In-Depth Analysis:

Norwegian Police Drone Search Techniques in SAR Operations

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Introduction

In 2022, following a trial period that commenced in 2019, the Norwegian police officially adopted the use of rotor based unmanned aerial systems (UAS), also known as drones, on a national scale. This necessitated systematization of drone usage to ensure their effective deployment across a diverse range of tasks, including search and rescue (SAR) operations. The Norwegian Joint Rescue Coordination Centre (JRCC) is responsible for leading all SAR operations, delegating local authority to the respective police district. The police districts manage the practical leadership and coordination of all search resources, including drones.

Early on, it became apparent that drones would introduce a novel SAR capability, previously inaccessible to the police force apart from the use of manned helicopters. However, initially unclear were the specific techniques and methods to optimize the probability of detection (POD) when employing drones as search tools. Additionally, an analysis of the trial period revealed that while drones were frequently used in SAR operations, they had a relatively low success rate in locating missing subjects.

Against this backdrop, the Norwegian Police Unmanned Air Support Unit (NPUAS) devised a set of search techniques aimed at achieving two primary objectives: To enhance the POD during drone searching and to harmonize these techniques with the established search methodology as outlined by the “bike wheel model” for SAR operations. The subsequent paper is designed to disseminate knowledge pertaining to these search techniques.

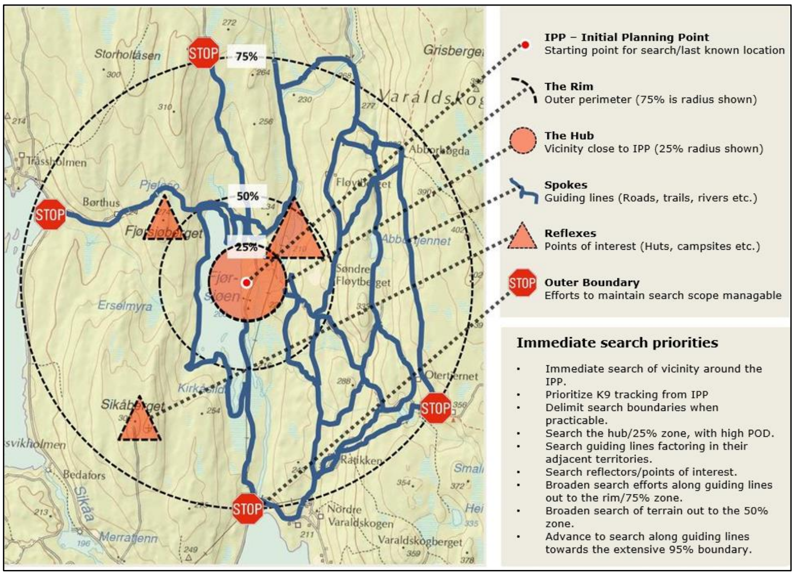
The rationale behind the search techniques is based on the understanding that successful person detection relies on two critical factors: an unobstructed line of sight between the missing individual and the sensor, and enough color or thermal pixel information in the image to discern a find. Additionally, the time factor becomes imperative when human lives and well-being are potentially at risk. The effectiveness of drone-based searches depends on how much area can be examined at an adequate image resolution within a specific time period. Practically speaking, this necessitates specifications related to the gimbal angle, field of view (FOV), flight altitude, search patterns and flight speed.

It is noteworthy that these search techniques were integrated into the educational program before the nationwide expansion. Within the first year of the nationwide drone service, the NPUAS noted a significant increase in successful locations of missing persons during SAR operations compared to the trail period.

Search and Rescue Methodology – the Bike Wheel Model

Modern SAR operations often rely on data from the International Search and Rescue Incident Database (ISRID), which contains analyses of over 50.000 SAR incidents worldwide (dbS Productions, 2023). This database is a crucial resource for understanding common patterns and factors that affect SAR operations. Data indicate that different groups of missing individuals often exhibit similar behaviors when lost, with factors such as age, mental state, physical fitness, and activity type playing a role in shaping these behaviors (Koester, 2008).

Insights from the ISRID have led to the development of a methodology known as the Bike Wheel Model (Koester, 2008). The model has been adopted by the Norwegian JRCC and is described in the “National Guideline for Rescue Operations in Searches for Missing Persons on Land” (JRCC, 2022). The Bike Wheel Model is named for its visual similarity to a bike wheel when its components are plotted on a map. Essentially, the map serves as a probability map, indicating where a lost individual is statistically most likely to be found. With this model, SAR operations can employ a data-driven approach to efficiently allocate resources and expedite the search process.



Immediate search priorities

- Immediate search of vicinity around the IPP.
- Prioritize K9 tracking from IPP
- Delimit search boundaries when practicable.
- Search the hub/25% zone, with high POD.
- Search guiding lines factoring in their adjacent territories.
- Search reflectors/points of interest.
- Broaden search efforts along guiding lines out to the rim/75% zone.
- Broaden search of terrain out to the 50% zone.
- Advance to search along guiding lines towards the extensive 95% boundary.

Figure 1: Example of the bike wheel model as used by Norwegian Search and Rescue personnel.

The elements shown on the bike wheel model are:

- *Initial Planning Point (IPP)*: This refers to the last known position or the starting point of the search – positioned at the center of the wheel.
- *Hub*: This encompasses the immediate vicinity around the IPP, typically limited to the radius where 25% of the missing individuals in the pertinent category are found.
- *Spokes*: These symbolize guiding lines or routes, such as paths, roads, or streams.
- *Reflectors*: Specific points of interest, including campsites, cabins, fireplaces and more.

- *Rim*: This signifies the outer boundary, generally set at the statistical radius where 75% of the missing individuals in the pertinent category are located.
- *Outer Perimeter*: This defines the boundaries or constraints of the search area, an effort to ensure the search scope remains manageable.

Conducting a SAR operation according to the bike wheel model requires an orderly approach to examine areas assigned by a search coordinator, focusing on the elements outlined above. Data from the ISRID suggests that missing individuals are predominantly located closer to the Initial Planning Point (IPP), in conjunction with guiding lines, or near Points of Interest (POI). In the context of a Norwegian Search and Rescue (SAR) operation, the ensuing steps are typically prioritized:

1. Perform a rapid and precise search of the immediate vicinity around the IPP.
2. Mobilize K9 units for scent tracking from the IPP.
3. Define outer search perimeters when possible.
4. Search the area within the hub / 25% zone, aiming for a high Probability of Detection (POD).
5. Search along along guiding lines, factoring in their adjacent territories.
6. Search areas surrounding all identified reflectors or points of interest.
7. Broaden search efforts along guiding lines out to the rim / 75% zone.
8. Broaden search of terrain out to the 50% zone.
9. Advance to search along guiding lines towards the extensive 95% boundary.

