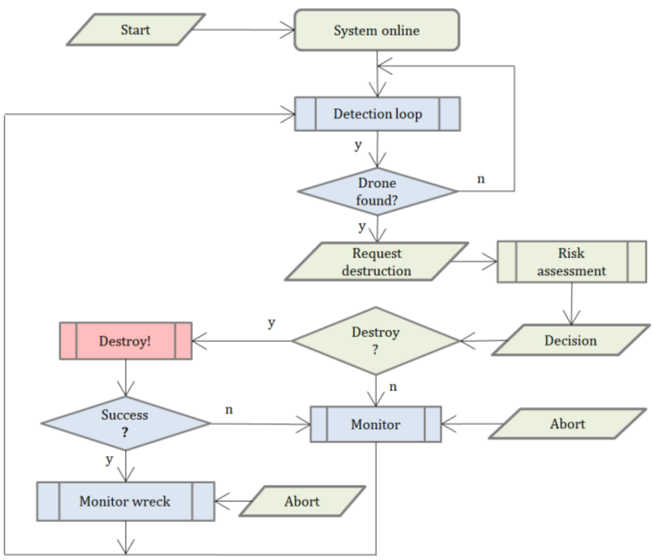


Figure 7.10 has a slightly lower level of abstraction, unravelling the Remove drone-function of Figure 7.9.

Company office espionage

The flow chart inside the Black Box of *Figure 7.5* is presented in *Figure 7.1,* where position information might be needed to delimit the alarm to the right area.

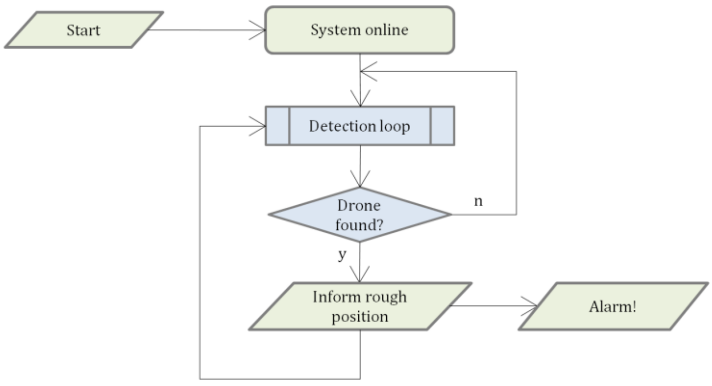


Figure 7.11 shows a flowchart for the company espionage scenario.

Prototype espionage

The simple Black Box in *Figure 7.6* consequently enables a small and easy flowchart for this problem. The flowchart is presented in *Figure 7.12*.

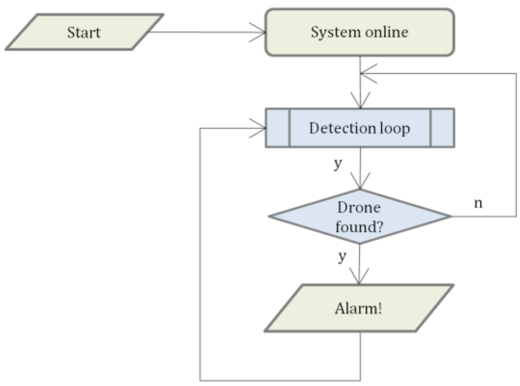


Figure 7.12 is a flowchart for a prototype espionage scenario.

8 Modular Multi Asset System

This chapter presents an overview of the Modular Multi Asset System and motivates design choices at a high abstraction level. The system is aimed to be future and application robust. The building blocks used to create such systems are also presented in this chapter.

8.1 System overview

The system is visualized in *Figure 8.1* where the *Perceive* section performs detection with high potential sensors. It also contains local processing as this is an important technical restriction far into the future for some sensors due to extreme data streams handled by logic circuits. The operations block can likely be solved by an operator to a large part, but going towards an automated solution has gains in costs, robustness, and performance. The overview also illustrates some of the systems modularity.

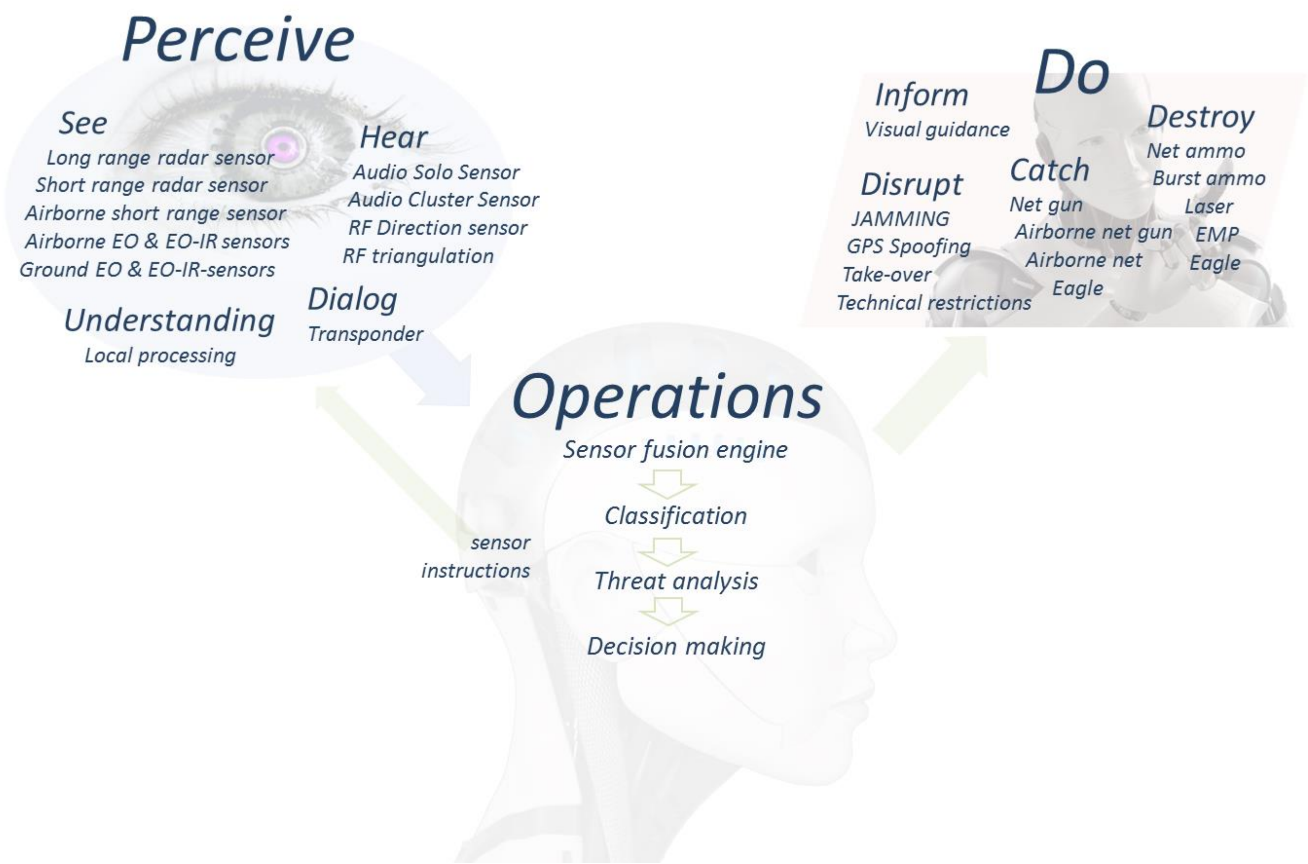


Figure 8.1 illustrates an overview of a C-UAS system.

8.2 Multi-Sensor System

A trend among competitors is the use of multiple sensors. The result from the needs analysis together with the strengths and weaknesses of different sensors in the underlying technologies chapter in this concept study also suggest that a multi-sensor concept is preferred. The multi-sensor system can easily be compared with the different senses of a human being. Hearing is strong for communication and is not impaired by low light or blocked line of sight while sight has long range and is very fast in classification of people and objects and measure distance due to stereo optical sensors (eyes). Fusing the different senses makes for a very powerful perception but requires a competent fusion engine. A multi sensor system's three main selling points are:

1. *Different sensors **fill the gaps of** each other's **weaknesses**.*
2. *A multi-sensor platform **can be scaled** to fit different applications.*
3. *Possibility to tailor a solution for a **specific site**.*
4. ***Upgradeable** by changing sensors.*

!

8.3 Modularity

Components from the *Do* and *Operations* sections should be modular at a high level of abstraction. Many of the modules can be existing third party products where there are great benefits of not developing Saab's own versions of them which would lead to locking in to quickly dating hardware. Such benefits include reduced time-to-market and delimiting development efforts to the company's core competence. In this case, a modular system has its main advantages in:

1. ***Scalability**.*
2. *Fit different customers / customer **segments**.*
3. ***Re-use** of modules.*
4. ***Faster NPD cycles** when a partly new design is perceived as a new product.*
5. ***Focus development** efforts at few parts at the time to reduce time-to-market.*
6. *Possibility to **use existing products** from other manufacturers.*

!

8.4 Building blocks for a Modular Multi-Asset System

Building blocks are the parts used to tailor solutions that fit different applications. Like in the system overview in *Figure 8.1* concept building blocks are sorted between *Perceive, Operations, and Do* which here serve as sub-chapters. Some of the sensors and countermeasures already appeared in chapter five as underlying technologies with benefits and drawbacks, but a building block can also contain several technologies and new ideas. In this section more specific and applied ideas for anti-drone system is demonstrated where their strengths have been analyzed to match applications effectively. The benefits and drawbacks here weight in both technical and strategic aspects with focus on being useful in the identified segments.

Perceive

The perceive part is argued to be the most dynamic task of the system as different applications have different needs when it comes to especially range and dynamic coverage.

Radar

Radars have a given place among the building blocks as:

- *It offers long range.*
- *It is weather and light robust performance.*
- *Strong proof of concept exists.*
- *Existing products and extensive competence at Saab.*
- *The most future robust sensor.*

Very long range radar

Saab's giraffe ground pulse radar family currently offers drone detection using the ELSS algorithm that can sort out drones from birds using behavior analysis.

