

Evaluating Response Times of UAS as Search and Rescue Resources Dispatched from Commercial Maritime Traffic

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ABSTRACT

This paper investigates if the response times could be reduced if all commercial traffic at sea carried an Unmanned Aerial Vehicle (UAV) that could respond to emergency calls from ships close by. Historical maritime search and rescue incidents in Sweden were studied, using Geographical Information Systems (GIS). For each incident, the closest commercial ship within a UAV's flying distance was identified, and the corresponding response time for the UAV was compared to the historical response time from land-based resources. It was observed that for the total system, the potential time gains are on average 15 minutes to reach the initial position of the incident if UAVs were widely introduced as required safety equipment on commercial ships.

Keywords

Search and rescue (SAR); unmanned aerial systems (UAS); maritime emergency response; geographical information systems (GIS)

INTRODUCTION

Search and rescue (SAR) at sea is a challenging task for several reasons. Skill and experience are required for understanding and managing the challenging environment, and for planning and performing an efficient search. Furthermore, if the position of the distressed vessel or person is unknown, vast areas might need to be searched due to an unprecise estimation of the last known position. This can be amplified by unfavourable weather and current conditions. Some of the risks associated with these challenges can potentially be mitigated by using new technologies, or existing technologies in a new way. One such technology is unmanned aerial systems (UAS).

In a report by the Swedish Maritime Administration, it was indicated that there exists great potential in utilising UAS as a complementary resource, both as a national shared resource and as smaller local resources in the Swedish search and rescue system (Swedish Maritime Administration, 2024). The report also recommended the introduction of UAS on commercial vessels as a supporting tool for faster search and rescue operations in their vicinity. This is in line with the international maritime safety regulations, which state that any ship close enough to hear an emergency call is obliged to offer help if they are able to do so (International Maritime Organisation [IMO], SOLAS, 1974; IMO, SAR convention, 1979). An UAS on such a ship may assist a search and rescue operation by reaching the distressed vessel or person faster than other land-based resources and confirm the position, enabling rescuing resources to reach the location faster. If every commercial ship had an UAS, there would be many resources that potentially could assist the initial part of a SAR operation, namely the search process, by locating the distressed vessel or person and ensure the correct position. It could also provide footage that may be of help when planning the rescue operation. This would enable a quicker start of the rescue operation.

The potential of UAS in SAR applications has been widely discussed in the research literature; however, the focus has mostly been on developing efficient path-planning algorithms and collaborations between multiple unmanned

and automatic or autonomous vehicles (Li et al 2023; Queralta 2020). System evaluations of how a widespread use of UAS in maritime SAR could enhance rescue and response are scarce, to the best of our knowledge.

Thus, the aim of this study is to evaluate the potential system of equipping commercial marine traffic with UAS that can be used in maritime SAR. Specifically, UAS that will assist the search part of the operation by confirming the location of the distressed vessel or person.

Explicitly, we compare the first response times of historical SAR cases with calculated expected response times for unmanned aerial vehicles (UAV) that are dispatched from commercial vessels, based on their historic position of the vessel at the time of the incident. The response time is defined as the time from the emergency call to a resource reaching the distressed vessel or person. The purpose is to investigate whether introducing new resources into the system would be a beneficial complement to the current responding resources, by assisting the search and rescue operation with a fast and flexible search resource. This also addresses the gap between the technological potential found in the current research literature, and the planning perspective.

Interviews with an operator at the Swedish Joint Rescue Co-Ordination Centre (JRCC) and a representative of the Swedish Sea Rescue Society (SSRS) gave a good base for understanding the Swedish Search and Rescue system, and for setting the context of the proposed new resources. Historical data on incidents was obtained from the SSRS and the Swedish Maritime Administration. Automatic Identification System (AIS; maritime positioning) data was obtained from the Danish Maritime Authority and analysed through QGIS and PostgreSQL with PostGIS.