However, case-specific intelligence information can always lead to changes in priorities or search strategies. The bike wheel methodology model served as the foundation for the development of the search techniques.

Preliminary Area Scan

Before starting a structured drone search pattern to thoroughly investigate an area, it’s advisable to perform a swift initial scan of the area using a thermal sensor and a video sensor if applicable. It is often effective to ascend to an elevated vantage point within the limitations of flight altitude regulations and simply rotate the drone around its yaw axis while panning the camera up and down to observe the area that will later undergo a detailed examination. This method is very time efficient and has the potential to locate missing subjects that might be located in open areas or visible from this overview point. An initial scan of the entire search area might also aid the drone pilot in planning the execution of the detailed search. If this method does not yield beneficial results, little time has been wasted, and a detailed systematic search based on subsequent principles can start:

Camera Sensor Selection

Several camera sensor technologies are applicable for search and rescue (SAR) applications. Prominent among these are the RGB (Visible light) sensors, low-light RGB sensors, and thermal sensors. Some drones can incorporate searchlights to illuminate an area to enhance visibility. This paper does not address light detection and ranging (LIDAR) sensors or different types of radio frequency (RF) receivers.

RGB sensors: These sensors emulate human vision by capturing a spectrum of colors. Their capability relies on color differentiation, contrast, and shape variations to pinpoint objects. However, practical tests and operations have revealed challenges in manually locating missing individuals in terrain. For instance, colors may not be as distinct as anticipated due to shadows, contrast variations, or environmental conditions. Yet, RGB cameras remain a valuable tool for locating missing individuals, despite the inherent limitations. When paired with a thermal sensor, the RGB sensor is adept at validating or further analyzing thermal signatures to assess their significance.

Low-light RGB sensors: These sensors maintain image clarity even in suboptimal lighting conditions, facilitating color observation when ambient light is minimal or augmented by external sources.

Thermal sensors: These sensors detect thermal radiation from objects. They differentiate between varying degrees of heat but do not provide color data. While not relying on visible light, the thermal sensor operates effectively in both darkness and daylight. The defining parameter of the thermal signature is the object's surface temperature. While the internal core temperature of the human body typically remains within a narrow range of ± 2°C (± 3.5°F) (Jessen, C., 2001), the temperature of exposed skin can vary widely from 0°C to 38°C (32°F to 100°F) (Xu, Karis, Buller et al., 2013; Jones et al., 2023), depending on climatic conditions, clothing, and the individual's level of activity. The temperature of clothing surfaces can also diverge widely, depending on insulation properties and ambient temperatures. For a thermal image to clearly reveal a human's heat signature, there should be a notable temperature difference between the surface of the persons skin or their clothing and their environment. When this is the case, thermal sensors are well suited for locating individuals who might otherwise remain visually undetectable.

Conversely, when the environment and the missing subject are at similar temperatures, detection becomes challenging. Considerations of the expected temperature of the individual are crucial. For instance, the core and surface temperature of a deceased person will eventually equilibrate with the ambient temperature, complicating detection. Additionally, insulative materials like heavy clothing, sleeping bags, or other survival shelters can significantly diminish a person's heat signature.

Another noticeable challenge are cool nights following a warm sunny day. These circumstances often result in a cluttered thermal image as remaining heat accumulated in dense materials such as rocks and trees are released, contrasting the cooler surroundings.

In conclusion, the thermal sensor is preferable for SAR operations when environmental and expected body temperatures facilitate distinct detection. If these temperatures are too similar, an RGB sensor, possibly supplemented by an LED searchlight, is more effective. Within the Norwegian climate, thermal sensors are primarily preferred for SAR operations, as the weather conditions often provide distinct thermal contrasts throughout much of the year.

Optimal Gimbal Angle to Enhance Clear Line of Sight Probability

Having an unobstructed line of sight entails that there are no barriers to the transmission of visible light or thermal radiation to the camera's image sensor. In practical terms, this can refer to terrain features, built structures, and vegetation that may exist between the missing person and the sensor. The unpredictable nature of such obstacles complicates the situation. Certain barriers permit successful detection via a vertical perspective (for instance, if the missing person is sitting behind a boulder or a shed), while others necessitate an oblique viewing angle for successful detection (for instance, if the person is under a tree). Consequently, prescribing one single optimal viewing angle becomes impractical. Given this context, the focus should shift toward maximizing the range of viewing angles aimed at a specific ground point.

To account for this, a good option is to configure the camera gimbal such that the lower section of the image displays a vertical downward view, while the upper section captures as gradual a viewing angle as permitted by the vertical field of view (vFOV).

Measurements indicate that thermal sensors on the most widely used enterprise drones per 2023, such as the DJI Mavic 3T, Matrice 30T, and Matrice 300 with H20T/N sensors are compatible with a gimbal angle of 75 degrees across the different sensors due to minimal variations in their horizontal and vertical fields of view. At a 75-degree gimbal angle, the lower part of the camera image will point very close to 90 degrees downward, while the upper portion will have an approximate 60-degree forward view. As the drone traverses the terrain with this camera gimbal setting, every point within the visual field will be observed at all angles ranging from a 60-degree oblique to a 90-degree vertical.

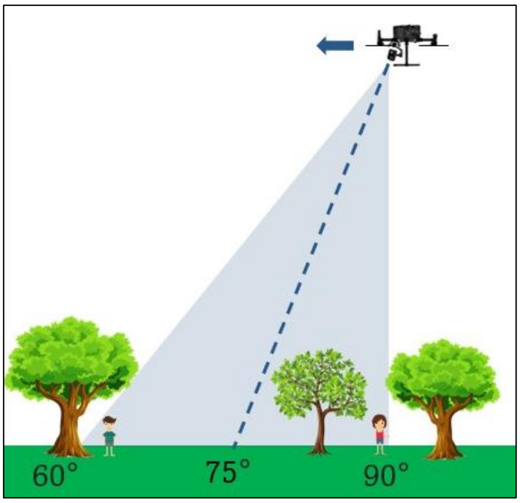


Figure 2: Illustrating the variety of viewing angles achievable with a gimbal angle of 75°.