Benefits

- *Low development efforts needed to perform detection task especially in military applications.*
- *Extreme range.*
- *High altitude coverage.*
- *Detects drones using ELSS.*
- *Possibility to upgrade sold products with counter drone features.*

Drawbacks

- *High price may limit civil application markets.*
- *Not streamlined for this purpose with a strong implication in size.*
- *Not streamlined for a multi-sensor system with remote operations.*
- *Inner blind spot grows with range.*

Technology

- *Enhance remote operations functionality.*
- *Add detection for robot birds.*

Long range radar

The smallest radar in Saab's current ground radar product family, the G1X, still has very high performance compared to other drone spotting systems on or near the market.

Benefits

- *Low development efforts needed to reach airport segment shortens time-to-market with benefits in:*
  - *Getting early a market share, associate brand with market.*
  - *Premium price.*
  - *Fast knowledge feedback in drone detection products.*
- *Low enough price to reach airports.*
- *Upgradeable software.*
- *Long range.*
- *High altitude coverage.*
- *Detects drones with ELSS.*
- *High potential to also work as bird radar at airports with upgraded software.*

Drawbacks

- *Rotating antenna generates maintenance.*
- *Restriction in placement due to 360° rotating antenna – needs its own tower.*
- *Radar drawbacks include line-of-sight coverage only.*
- *Not streamlined for a multi-sensor system with remote operations.*

Technology

- *Add effective bird monitoring for airports as software add-on feature for delighter functionality.*
- *Possibly add SMR ground radar capabilities to do that job aswell.*

Medium range AESA radar

This is a suggestion of expanding Saab's ground radar product range one step below the G1X with a static panel 90° radar panel. Easy placement on buildings or towers and low maintenance due to absence of moving parts makes this concept attractive compared to rotating radars. This type of radar is the most common type found in C-UAS systems today.

Benefits

- *Easy to install on current towers or buildings as it does not need a 360° view.*
- *Low maintenance due to absence of moving parts.*
- *Low enough price to reach airports.*
- *Low price reaches other applications like prisons and crowds.*
- *Upgradeable software.*
- *Detects drones with ELSS.*

Drawbacks

- *Competitors sell products like this one.*
- *Radar drawbacks include line-of-sight coverage only.*

Technology

- *Implicates full product development in a new technical segment where many competitors already offer products.*

Audio

The strongest selling points for audio sensors are the high use of similar technology in other applications from music production to audio surveillance. Those benefits are not restricted to the sensor itself, as audio signal processing is the main ingredients of successful audio drone detection. The strongest drawbacks of the technology are limited range for soundwaves (especially ultrasound), the relatively slow speed of sound and a strong possibility of future drones be much more quit.

Mobile audio ultrasound sensor

This concept sensor can only hear if there is a drone or not, no information of position, what direction or speed it has is given. With a potential of being small and cheap it could however be used as a grid in for instance a city environment, where one audio sensor giving a positive response or alert is enough information to use another sensor for more information. Depending on placement, it could also be used for triangulation with the benefits of getting position and speed information. *Image 8.2* illustrates a small ultrasonic smartphone-based audio sensor attached to a car window in a city environment at night.

Benefits

- *Potentially very small.*
- *Potentially very cheap.*
- *Use sound reflections between houses.*
- *Does not require line-of-sight.*
- *Clip-on ultrasound Bat-microphone exists as a kind of proof of concept.*

Drawbacks

- *Short range for audio, especially for ultrasound.*
- *Future drones could be quiet, especially robot bird type drones.*

Technology

- *Possibly borrow technology from microphones used for bat detection.*
- *Possibly borrow technology for smartphone soundcards for hobbyist music production and mobile sound recordings.*
- *Use smartphone as platform for power, communication, mobility, and local processing.*
- *App development, integration to operations.*

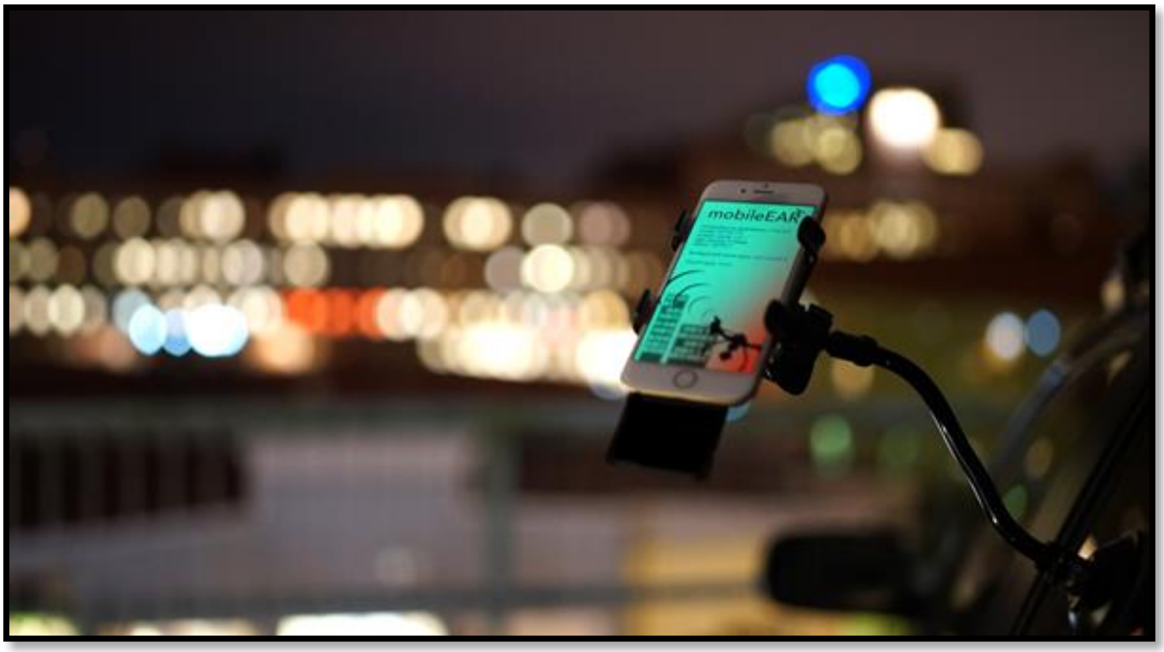


Image 8.2 illustrates a mobile single audio sensor concept.

Cluster audio ultrasound sensor

Making the audio sensor a few steps sharper, the cluster audio sensor increase sensitivity and range but the main advantage is the possibility to sense direction of the drone sound due to time of arrival.

Benefits

- *Possibly detects beyond line of sight, for example behind buildings or trees.*
- *Technology has been developed at Saab.*
- *Identifies direction of sound.*

Drawbacks

- *Short range.*
- *Does not sense speed or distance.*
- *Possibly not future proof.*
- *No proof of concept in noisy environments.*

Technology

- *Proof of concept exists within company.*
- *Reduce price and complexity and increase mobility to make for an attractive sensor.*

EO

In general this technology has the benefit of being swiftly developed by other applications. Especially smartphone cameras constantly push the technical boundaries for what can be achieved with a very small sensor. A smartphone also offers an off the shelf platform for local processing, communication, mobility and environmental performance (like weather resistance). For camera sensors, local processing likely implicates more weight, size, and price than the optical sensor itself.

High coverage cluster EO sensor

This concept uses multiple fixed focal length camera sensors to increase coverage for initial detection. Camera sensors are usually not strong for initial detection as takes many pixels to both get good angular coverage both vertically and horizontally. Instead of using an extreme sensor and lens to get precision, the benefit with the cluster EO sensor is that it can use a large set of cheap camera sensors that has economy of scale from use in other applications. It also lacks moving parts which enables an easier construction with lower maintenance.

Benefits

- *Enables initial detection with low price camera sensors.*

Drawbacks

- *Many pixels to process – Need of local processing.*
- *Poor night vision without IR-capability with small camera sensors.*

Mass produced industrial inspection multicopter

This sensor can also be described as an airborne PTZ-camera. Wind-resistant hovering and stabilizing gimbals enable a combination of zoom cameras and airborne surveillance. This sensor is a powerful combination with an initial detection sensor or sensors. The drone itself cannot monitor a large area easily with one camera but when an indication is generated from another sensor, this UAV can be used to zoom in an area to classify and track objects. A hovering airborne camera, looking at the ground is favorable for classification and determining position and speed of trespassing drones as the movement/pixel change stands out from the background. This type of multicopter is already used for other purposes by police forces in many countries including Sweden. As this platform to the larger part is rapidly being developed for commercial and hobbyist use, most of the development is being done "for free". *Image 8.3* illustrates a PTZ-camera equipped commercial drone

Benefits

- *UAV platform primarily developed for other purposes can be used with benefits in time-to-market, avoid technological lock-in, and hook on to rapid development of drones.*
- *Get the most out of an optical sensor from above.*
- *Can be used manually without development.*
- *Relatively low price.*
- *4G connectivity is demonstrated to avoid range restriction.*
- *Enables good strategic footage for more than just drones during a crowd situation.*
- *Automated navigation routines demonstrated by commercial drones.*

Drawbacks

- *Airtime restricted by battery for wireless multicopter.*
- *Many pixels to process*

Technology

- *Possibility to use 3rd party UAV platform from industrial inspection applications with adjustments.*
- *Drone recognition algorithms.*
- *Robust navigation.*
- *Robust communication.*
- *Automatic battery replacement.*

Image 8.3 illustrates a PTZ-camera equipped commercial drone

Birdwatch

This concept uses existing bird robot technology combined with optical sensors to create a silent, hard-to-detect, non-threatening eye in the sky. Bird Watch is mainly used to locate hostile drone operators using cameras. It can also be used for strategic optical surveillance. *Figure 8.4* illustrates the concept in action used for airborne surveillance with its primary use in locating and identifying operators of illegal drones. The absence of loud propellers and motors, birdlike sky silhouette and movement pattern makes it hard to discover from the ground.