However, when conducting an aerial search using the indicated 75-degree gimbal angle, the terrain is observed from a singular celestial direction. If not accounted for, subjects may remain undetected on the opposite side of barriers during the flight, such as behind a tree, beneath a canopy. Consequently, it's imperative to pair the camera's gimbal angle with a strategic search pattern. This approach ensures oblique viewing angles from multiple celestial directions, increasing the chance of detecting subjects who might have been missed on the initial passage.

Flight Altitude

Flight altitude directly corresponds with the ground area that can be covered with a given field of view (FOV). Flying at an excessively high altitude can result in elements of interest becoming too minuscule to detect on the Ground Control Station (GCS) screen, or one may encounter limitations in the sensor's resolution and its ability to discern fine details.

This is particularly true for thermal sensors, which typically have a much lower resolution than traditional image sensors. Therefore, determining an appropriate flight altitude requires considering the sensor's capacity, the GCS screen's resolution, and the drone pilot's ability to manually identify elements. A secondary consequence of flight altitude relates to efficiency: a lower altitude increases the effective resolution, but the smaller visual footprint inevitably leads to increased time needed to cover a specified area.

Practical testing has shown that a thermal sensor at a 75-degree gimbal angle from a flight altitude of 100m (330 ft) above ground level (AGL) serves as a good starting point. This setup works well when the thermal sensor has a 30 to 40-degree horizontal field of view (hFOV) and a resolution of minimum 640x512 pixels. As of 2023, these specifications align well with most drone-mounted thermal sensors available in the market, effectively balancing the likelihood of human detection with time efficiency.

Regarding ground sampling distance (GSD) for this setup, it is approximately 9 cm (3.5 inches) per pixel. This translates to a person's shoulder width typically spanning 5 to 6 pixels on a 640-pixel wide image, while an adult lying on the ground will measure between 18 to 22 pixels in height.

Utilizing a gimbal angle of 75 degrees and a flight altitude of 100m AGL (330 ft), the ground's visual footprint forms a trapezoid. For a sensor displaying a 33-degree hFOV, its dimensions approximate a 60m (200ft) width at the image's lower part, a height of 60m (200ft) from bottom to top, and a 70m (230ft) width at the image's top. Slight variations apply according to differences in sensor FOV across models. With these dimensions in mind, the coverage width is set at 60m (200ft) since this represents the narrowest section of the visual footprint when moving forward across an area. The broader coverage at the top of the trapezoid is considered a beneficial overlap.

The thermal sensor has been instrumental in shaping the search techniques, as the thermal sensor has unique capabilities in locating human heat signatures. However, these techniques can also be adapted for use with a conventional camera sensor, provided the zoom level or flight altitude is modified to match the desired visual footprint.

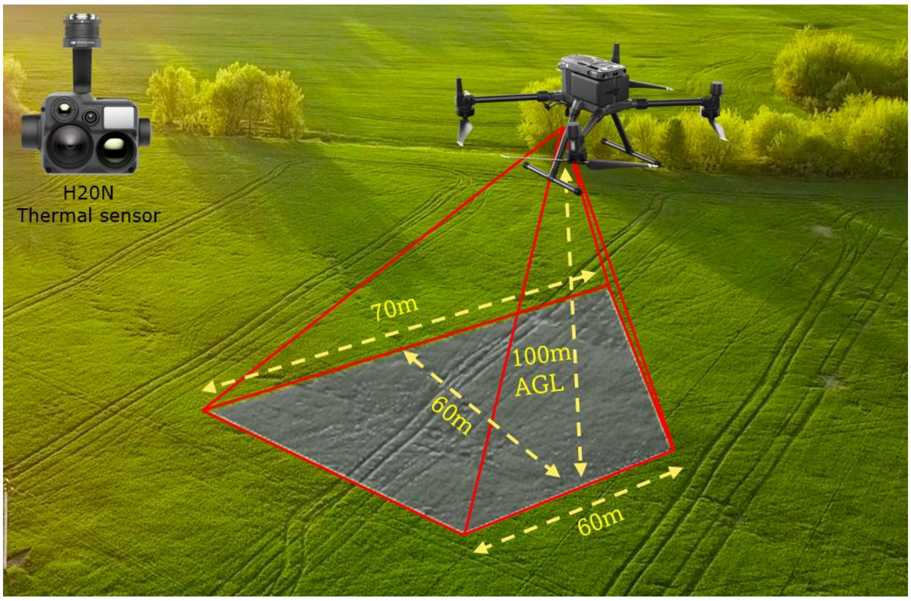


Figure 3: The visual footprint from a 33° hFOV sensor using a 75° gimbal angle at a flight altitude of 100m AGL

Flight Speed and Visual Searching Techniques

Flight speed has proved difficult to standardize due to the multitude of variables affecting the ease of detection. Difficult thermal conditions and dense vegetation normally increases the time required to manually analyze the video image, as the human thermal signature might be partially concealed or less prominent.

The dynamic change in viewing angles of the ground, as it progresses across the Ground Control Station (GCS) screen, underlines the importance of consistently monitoring the entire display. A study on eye movements during drone SAR operations found that untrained drone pilots direct their visual attention to the upper center of the GCS screen, leaving the sides and bottom of the screen less observed (Vollan, Nyås, Saunderson, 2020). This occurs even though the missing subject could appear anywhere within the frame. This finding highlights the importance of systematically scanning the entire screen, including all edges and corners, to ensure all elements within the camera's view are observed. Additionally, the need to repeatedly scan sections of the ground as they cross the screen suggests that the drone's flight speed should be calibrated to allow thorough observation.

Tests indicate that a flight speed of 2 to 5 m/s (4 to 11 mph), adjusted for vegetation density and thermal conditions, is a good starting point.

Search Patterns

A gimbal angle optimized to 75-degrees and a flight altitude of 100m AGL, need to be paired with a suitable search pattern. The necessity to traverse an area from multiple celestial directions depends on the terrain's characteristics and the density of obstructions. Relatively open areas can typically be covered satisfactory with one or two passes, while areas with medium to dense vegetation would benefit from two to four complimentary passes.