Benefits

- *Proof of concept for bird robot platform.*
- *Non-threatening appearance.*
- *Silent compared to loud surveillance multicopters.*
- *Hard to distinguish from real birds for perpetrator operator of hostile drone.*

Drawbacks

- *Cannot hover like multicopters.*
- *Low knowledge on feasibility compared to multicopters.*
- *Harder to maneuver than multicopters.*

Technology

- *Existing technology for robot birds.*
- *Robust navigation.*
- *Robust communication.*

Figure 8.4 illustrates the silent BirdWatch concept.

The Overlord

This is a concept using a surveillance airship (blimp) as a platform for medium to long range with the benefit of good dynamic environmental coverage. The overlord uses a cluster image sensor consisting of multiple EO sensors with prime lenses (fixed focal length) for large coverage and initial detection and PTZ cameras to enable detailed confirmation. The choice of prime lenses for coverage leads to better low light performance due to aperture construction in the optics. The Overlord needs to monitor with many pixel coverage to be able to optically perform initial detection.

This blimp (illustrated in *Figure 8.5*) carries local processing that handles the pixel stream of the many EO sensors, and react to irregular movement that are not people, trees, or vehicles for initial detection. When a movement is suspected to be a drone with likelihood over a threshold, the PTZ camera takes a closer look to determine if it is a threat. A large number of PTZ cameras enable multiple threat classifications at once.

Benefits

- *Possibility to perform both initial detection and classification using optical sensors.*
- *Offers extensive strategic surveillance overview beyond drone detection.*
- *The airship enables long airtime.*
- *Proof of concept with airships for cameras surveillance.*
- *Large enough to enable local processing for large megapixel resolution.*
- *Possibility to anchor with wire enabling power and fast data transmission.*

Drawbacks

- *Easy target in a hostile situation.*
- *Low knowledge on feasibility.*
- *Weather sensitive according to an article about an English police airship (Narain 2010).*

Technology

- *Existing technology for surveillance and filming blimps.*

Figure 8.5 illustrates the Overlord concept which is a surveillance airship using both prime lens cameras and a PTZ camera.

The blackbird

The blackbird is a small robotic bird like birdwatch with a substantially smaller size. This difference makes results in both benefits and drawbacks. The blackbird's greatest benefit is that it can get close to a hostile drone operator without him or her noticing its presence.

Benefits

- *All benefits of Bird Watch.*
- *The blackbird can get close to a hostile drone operator without getting spotted, closer than a larger robotic bird.*
- *Proof of concept for flying platform.*

Drawbacks

- *All drawbacks of Bird Watch.*
- *Existing small robot birds generate more shaky images and video than larger ones due to higher wing flapping frequency.*
- *Smaller size implicates shorter airtime.*

Technology

- *Existing technology for robot birds.*
- *Robust communication.*
- *Robust navigation.*

Figure 8.6 illustrates the small robotic Blackbird concept.

RF

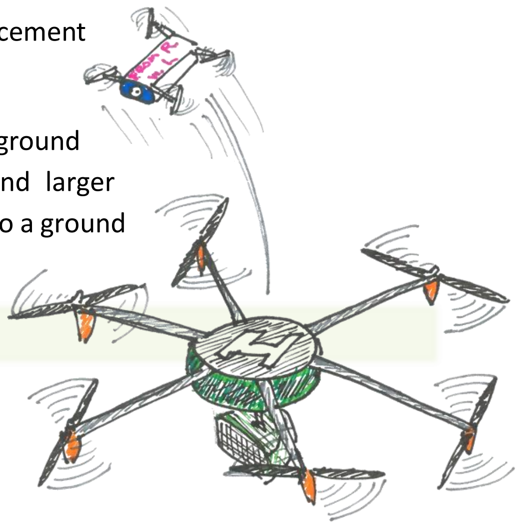
As long as drones are not automated without an operator signal, a sensor looking for drone RF signal emittance is a strong alternative in some scenarios, especially as it to some extent can pick up signals without perfect line of sight.

The mothership

The core idea of the Mothership is that it is a large UAV platform with airborne surveillance capabilities that as a small drone swarm are used together to create a safe perimeter. The concept is illustrated in *Figure 8.7* where the closest mothership deploys a conceptual countermeasure Jamzie nano drone. The motherships scan the air for moving RF-emissions and use triangulation from the different units to determine position and thereby also speed of drones. If a threat is detected they dispatch fast and agile countermeasure drones to fight that target. Due to its large multicopter body it can carry enough stored energy to have a relatively long airtime. Their high altitude enables good conditions for direct communication with their countermeasure drones.

In a wireless implementation, one at the time, the Motherships are replaced with a relief unit with a fresh battery. The relieved unit switches batteries and replaces the next Mothership drone. Automatic battery replacement is an important part in reducing maintenance.

In another implementation, the motherships use cables from the ground for power and data transmission. This enables long airtime and larger bandwidth for information flow, possible moving local processing to a ground unit.



Benefits

- *Highly mobile solution.*
- *Good coverage.*
- *Scalable.*
- *Mostly uses tested existing technology.*
- *Possibility to use other sensors than RF-detection*
- *Possibility to use wire from ground to enhance processing capabilities, simplify information flow and reduce obstacle for long airtime.*

Drawbacks

- *RF-detection does not detect rogue drones!*
- *Maintenance for swarm of large multicopters.*

Technology

- *Possibility to use 3rd party UAV platform with adjustments.*
- *Light swarm behavior.*
- *Automatic battery change.*

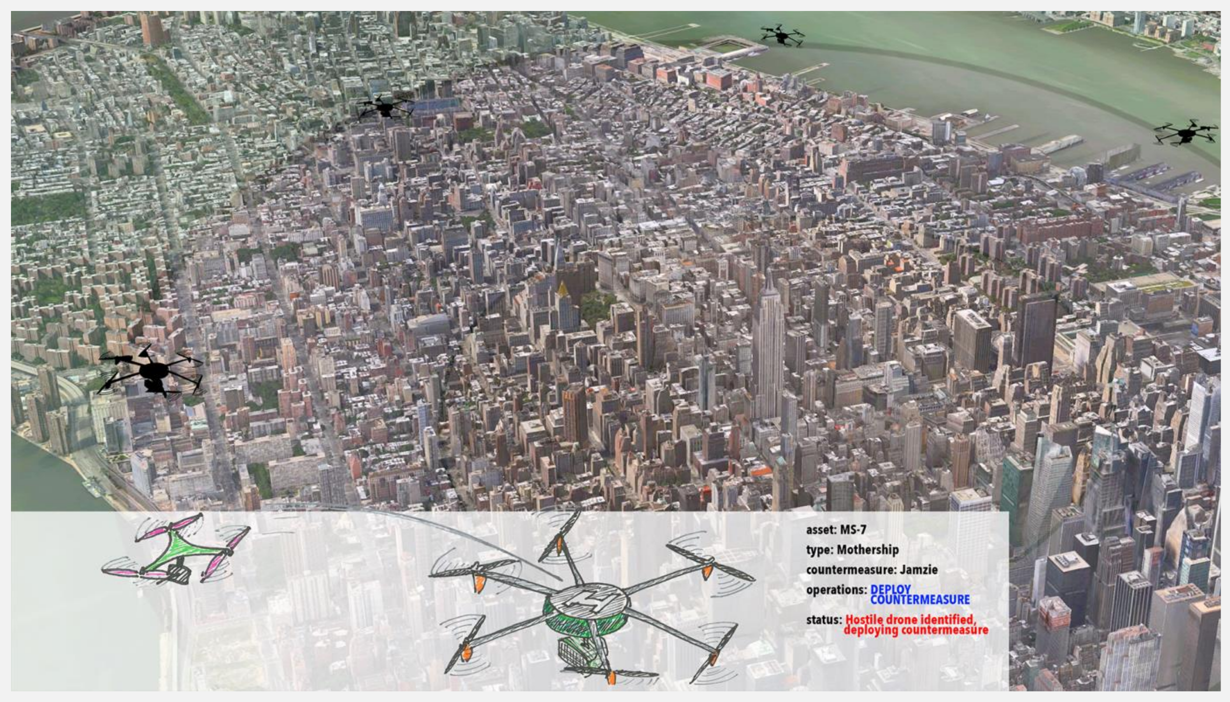


Figure 8.7 illustrates multiple motherships.

Operations

In the system overview, Operations include multiple building blocks. All of them are however necessary in all applications and Operations is therefore viewed as one module here. A robust centralized operation unit increases the modularity and future robustness of the system. Building a system with this in mind is essential to making it robust to future needs with the ability to adopt new sensor and countermeasures.

For a user who wishes to manage everything locally, the remote operations still offers advantages in mobility and strategic overview as relevant information feed can be given back to users through for example a tablet app. For a larger city with multiple protected sites where the police has an interest in identifying the operators in all the cases, the operations unit may be under police control or at least offer information infrastructure to offer the right information to the police at the right time.

Automated remote operations are illustrated in *Figure 8.8*. The Operations unit controls scenarios in different European cities as it analyzes information from simultaneous drone alarms and provides decision making for countermeasures.

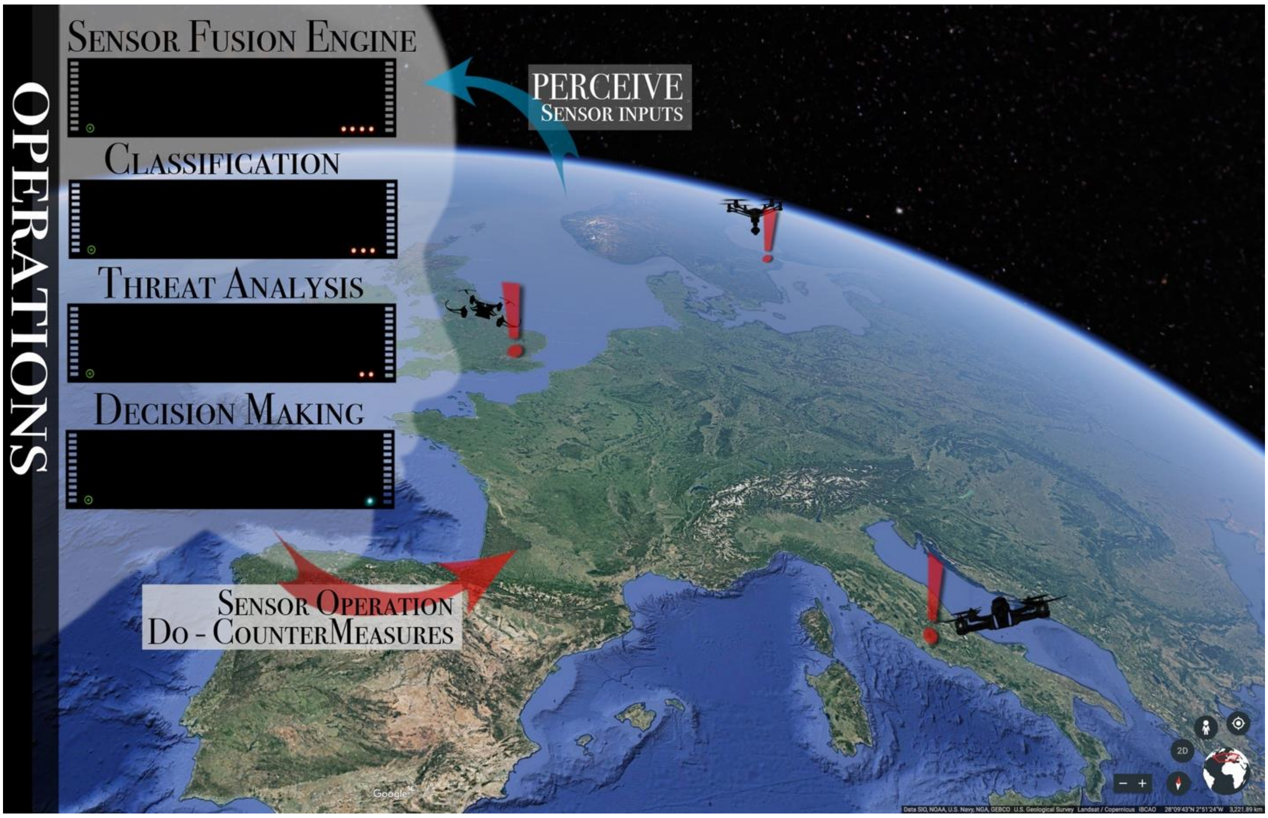


Figure 8.8 illustrates the remote operations concept.

Benefits

- *Enables goods strategic overview.*
- *Reaches civil applications that do not have possibility to operate the system.*
- *Possibility to perform qualified Do-operations remotely.*
- *Multiple nearby applications can share assets like long range sensor and countermeasures.*
- *Efficiency.*
- *Can be either local or highly remote.*
- *Centralized unit for machine learning and/or personnel experience building.*
- *Possibility to field test solution from R&D-site.*
- *Knowledge from Traffic management's remote tower product.*
- *Possibility to steer or monitor through app.*
- *Possibility to utilize a larger and wider set of assets.*
- *Highlights a strong product offering within Saab's core competence.*

Drawbacks

- *Technical development needed.*

Do

The countermeasure section in the underlying technologies chapter as well as the system overview show how the do-actions are divided into four categories. It is argued that the fourth and most aggressive category; Destroy is only applicable in some military scenarios and never in a civil application.

Jamzie

The benefits of jamming, coordinate spoofing and take-over are strong and this type of disruption technologies dominate existing or near the market C-UAS solutions. One major drawback of those technologies is that it is almost always illegal and inappropriate to perform such actions. Currents systems offer jamming at kilometers of range as it is a technically efficient way of stop the drones. However, long range jamming must amplify the signal enough to drown the operator or satellite signal and this leads to a blast ray of disruption that is likely to disturb all kinds of innocent signals, especially in a city environment as illustrated in *Figure 8.9*.

Figure 8.9 illustrates how a long range jamming equipment can disrupt untargeted wireless traffic.

As the major drawback of this disruptive method can be derived to the jamming signal strength, a drastic decrease in signal strength could solve that problem as summarized in this list:

1. *Jamming is an effective way of stopping remotely operated or satellite navigates drones.*
2. *Strong jamming signals disturb other signals.*
3. *Decreased jamming signal strength could solve that problem.*
4. *Jamming antenna must get closer to hostile drones.*
5. *Make jamming functionality a fast an agile airborne asset.*

Table 8.10 quantifies the gains of using short range jamming with a few comparisons of effect needed for different jamming distances. It is similar to the radar equation from Chapter five but this signal only goes one way which means that the effect only has a squared relation to distance. That is still enough to generate a need for very strong signals at greater range. The red fields in the table shows clearly that close jamming needs only a fraction of signal effect compared to long range jamming.

Table 8.10 compares signal jamming at different ranges.

Compared distances / Differances	Differance in distance [m]	Distance differance factor	Jamming effect
5 km vs 5 m	4995	1000 - 1	10^6-1
1 km vs 10 m	990	100 - 1	10 000 -1
500 m vs 15 m	475	33,3-1	1111-1

Jamzie (*in Figure 8.11*) is a small and agile drone with signal disruption capabilities that uses short range jamming close to target to avoid causing the mentioned troubles. The size of the aerial platform is determined by battery life which implicates range and size of jamming equipment. In comparison the existing and common DJI Phantom 4 can carry heavier payload and has longer battery life than needed here. The Jamzie should be smaller and faster in resemblance to existing toy competition drones. For more extensive jamming, multiple Jamzie drones could be used targeting the hostile drone from different directions and altitude as communication antennas to operator, cellular network and GPS satellites would use different directions for strong reception.

Jamzie uses a camera and multiple IR distance sensors to be able to lock-on to the targeted drone and enable automated obstacle avoidance capabilities demonstrated by DJI Phantom 4. Continuous feedback to operations is given through video feed and the need for local processing is limited.

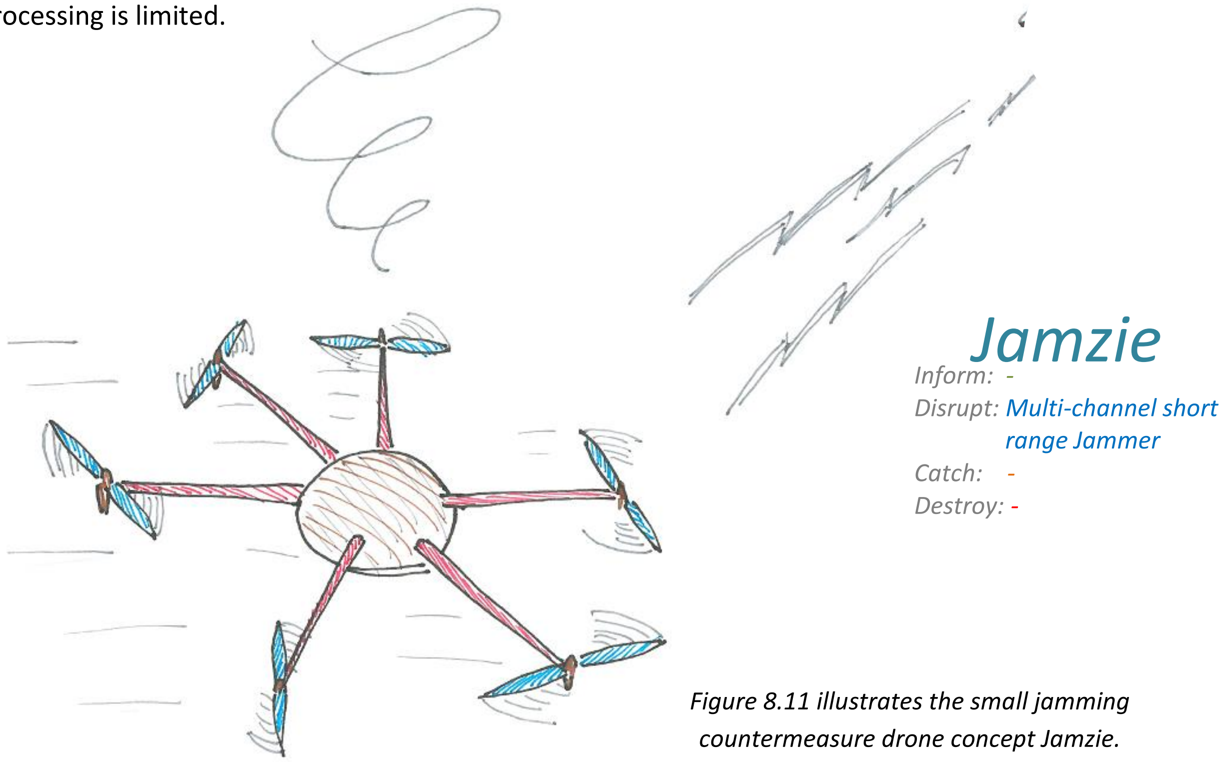


Figure 8.11 illustrates the small jamming countermeasure drone concept Jamzie.

Benefits

- *Solves the largest drawback of jammers by reducing needed jamming energy dramatically – it does not affect untargeted background signals.*
- *Small, agile and fast UAV platform allows it to target different classes of drones.*

Drawbacks

- *Smaller size UAV platform usually implies shorter range due to battery life.*
- *Jamming operator signal does not help against rogue automated drones.*
- *Coordinate spoofing does not work against spoof-proof drones; using other navigation sensor inputs, secure coordinates or spoof-proof software recognizing a spoof infection.*
- *Legality issues due to the use of jamming.*

Technology

- *Short range jammer.*
- *Robust navigation.*
- *Robust communication.*

The parasite

For good satellite reception, drone navigation antennas are direct towards the sky. This means that they to some extent can be built to withstand spoofing signals from other directions.