Based on the elements of the bike wheel model and assuming a 75-degree gimbal angle and a flight altitude of 100 m AGL, six distinct search patterns have been defined. These patterns are abbreviated based on their intended applications and are numbered according to the count of overlapping celestial directions they complement.

GLS1: Guiding Line Search 1 *(Norwegian: Ledelinjesøk, LS1)*

- Performed at 100m (330 ft) AGL flight altitude and with a 75-degree gimbal angle.
- Used to search a guiding line (roads, trails, creeks) and flanks out to approximately 60 m (200 ft) out on each side.
- The GLS1 (single-pass version) is executed rapidly, but it only covers flanks in one singular direction. It is most effective in open terrain.
- Manually executed by flying parallel to the guiding line, ensuring the guiding line remains visible in the GCS screen's lower corner. After covering both the guiding line and one flank, the drone pilot transitions to the opposite side, covering the guiding line and its adjacent flank on the return.

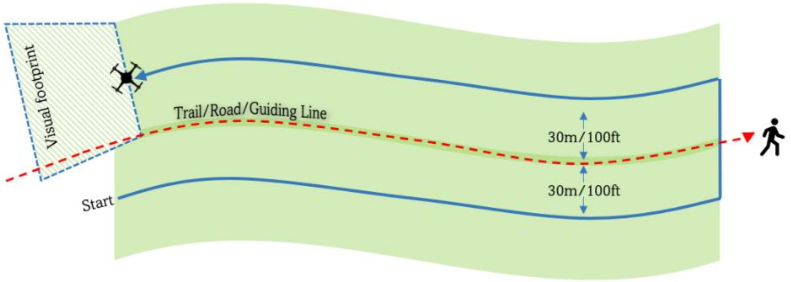


Figure 4: Illustration of the Guiding Line Search 1 (GLS1) search pattern.

GLS2: Guiding Line Search 2 *(Norwegian: Ledelinjesøk, LS2)*

- Performed at 100m (330 ft) AGL flight altitude and with a 75-degree gimbal angle.
- Used to search a guiding line (roads, trails, creeks) and flanks out to approximately 60 m (200 ft) out on each side.
- The GLS2 (dual pass version) is more time consuming than GLS1, but at the benefit of covering flanks from two opposite directions, increasing POD when obstructions are present.
- Manually executed by flying parallel to the guiding line, ensuring the guiding line remains visible in the GCS screen's lower corner. After covering one full GLS1 pattern, the search is performed once more in the opposite direction, ensuring both flanks are searched from opposite directions.

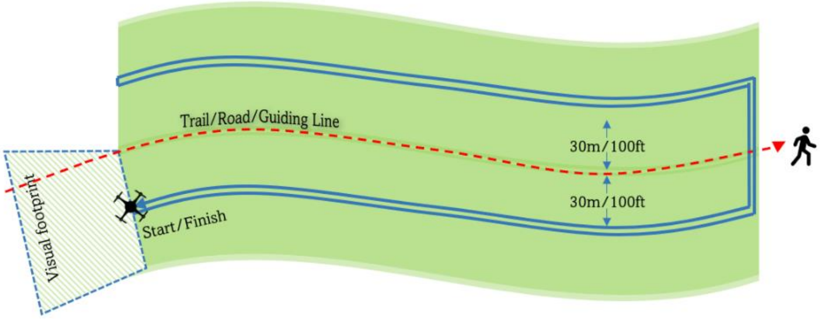


Figure 5: Illustration of the Guiding Line Search 2 (GLS2) search pattern

SS3 – Sector Search (3) *(Norwegian: Sektorsøk, SS3)*

- Performed at 100m (330 ft) AGL flight altitude and with a 75-degree gimbal angle.
- This triple-direction pattern is used to perform a high-POD rapid search around a point of interest (POI)/reflector.
- Takes approximately 3-4 minutes to complete at 3 m/s flight speed.
- Area within 60m (200 ft) radius is covered from at least 3 complimentary celestial directions, resulting in high POD.
- Area outside the radius (Out to approximately 100m radius) will also be searched, however not with the same systematic directional overlap, and is considered a bonus coverage.
- The pattern is intricate to execute manually by intuition; there is need for specialized training or automation to perform effectively.
- To manually execute, place a map marker at the center to gauge distance. Begin at the marker flying the first leg in the 0° (North) direction. After traveling 60m (200 ft), make a 120° right turn (now facing 120°). Fly another 60m (200 ft) (note: the distance to the marker will first decrease, then increase to show 60m (200 ft) when the second leg is completed). Then, turn by 120° (now facing 240°) and fly 60m (200 ft) to return to the marker. To create the "inverted star" pattern, repeat this triangle formation: once starting in the 240° direction, and then lastly in the 120° direction. *Note that all turns are 120° right hand turns, and all legs are 60 m (200 ft) serving as a mnemonic*.