This nano spoof drone gets dispatched from the mothership when a hostile drone has been detected with the benefit of the mothership hovering at high altitude. The parasite attacks the hostile UAV from above (where it is less likely to have drone detecting sensors) and infects it with false satellite coordinates to send it off track. Like Jamzie, it benefits its close range capabilities to use a weak spoofing signal to avoid disturbing untargeted surrounding antennas.

Benefits

- *Works against rogue drones that rely on satellite navigation.*
- *Fast and agile.*

Drawbacks

- *Does not work against encrypted satellite navigation.*
- *Does not work against drones that navigate with environment sensors.*
- *Challenge to work against drones with spoof-safe software routines.*

Technology

- *Automation.*
- *Robust communication.*
- *Robust navigation.*

LedDrone

This is countermeasure which uses visual guidance through the use of lights in a LED grid. It can inform the operator of a drone visually through the drone video link simply like a siren or even drawing symbols like stop sign or pointing arrows. The LedDrone uses a commercial drone platform with a led grid as shown in *Figure 8.12* seen from the camera of an unknowingly trespassing drone. This countermeasure is aimed for airports where it is problematic to perform active countermeasures. When an airport already has been shut down due to drones in the control zone, the LedDrone can be used to reduce the airport lockdown by gently telling the trespassing drone to get lost.

Benefits

- *Complies with most regulation.*
- *Perceived as a very friendly countermeasure.*
- *Low cost.*
- *High potential to reduce an airport's lockdown-time in drone visit-scenarios.*

Drawbacks

- *Only works against non-hostile drone visits.*
- *Only works where there is a video feed from the trespassing drone to its operator.*

Technology

- *Automation – drone avoidance.*
- *Robust navigation.*
- *Robust communication.*
- *High potential to use commercial drone platform with add-on components.*

Figure 8.12 illustrates the LED-drone concept from a first person view of a trespassing drone.

ActionDrone

This powerful airborne asset enables all classes of countermeasure except for destruction as performing that action has been argued to be problematic in all applications. The ActionDrone is deployed from its small base which can be a rooftop or a vehicle, as illustrated in *Figure 8.13*. When reaching the intruding drone, this asset has the possibility of visually informing the drone and its operator through the use of a LED grid (like the LED-drone). As a second intensity step, the ActionDrone carries a short range jammer like Jamzie with capabilities of signal blockage, coordinate spoofing or control hijacking. If previous measures do not work against the hostile drone, the third and mechanically robust way of stopping the drone is a net-catcher-gun.

The ActionDrone uses multiple small cameras for extensive optical feedback to operations and counter-ambush capabilities. As for all concept counteraction drones, it is technically able to perform tasks automatically but is under the command of operations due to benefits of its strategic overview and continuous risk analysis as the spider in the multi asset system web.

The ActionDrone is equipped with a parachute to avoid compromising personal safety in case of malfunction or hostile drone attack.

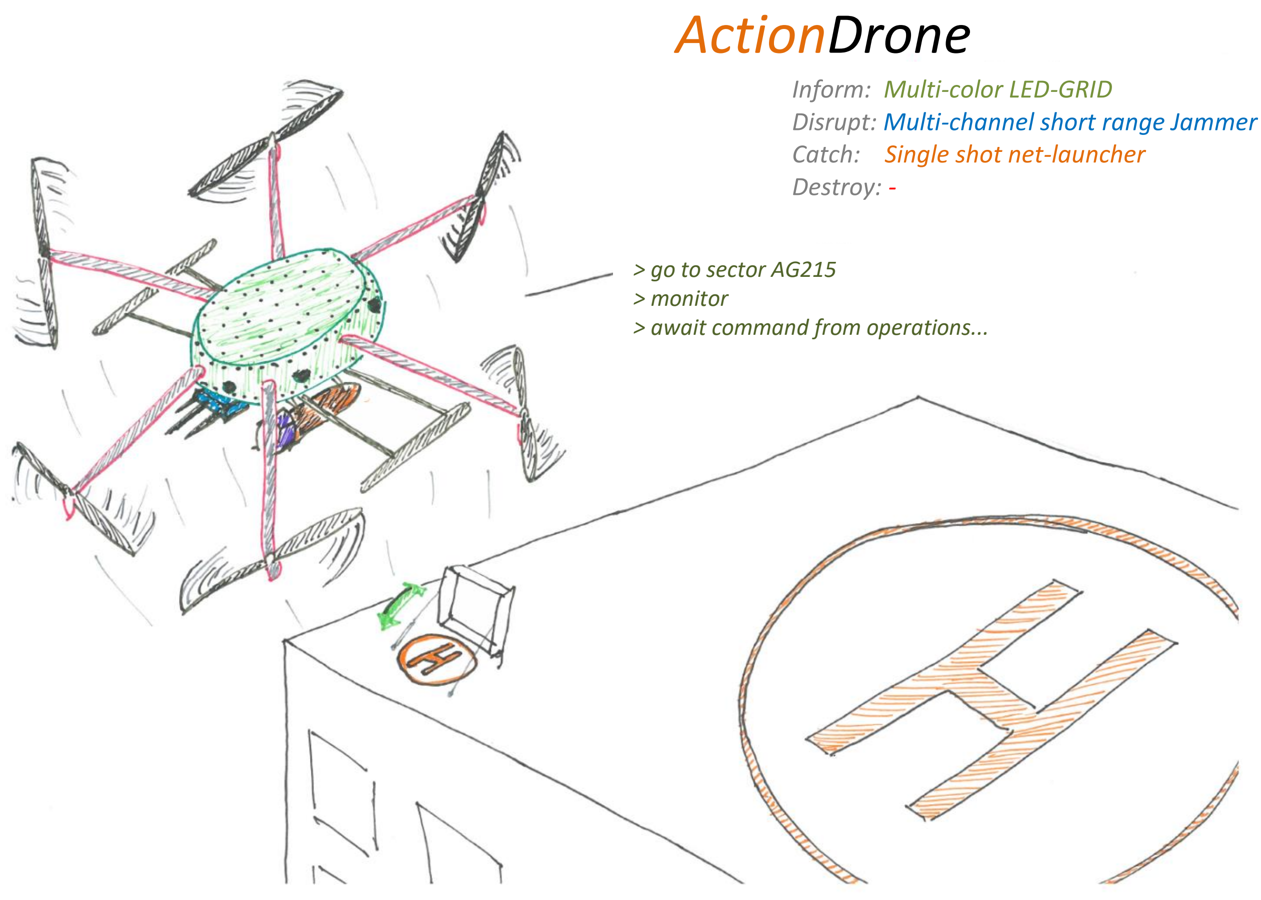


Figure 8.13 shows the conceptual ActionDrone.

Benefits

- *All benefits of Jamzie except size and speed.*
- *Holistic approach on countering drones as it includes three counteraction class capabilities.*
- *All underlying technologies exist.*
- *Very feasible to use COTS for underlying technologies.*

Drawbacks

- *It is challenging to catch a drone of equal or greater size than the ActionDrone itself.*

Technology

- *Short range jammer.*
- *Net-gun.*
- *Robust navigation.*
- *Robust communication.*
- *Parachute for personal safety.*

Net Boom Down

The Net Boom Down in *Figure 8.14* is a drone seeking small suicide drone that detonates to a large drone catching net close to target. Although it is remotely controlled by operations it uses automated features to perform both seek and catch. As catching can be seen as a semi-hostile action, the Net Boom Down needs the continuous risk analysis and decision making capabilities from operations to ensure safe functionality. Continuous video feedback is provided to operations during this suicide drone's flight.

- *Suicide drone.*
- *Automated capabilities.*
- *Use wisdom of the operations strategic capabilities to do the right thing.*
- *Use parachute to fit the catch class, avoiding the destroy-class.*

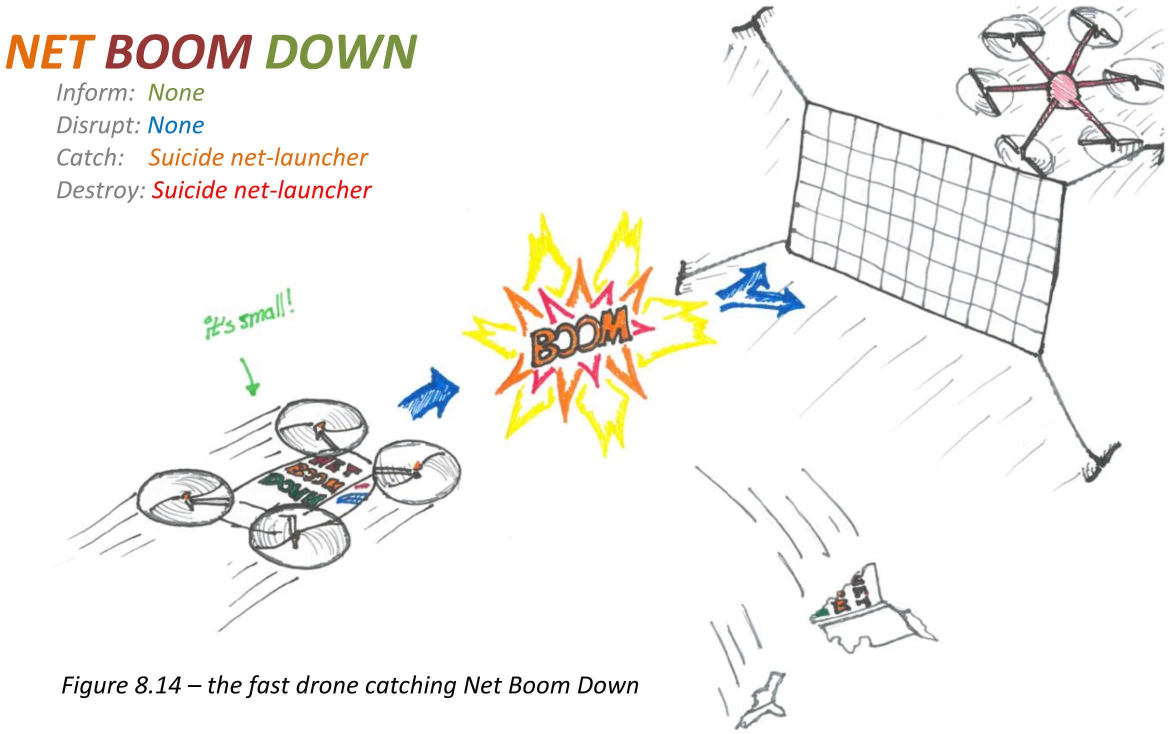


Figure 8.14 – the fast drone catching Net Boom Down

Benefits

- *Small size decreases most hostile drone's ability to see it coming.*
- *Provides optical feedback to operations.*
- *Fast and agile to catch fast drones.*