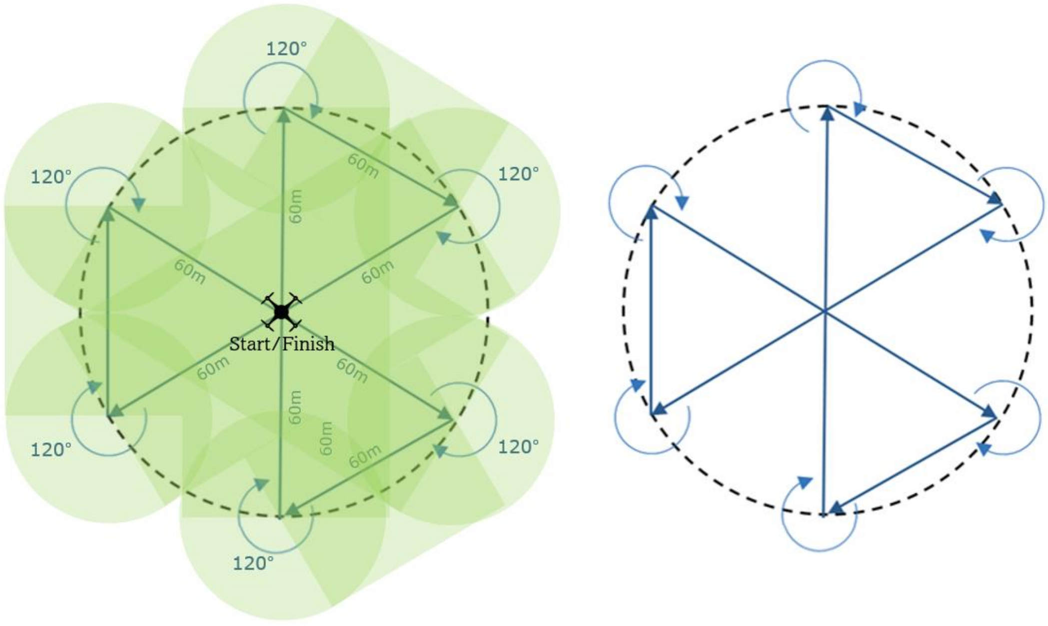


Figure 6: Illustration of the Sector Search 3 (SS3) search pattern

PS1: Parallel Search (1) *(Norwegian: Parallelsøk, PS1)*

- Performed at 100m (330 ft) AGL flight altitude and with a 75-degree gimbal angle.
- Standard grid search pattern covering an area with parallel flights back and forth; the single pass version has 50m spacing between paths ensuring a 10m overlap to avoid missed areas.
- Best suited for open terrains due to its singular passing direction.
- Both leg length and number of runs are adjustable to accommodate any area size and shape.
- Available as a standard flight pattern in the flight route planning function of most drone systems.

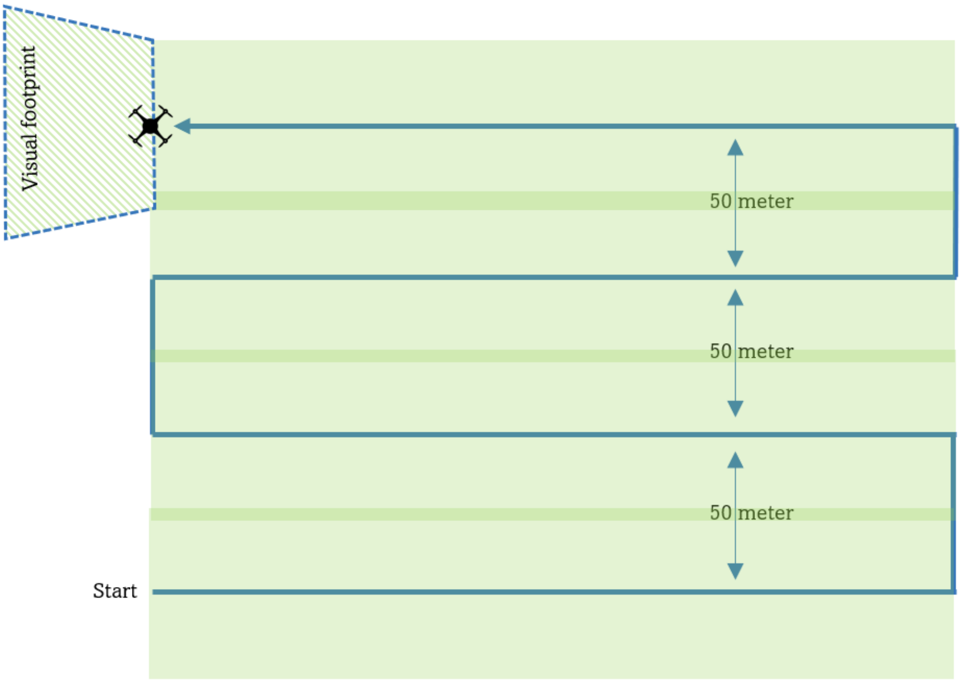


Figure 7: Illustration of the Parallel Search 1 (PS1) search pattern.

PS2: Parallel Search 2 *(Norwegian: Parallelsøk, PS2)*

- Performed at 100m (330 ft) AGL flight altitude and with a 75-degree gimbal angle.
- Standard grid search pattern with parallel flights back and forth; the double pass version incorporates opposite traversals of the entire area, enhancing the Probability of Detection (POD).
- Dual pass ensures 50% overlap per leg for double coverage.
- Ideal for areas with medium to dense vegetation due to its multiple passing directions.
- Both leg length and number of runs are adjustable to accommodate any area size and shape.
- Available as a standard flight pattern in the flight route planning function of most drone systems.

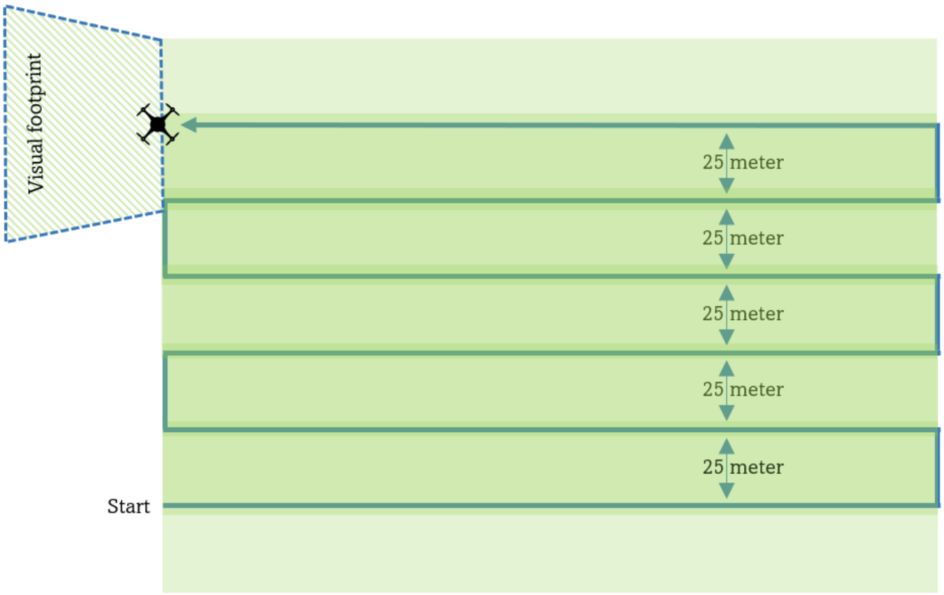


Figure 8: Illustration of the Parallel Search 2 (PS2) search pattern

PS4: Parallel Search 4 *(Norwegian: Parallelsøk, PS4)*

- Performed at 100m (330 ft) AGL flight altitude and with a 75-degree gimbal angle.
- A fusion of two PS2 patterns executed perpendicularly.
- High POD due to four complimentary traversals.
- Carried out as two intersecting PS2 grid patterns, each with a 50% overlap per leg, ensuring fourfold coverage of entire area.
- Suitable for dense vegetated areas or when the POD requirement is stringent.
- Demands more time, especially over large regions.
- Both leg length and number of runs are adjustable to accommodate any area size and shape.
- Available as a standard flight pattern in the flight route planning function of most drone systems.