Drawbacks

- *Extensive development needed.*
- *Only one chance to get the target.*

Technology

- *Automated features.*
- *Robust navigation.*
- *Develop complete mechatronic solution*
- *Not likely to use OTS commercial UAV platforms.*

Quad squad

The Quad Squad is four multicopters joined together in a mechanical construction containing a large net and extra battery for long range. When it reaches the hostile UAV it drops part of its construction, freeing each multicopter to unfold a net to work as a landing net. Unlike The Net Boom Down the multicopters can still operate after detonation and initial drone capture and catch additional drones when needed. The net span is thereby appropriate for mechanically stopping a drone swarm. A drawing of the concept is shown in *Figure 8.15.*

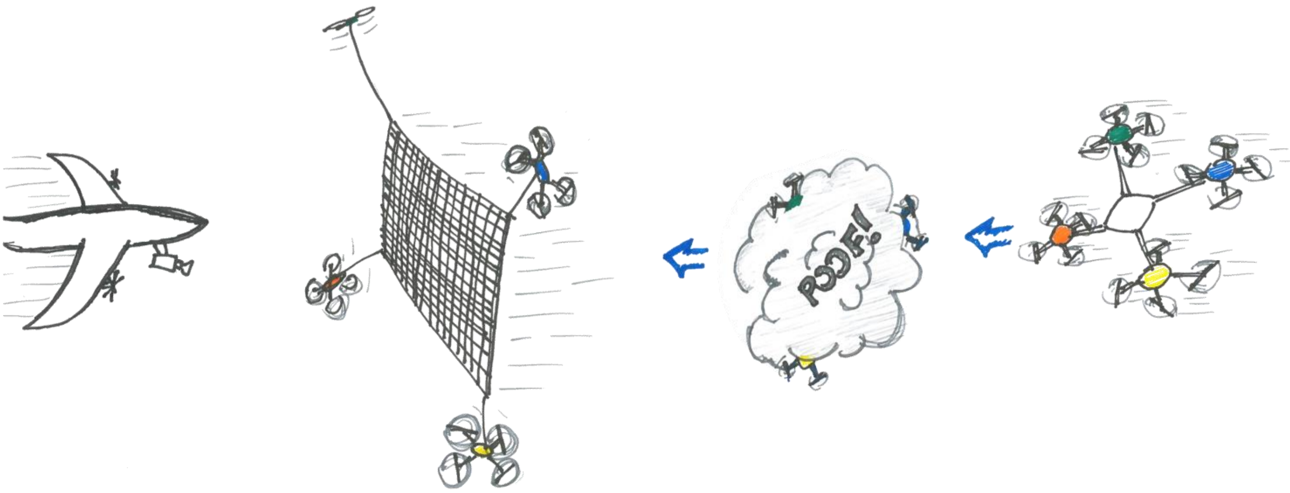


Figure 8.15 illustrates the Quad Squad in action.

Benefits

- *Robust against varying drone sizes.*
- *A large net makes it easier to catch small and agile drones.*
- *Strong mechanical solution versus drone swarms.*

Drawbacks

- *Complex mechanical solution.*
- *Complex automation capabilities including drone swarm technology.*

Technology

- *Swarm behavior.*
- *Parachute.*
- *Mechanical design.*
- *Automation.*
- *Robust communication.*
- *Robust navigation.*

9 Application Concepts

In this chapter, concept building blocks are combined to tailor systems that fit the different segment scenarios. Some scenarios overlap as the benefits of shared assets in the same geography is visualized.

9.1 Airport

Building blocks are combined to create a strong system for airports. The system uses two Long Range radar sensors of Saab G1X model. Closer to the runway and airport, the aircrafts fly at low altitude and the dynamic coverage of aircrafts, airport buildings and city environment is important. The system therefore uses additional Saab Medav Technologies RF detection sensors with shorter range to enable robust detection coverage. In the scenario of *Figure 9.1* and *Figure 9.2* (same scenario but different angle) careless hobbyists have planned to fly for 40 minutes, testing a newly purchased battery pack, unknowing that they disrupt the heave air traffic of the airport. The airport needs to shut down due to the crash risk. The airport uses the conceptual building block LED-drone to inform the operator through video link that their drone must be removed.

The range of the radar sensors in the images is ideal and simplified as the radar is a very complex sensor. The range depends especially on the size of the drone and for large aircrafts the range is more than tenfold. For strong protection at an airport, an even larger Saab Giraffe radar sensor could be suitable to ensure an even longer drone free passage for landing and descending aircrafts.

Figure 9.1 illustrates a strong multi asset counter drone system for a large airport. The part of the airport's control zone that is not covered by the system is marked with red.

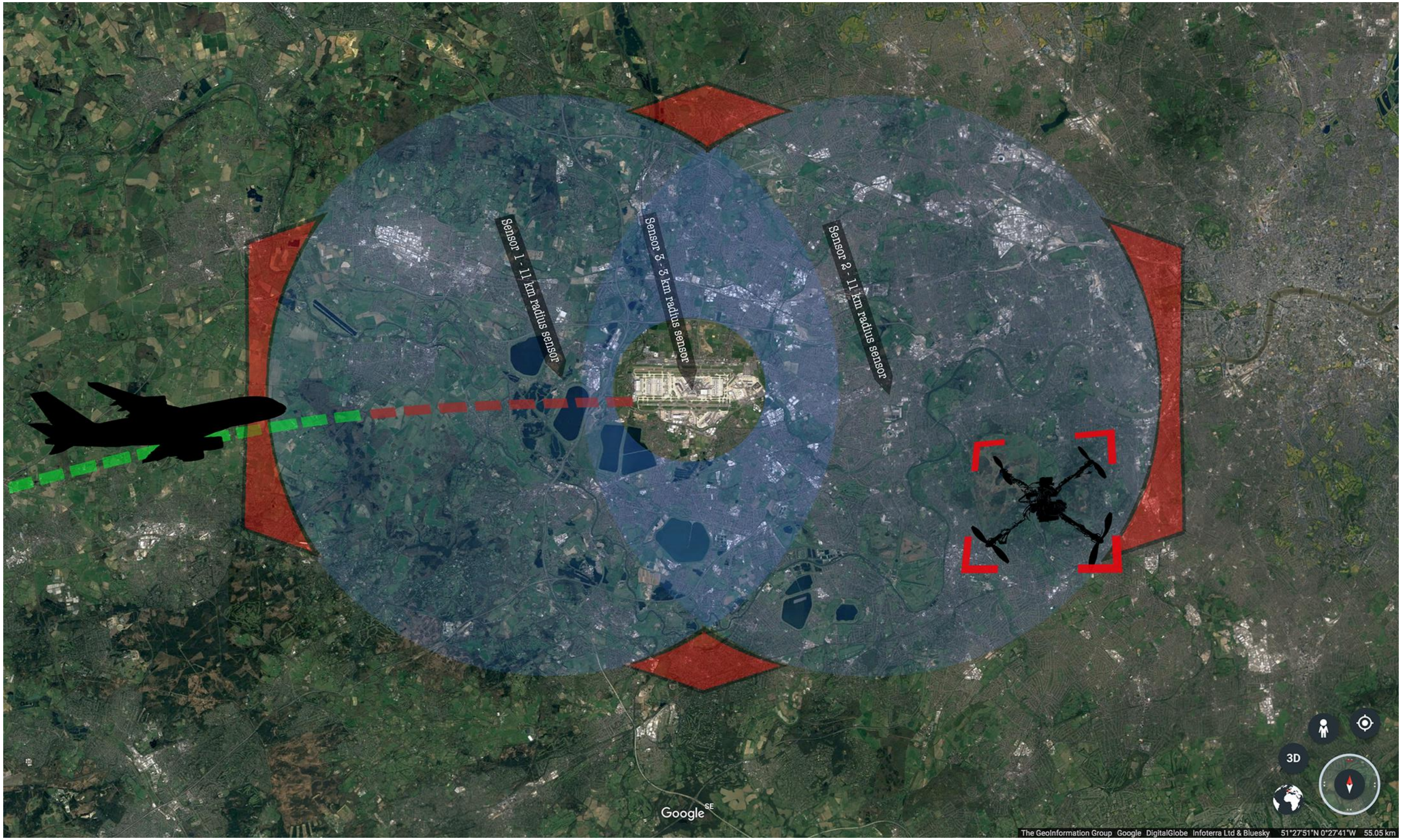
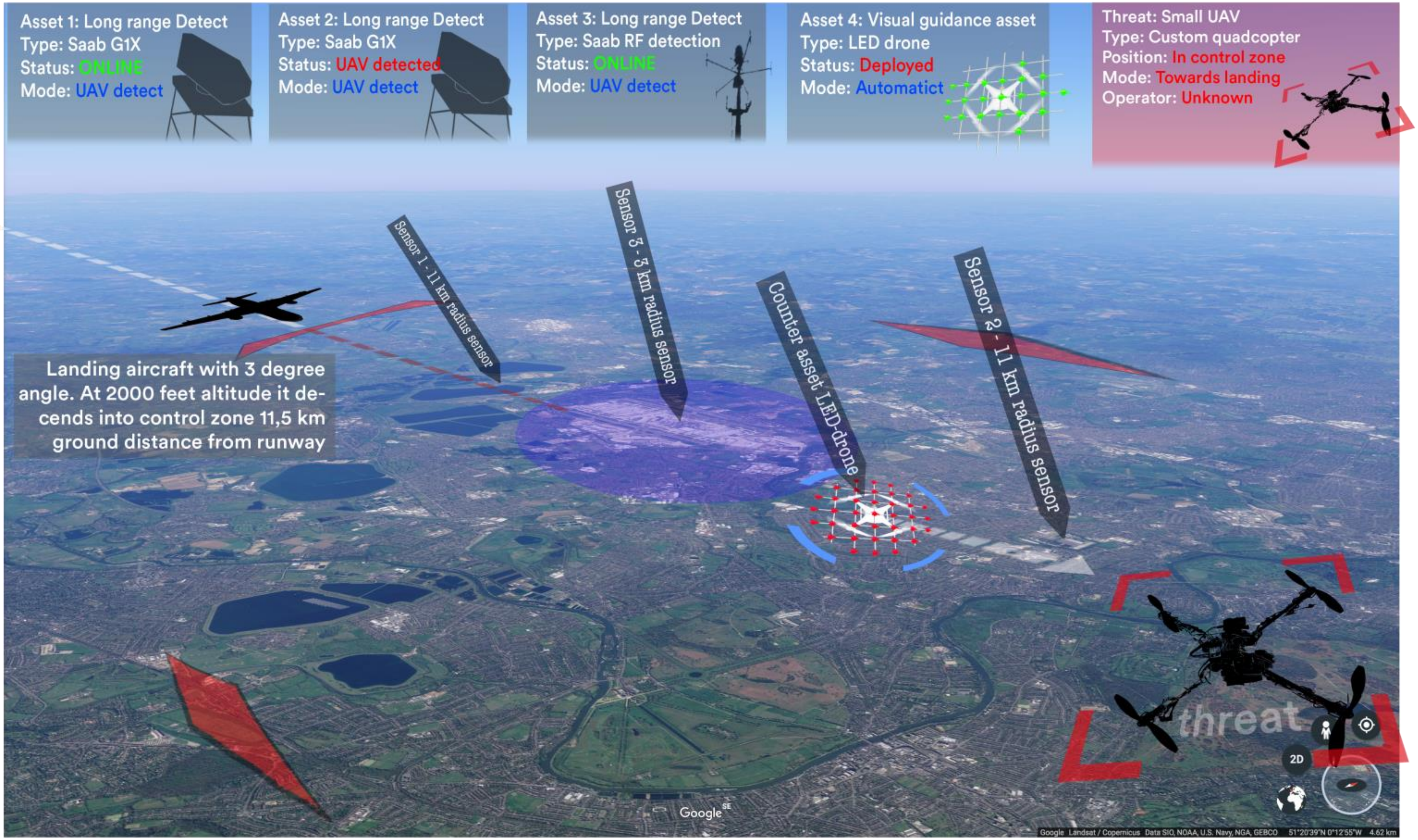


Figure 9.2 shows the same scenario as Figure 9.1 but from another wide-angle perspective with asset information and the conceptual LED-drone counter asset.



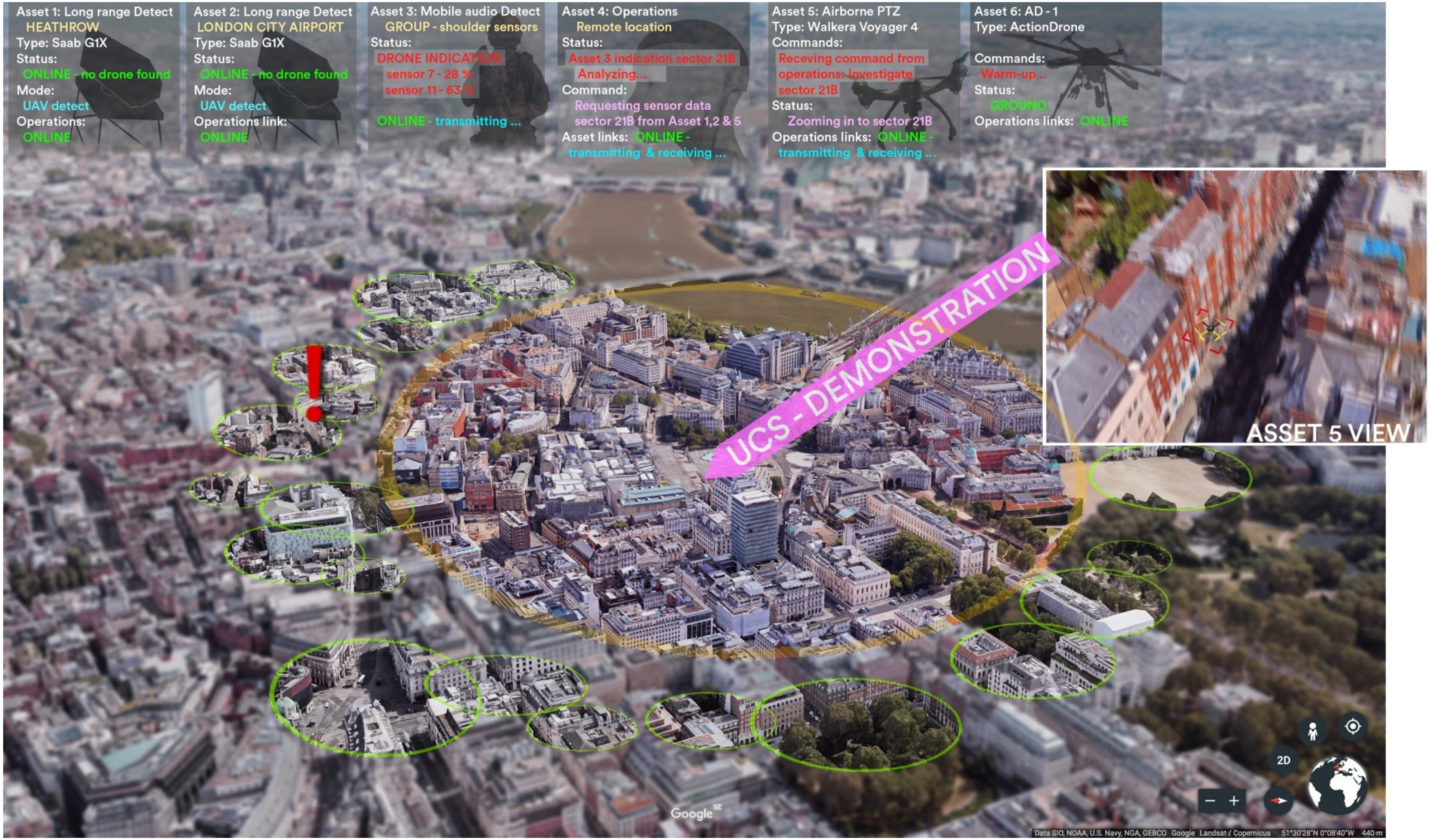
9.2 Urban crowd scenario

As this scenario has different performance needs than the airport, shorter detection range with extensive dynamic coverage is needed along with complex countermeasures as the flowchart analysis showed. In this case the temporary area in need of protection holds a demonstration with a pre-event indicated threat level. As the protected area lies between the two airports, airport drone radar sensors can be used as high performing initial detection assets in a larger system.

The scenario is illustrated in *Figure 9.3* and *Figure 9.4*. Adjacent long range airport drone radar sensors are used but in this case the trespassing and potentially dangerous drone is not detected by them. For some reason the drone flies below the height of surrounding buildings, illustrating the need of dynamic coverage. The drone is instead detected by conceptual mobile short range audio sensors (carried by security / police personnel) which can only supply a binary sensor response (Hear drone? Yes / No) along with some estimation of sound signal strength. The system implements conceptual use of a commercial PTZ-equipped inspection drone to zoom in and classify the initial alarm source. Note that an off-site operation asset controls the system. Green rings indicate audio sensor placement and coverage in *Figure 9.4.*

Figure 9.3 shows London area airports and a conceptual placement of radar sensors.

Figure 9.4 shows a closer image of the urban crowd scenario.



9.3 Prison

This scenario also takes place near the previous ones at a category A prison (which means the highest class of security) with about 900 prisoners. The object lies in range of both London City Airport's conceptually placed radar and RF detection sensors which serve as robust initial detection. Except for the same remote operations demonstrated in the UCS scenario, the same type of PTZ drone is also used, but in another way. *Figure 9.5* shows the prison and points out where the drone is placed in stand-by mode, awaiting instructions from operations in case of a hostile drone.

In this scenario a drone is identified by both radar and RF triangulation detection sensors with calculated probability scores of each sensor. There is also extensive data in terms of drone type, size, altitude and speed from the radar sensor as it is a highly competent drone detector where there is a clear line of sight. As the second figure shows, *Figure 9.6*, the probability scores (probability of identified object being a drone based on imperfect readings due to city background complexity) of the sensors are 88 % and 62 %, which together makes for a high probability score of 95,5 %, illustrating a benefit of multiple sensor inputs as:

$$1 - (1 - 0{,}88) \cdot (1 - 0{,}62) = 0.9544$$

In *Figure 9.5*, operations determine that the threat level is high and use Asset 4 to both to watch a potential contraband drop and also follow the drone back to its operator. The idea is the Asset 4 reach a high altitude before the hostile drone is close enough to see it. The hostile drone makes its drop on the prison yard while Asset 4 and use its long range optical lens to zoom in from above. In that way it can supply the guard with position information, but also gather evidence for prosecution. As the sound from Asset 4 only is heard from directly below and it flies too high to be seen, it can follow the contraband drone back to its operator for identification by flying slightly behind it while being zoomed in. In this way, the contraband drone operator would not notice Asset 4 while being identified.

Figure 9.5 presents the prison scenario, using airport sensors and remote operations.