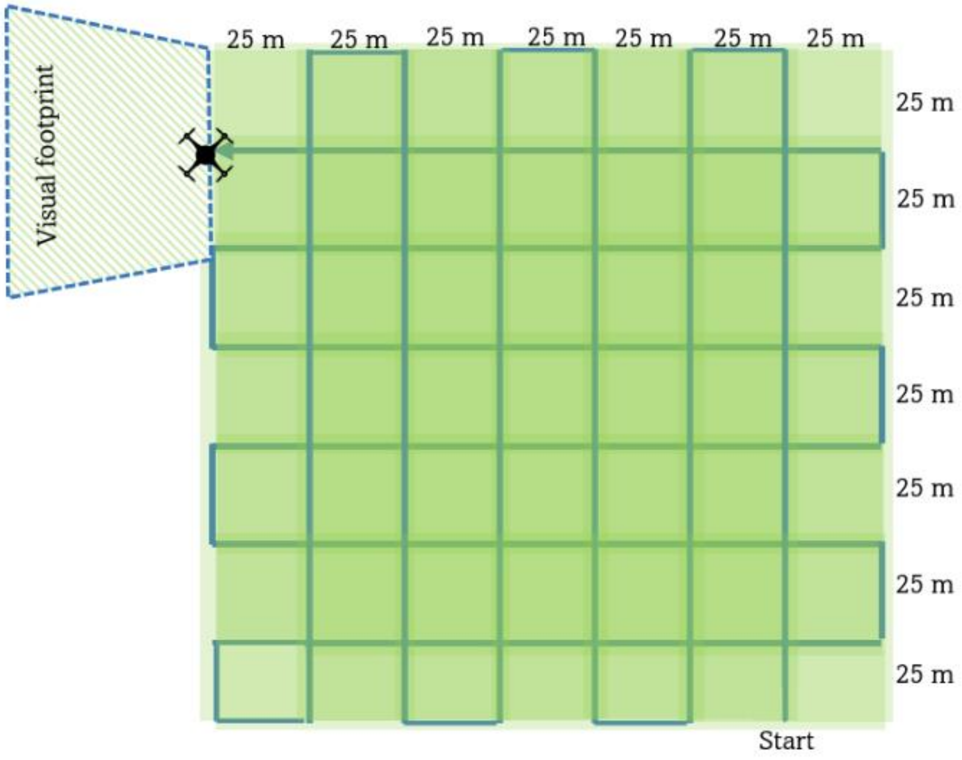


Figure 9: Illustration of the Parallel Search 4 (PS4) search pattern

Guidelines for Water-Based Drone Searches

Utilizing drones to search for individuals located in water presents distinct challenges. Thermal radiation does not penetrate water, meaning submerged individuals remain undetectable for a thermal sensor. However, if an individual is partially exposed and retains body heat, spotting a thermal signature becomes comparatively swift given the absence of vegetation and other structures. In such cases, a gimbal angle shallower than the previously noted 75 degrees can be advantageous, broadening the area covered from a single viewpoint.

When searching for a submerged person, visual identification via a standard RGB video sensor becomes viable. However, the efficacy of this approach depends on several factors: water clarity and depth, surface disturbances, lighting conditions, and the backdrop provided by the underwater terrain. With reference to Snell's Law of Refraction and the Fresnel equations concerning the physics of light transitioning between disparate media, in this case from water to air, we can note that as the angle at which light strikes the water's surface becomes more oblique, the amount of light reflected back into the water increases. There is a critical angle (48,6°) beyond which all the light is reflected back into the water, known as total internal reflection. Thus, a gimbal angle oriented perpendicularly to the water's surface results in optimal visual penetration capability. Yet, when glare (from sources such as the sun or a drone-mounted searchlight) impedes this angle, adjusting the angle based on iterative testing is advised.

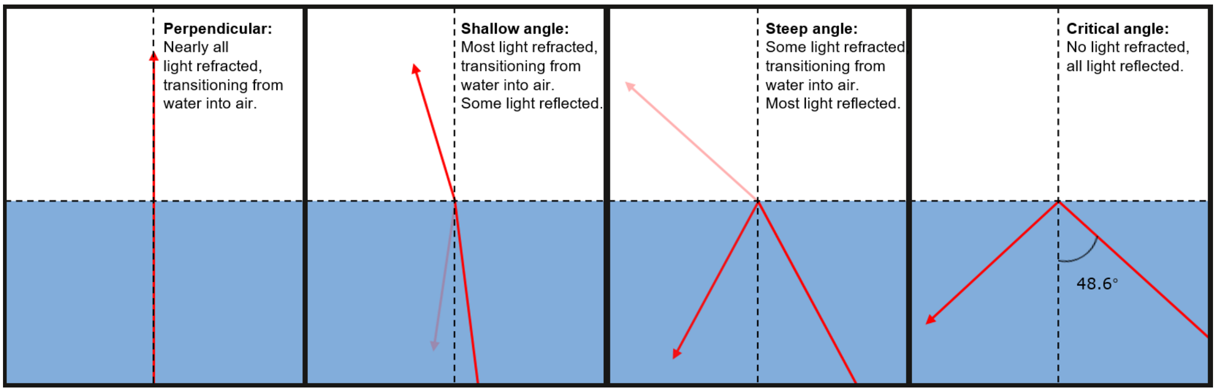


Figure 10: Illustration of light transitioning from water into air at different incidences.

As visual details may be distorted by waves or ripples on the water surface, opacity, depth and contrast against the soil, a lower search altitude or a higher zoom level is recommended as a compensating measure. If the camera optics allow for a higher zoom level while remaining image quality, this is usually preferred, as the combination of high altitude and high zoom level allows for more vertical perspective across the image compared to low altitude using a wide-angle lens. The vertical perspective throughout the image yields a greater degree of perpendicular viewing angles to the surface thus allowing for better visual penetration through the water surface.

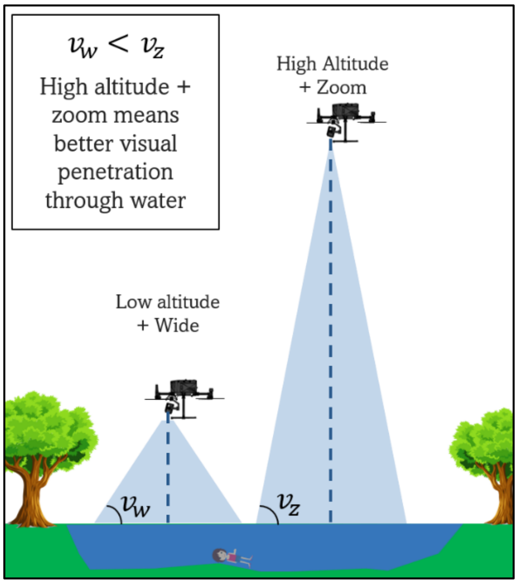


Figure 11: Low flight altitude and wide-angle camera compared with high flight altitude and increased zoom level covering the same visual footprint.

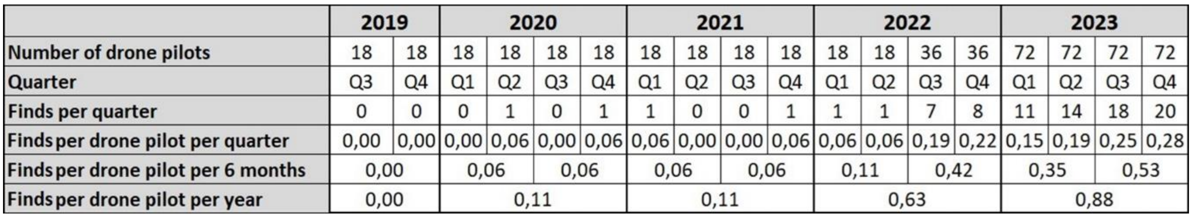
Alternative Search Patterns Tailored to Specific Needs

All the techniques outlined above are meant as tools that the drone pilots can employ when deemed applicable. In a variety of specific search tasks, other search parameters might be better suited. The drone pilots must always use their professional judgement in choosing the technique to best fulfil the aim of the objective, be it one of the techniques outlined above or using a customized technique for a specific situation.

Results

During the 2019-2020 trial, drones were operational in three of the twelve Norwegian police districts. In each district, six police officers had undergone basic UAS training and operated drones from their patrol vehicles. Their use persisted beyond the trial, in anticipation of a national rollout in Q3 and Q4 of 2022. During this period, drones successfully located 6 missing individuals, equating to 0.11 finds per drone pilot per year.

During Q3 and Q4 of 2022, drones were rolled out nationally across all twelve police districts, each district having six officers proficient in newly adapted advanced SAR drone search techniques. In 2023, 63 people were found, equating to 0.88 finds per drone pilot per year. This marks an 8-fold increase in successful locations of missing individuals compared to the trial period.



	2019		2020				2021				2022				2023			
Number of drone pilots	18	18	18	18	18	18	18	18	18	18	18	18	36	36	72	72	72	72
Quarter	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Finds per quarter	0	0	0	1	0	1	1	0	0	1	1	1	7	8	11	14	18	20
Finds per drone pilot per quarter	0,00	0,00	0,00	0,06	0,00	0,06	0,06	0,00	0,00	0,06	0,06	0,06	0,19	0,22	0,15	0,19	0,25	0,28
Finds per drone pilot per 6 months	0,00		0,06		0,06		0,06		0,06		0,11		0,42		0,35		0,53	
Finds per drone pilot per year	0,00		0,11				0,11				0,63				0,88			

Figure 12: Data showing number of drone pilots and number of finds per quarter, 6 months, and year.

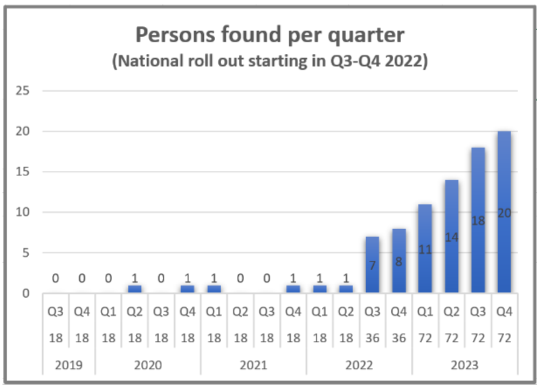


Figure 13: Number of finds per quarter year.

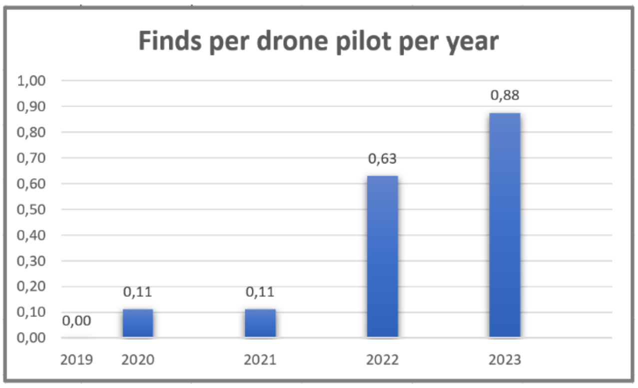


Figure 14: Finds per drone pilot per year.

Discussion

Drone technology and software are advancing at an unprecedented pace. Year after year, camera sensors are enhanced, and innovative software tools are introduced to process live video streams-and automate flight paths. There is a perspective that this rapid technological development could render manual drone searches redundant in the near future. However, we contend that manual searches will persist until these advanced technological promises materialize. In the interim, refining and improving the tools at our disposal is essential. We advocate that honing effective search methods and continuously melding them with advancements in automation, AI-driven video analysis, and technological progress will lead to improvements in the accuracy and efficiency of drone-based SAR operations.

While the increase in success coincides with the implementation of new search techniques, it is important to note that this observation is anecdotal, and other influencing factors are expected to contribute. Among these are the selection of Norwegian drone pilots based on cognitive skills such as vigilance, spatial abilities, and logic reasoning (Johnsen et al., 2023) and advancements in thermal imaging technology, notably thermal sensors with zoom capabilities. Additionally, the Norwegian police's ability to conduct beyond visual line of sight (BVLOS) operations has expanded the scope of the searches compared to traditional visual line of sight (VLOS) operations.