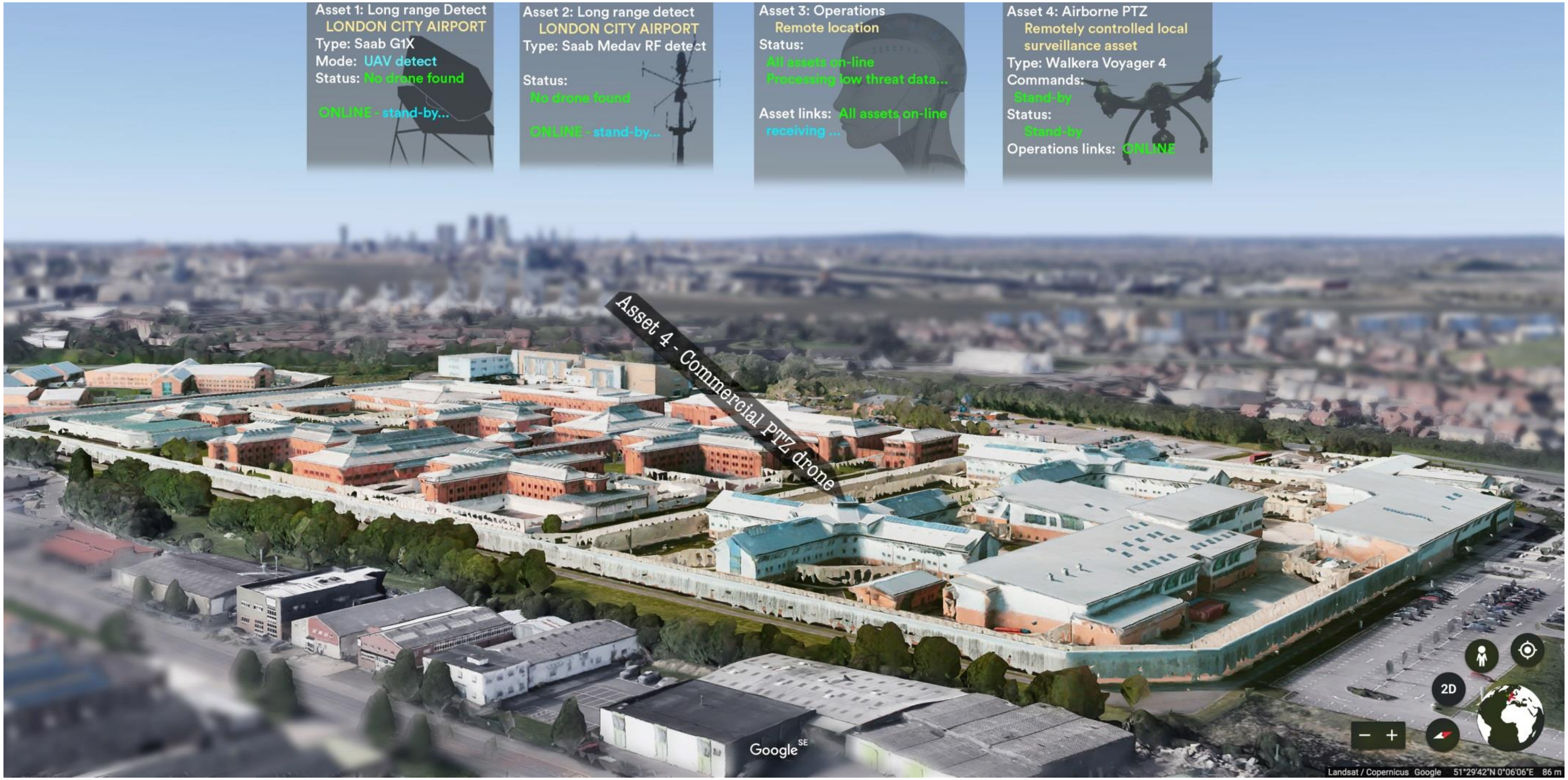


Figure 9.6 shows the prison scenario with an approaching contraband drone.

10 Next Step

This section consists of recommendations to the company on further work within the context of this study.

10.1 The way in with a Minimal Viable Product (MVP)

A MVP is a slimmed version of a product that has the core features that early adopter customers are willing to pay for. The MVP enables getting to the market early and should enable valuable feedback from a new market to guide future product development efforts from the company. The current need that airports shout out is detection only. It is motivated in this study that it will change over time, but the future detection need at an airport still fits Saab Surveillance's radar product offering very well. For now the airports' needs fits the ideal of an MVP in that it has low system complexity compared to other segments, although having a high and expensive need for long range.

In many ways the airport is the way in for Saab to a civil anti-drone market:

- *Existing Saab products more than well fits an airport drone detection system's need of long detection range.*
- *Existing competitors that aim for airports underestimate the need of detection range.*
- *Strongest purchase willingness and Pain factors among civil application customers.*
- *Airports bleed money on drone related stops that well motivates the high performance price tags that follows a high performing system.*
- *Saab already reaches airport markets with Remote Tower and SMR radars.*
- *Relatively low need of stopping the drone at airports.*

Start selling

A long range drone radar like the G1X (not only a drone radar) over even an Giraffe AMB has the potential to solve bird problems and perhaps also function like the large and costly ground SMR-radars at an airport. Adjusting the G1X or AMB to solve all needs at once is a dangerous trap that can lead to destructively delayed delivery. It is important to see that short time-to-market and fast response to customer Pain is a highly valuable attribute to have. Getting early to the market of large airports with the military type G1X enables getting the Saab brand associated with the market and being perceived as the first system that really solves the problem and thus setting the standard for that market. Adding years of development could lead to entering the market as number 15 (15^{th} solution worldwide that solves the problem) and makes for an anonymous product without the premium price available for early players. And what would be the point of reducing manufacturing cost with 30 % when the market prices drops with 40 %? In a few years the need might also change and delighter needs like bird detection could slide down to become basic attributes of an airport drone radar (KANO-model of chapter 4.5) and solving the underlying problem will become more important even for airports (this study's Needs classification of chapter 4.4).

Saab's ground radars will of course also function as very strong air traffic management radars for aircrafts.

Feedback channels – Drone detection data

Large airports often lies in cities and a long range airport drone detections sensor will likely spot a large number of drones. Getting a product out early also enables a channel to get measurement feedback, learning more about drone scenarios and different types of drones – If the system and airport allows a the necessary data stream back the manufacturer.

10.2 United efforts – Drone council

When responding to individual customers with product offerings, it is of course important to put that customer in focus and show how a system in made for their needs. But when customer Pain indications starting surfacing like rings on water, it is important to zoom out and look from above – look for pattern. The proposed system in this concept study highlights the importance of being robust for different scenarios and change over time. All similar efforts should be coordinated to some degree to ensure that the same thing or contradicting foundations are not being developed at different parts of the company.

It is therefore recommended to use a strategic drone group which keeps track of all drones and counter-drone activities within the company. This group must not be restricted within internal business areas but to work over the borders to be strong and enhance facilitate focused development efforts.

10.3 New sensors and assets

This section consists of a number of recommendations on further technical analysis and development. It is not recommended to dive head-first into development of any suggested topic, but to continue with pre-studies and technical investigations along with needs and market analysis.

Medium range radar

Looking at way of developing a smaller and cheaper radar sensor was the original idea of this concept study and still has attractive features for all scenarios of this study except airports. It would outperform most other sensors in many performance aspects (not all). To move further with that idea, a pre-study focusing on that sensor for external opportunities (technologies and applications/markets) and threats compared against internal strengths and weaknesses would be needed to motivate development.

Audio sensor

Due to short range and sensitivity to wind and future silent drones, this sensor type is considered to have its best potential as a low cost (very short range) sensor. Even with the problem of silent drones in mind, looking after drones below build roof line is so problematic that audio sensors cannot be ignored. Looking into how cheap, mobile audio sensors could be developed could be interesting – like the conceptual single audio sensor building block.

EO sensor

EO sensors are already found at different parts of the company. A future study of all current EO sensors alongside with future ones and benchmark potential in different use cases would be very interesting as this sensor type in many ways naturally complements a radar sensor. The study should not only focus at the camera technology, but also algorithms and hardware technology used to perform initial detection, classification, and tracking.

Ride the wave - Implementing commercial 3rd party drones

Hooking on to the disruptive force of commercial drone technology development would need testing for example commercial long zoom drones in different scenarios as their potential is demonstrated in this study. 3rd party drones must not be sold from the company to play a vital part in a solution. Knowledge of how they can be implemented strengthens the value of large radar sensors and operational assets which are main products to sell. The Support and Services branch of Saab also has the potential to provide the drones in such systems if it should be considered profitable.

Modular robust Drone development

For drone development at the company, a number of features are common for all concept drones and should be developed as modular parts that fit all drones.

- ***Robust navigation**: Automated capabilities that enable high performance navigation.*
- ***Additional sensors for navigation**: For example ultrasonic distance sensors, laser distance sensor, optical navigations sensors and gyro sensors.*
- ***Robust communication**: Securing a robust link to operations that can transmit necessary sensor and operational data.*
- ***Personal safety**: This can be done by for example protecting the rotor blades with cages, light material body and parachutes.*
- ***Weather durability**: Rain & wind.*

For countermeasure drones that benefit from being close to the target drone, it would be beneficial to use data from the drone detection sensors (like ground radars) to increase precision with multiple sensor inputs. This of course also relies on a centralized operations asset with building blocks from the Modular Multi Asset System overview in *Figure 8.1.*

Looking at the extensive list of drone features that is required, using a professional drone platform like the Japanese ProDrone and add modular functionality looks attractive as it massively decreases development efforts.

10.4 Operations product

In future complex scenarios, also outside of drone detection, the need for robust building block implementations of the operations section in *Figure 8.1* will also be needed. A market for operational capabilities will likely grow (possibly in the name of Digitalization) and the capabilities within the company to provide those products are strong. A number of operational product applications exist in the company's product offering but defining them as an own branch of products could strengthen their value and harvest long term benefits of modularity.

The need of a product like this is clear when it comes to a modular multi asset system like a civil application drone detection system.

10.5 Continuous needs analysis

It has been motivated in this study that the key to getting a strong market position is to understand the customer needs better than competitors and all outside factors that change as we go into the future (*Figure 6.2*). Continuous studies for new markets and extensive needs analysis is needed to sail in the right direction for a strong future product portfolio.

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