There is also a growing demand for drone assistance in SAR operations, which may lead to more frequent callouts. Variations in SAR incident rates across police districts could affect national averages, but these factors alone are unlikely to fully explain the significant rise in successful location of missing individuals.

Limitations

One notable limitation of these methods is the lack of comprehensive analysis on the probability of detection (POD) – specifically, quantifiable metrics indicating search pattern effectiveness across different terrains and thermal conditions. Our understanding of their efficacy largely relies on qualitative reports about the success rates of locating missing individuals during SAR missions across the nation. While these accounts suggest an elevated POD, a more rigorous and standardized evaluation would benefit evaluation of these search methods. Such a process would not only offer a more precise measurement of the POD but also enable more substantive comparisons with other search techniques or potential refinements.

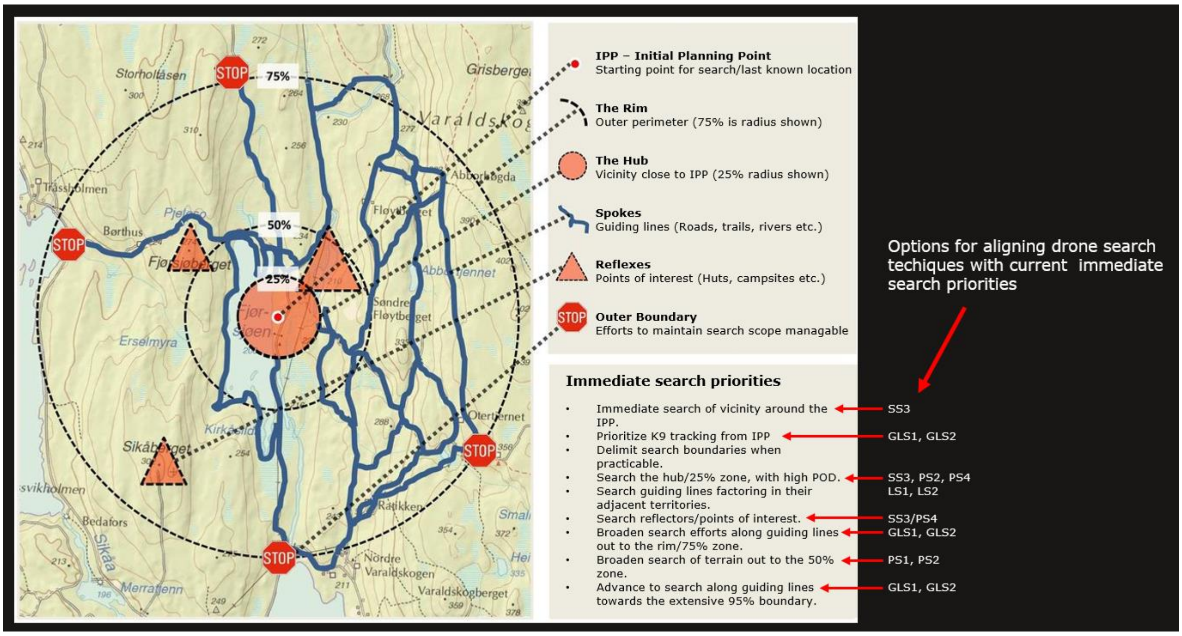
During training, a significant challenge encountered was balancing the mental effort required to manually follow the flight patterns while maintaining a high degree of vigilance for visual inspection of the images. This was particularly evident in the execution of the SS3 search pattern, due to its intrinsic complexity. Although repeated training enhanced manual execution, it is expected that automating the flight patterns would allow drone pilots to dedicate most of their attention towards the crucial task of searching for missing individuals, and less attention towards navigating complex flight patterns.

Conclusion

In 2022, the Norwegian police initiated the full-scale use of drones for various tasks, including search and rescue (SAR) operations. The initial trial period revealed a need for more optimized techniques to increase the success rate of drones in locating missing individuals. This led to the development of specific search techniques by the Norwegian Police Unmanned Air Support Unit (NPUAS), harmonized with the "bike wheel model" for SAR operations.

For drone-based searches to be effective, it's essential to recognize the interconnected nature of various parameters. The gimbal angle, flight altitude, and search pattern should not be viewed as isolated elements but rather as parts of a cohesive system designed to enhance search efficiency. Specifically, the advised 75-degree gimbal angle ensures a comprehensive range of viewing angles towards the ground during flight, while maintaining an altitude of 100m (330 ft) AGL strikes a balance between the likelihood of detection and search speed. Six search patterns, tailored to specific tasks defined by the bike wheel model, further augment the overall probability of detection (POD). While thermal cameras are the primary tool, standard camera image sensors remain invaluable under specific conditions, operating under the same foundational principles.

Equipped with these tools, drone pilots can apply the most suitable search technique according to the task assigned by the search coordinator and the vegetation density. For instance, if asked to search along a trail, the relevant search patterns might be GLS1 or GLS2. If the objective is to investigate a campfire site, the SS3 might be a good option. For covering more extensive areas, the PS1 or PS2 might be preferred, and for covering a small to medium sized area with the highest possible POD, the PS4 would be a good option.



IPP – Initial Planning Point
Starting point for search/last known location

The Rim
Outer perimeter (75% is radius shown)

The Hub
Vicinity close to IPP (25% radius shown)

Spokes
Guiding lines (Roads, trails, rivers etc.)

Reflexes
Points of interest (Huts, campsites etc.)

Outer Boundary
Efforts to maintain search scope managable

Immediate search priorities

Immediate search of vicinity around the IPP.	SS3
Prioritize K9 tracking from IPP	GLS1, GLS2
Delimit search boundaries when practicable.	
Search the hub/25% zone, with high POD.	SS3, PS2, PS4
Search guiding lines factoring in their adjacent territories.	LS1, LS2
Search reflectors/points of interest.	SS3/PS4
Broaden search efforts along guiding lines out to the rim/75% zone.	GLS1, GLS2
Broaden search of terrain out to the 50% zone.	PS1, PS2
Advance to search along guiding lines towards the extensive 95% boundary.	GLS1, GLS2

Options for aligning drone search techiques with current immediate search priorities

Figure 15: Illustration of the Bike Wheel Model and options for aligning drone search techniques to immediate search priorities.

With this integrated approach, the Norwegian drone service located 63 missing individuals during 2023, a significant improvement from the trial period. This adaptation signifies a promising future for drone utilization in SAR operations, combining technology and strategy to save lives.

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