RELATED WORK

There has been a great interest in the development of UAS for emergency response applications in the research literature (Wankmüller et al, 2021). For SAR, UAS are proposed to support searching in difficult environments such as vast areas at the open sea or archipelago sites with poor accessibility, as well as in dangerous situations with risk of explosions on board of a ship (Li et al, 2023). In particular, Li et al (2023) proposed the use of UAS combined with unmanned surface vehicles (USV) to utilise the benefits of each type of vehicle. This was also explored by Mendonca et al (2016); they experimented in a real setting with an UAS equipped with thermal cameras, escorted by an USV to respond to a rescue call. The USV functioned as a landing station for the UAS, and the USV could communicate with a human operator at shore, while also having computational power capable of performing analyses on data from the UAS. The combination of UAS and USV was also used for post-disaster damage assessment by Murphy et al (2008), showing the potential of the unmanned systems to carry out difficult and dangerous tasks after disasters. Queralta et al (2020) discussed opportunities and challenges for SAR indicating that a UAV could provide a birds-eye view on the situation, so that an USV and potentially also an unmanned underwater vehicle (UUV) could operate effectively. A small UAV has the advantage that it can be easily carried and deployed from a small boat (Queralta et al 2020). However, Queralta et al (2020) stated that there was a need to make more real-life experimental studies, moving on from simulated experiments for these types of systems. Indeed, many studies have presented the development of potential SAR systems for autonomous unmanned vehicles for marine purposes, using simulated results that give promising results for further research on the topic (Bhuiya et al, 2022; Boulares et al 2024; Feraru et al 2020; Liu et al 2023; Ma et al 2023; Shih et al 2018; Zhang et al 2023). UAS may also support emergency response close to the shore, to for instance drowning incidents (Claesson et al, 2020). Introducing UAS in SAR comes with challenges, e.g. when it comes to the questions of their purpose, who will operate them and have the responsibility for their deployment. Furthermore, they might be used for both SAR and border control, as exemplified by a case in the Mediterranean Sea (Loukinas, 2022).

The focus of the research on UAS in maritime SAR has been on the development of the technological parts of the system, including autonomous features, and less on the implementation and integration of new resources into the current SAR organisations. Zhang et al (2023) highlighted that many resources collaborate during a real-world SAR incident, which creates a need to evaluate the whole system when examining SAR at sea. The study most related to our own is Medić et al (2019). They discussed the probable usefulness of having all national Search and Rescue Units of Croatia equipped with UAVs, with the potential to reduce the time to locate a distressed person or vessel, which in turn could reduce the search area. They were also expected to be useful to enable a quicker search of the established search zone. However, the work of Medić et al (2019) is conceptual, with no quantitative analysis of the proposed potential changes to the rescue system of Croatia. Therefore, this study is adding to the current work in the field by quantitatively analysing the introduction of UAS into the rescue system, specifically search and rescue at sea.



Figure 1 - Sweden search and rescue region (SRR), area of responsibility for Swedish sea and air rescue.

SWEDISH SEA RESCUE

The maritime search and rescue process in Sweden is managed by the Joint Rescue Co-Ordination Centre (JRCC), a part of the Swedish Maritime Administration. They are responsible for carrying out and coordinating all maritime and aerial search and rescue operations in the Search and rescue region (SRR) of Sweden. This includes maritime areas as well as the three largest lakes in Sweden (see Figure 1).

A SAR case can be received through different channels; common examples are through the Very High Frequency (VHF) radio channel 16, and the Swedish public safety answering point (PSAP) SOS Alarm, who operates the national emergency number 112. An assessment of the situation is performed by the operator at JRCC receiving the call to confirm whether it is an emergency rescue case, based on the initial information received as well as an initial localisation. The initial position that has been communicated may come through Global Navigation Satellite Systems (GNSS) positioning; for example, a cell phone with GPS activated (if close enough to the shore, e.g., in an archipelago), or navigation equipment onboard a vessel sent through Automatic Identification System (AIS). The latter is the tracking system used for ships all around the world. Such a position can be considered accurate as either the current position or as a last known position of the person/vessel (depending on the type of incident). However, there may be no GNSS position available; in such a case, location estimations are based on information from the caller (e.g., a point last seen) or on rough estimates from the mobile phone network. Depending on the weather, type of vessel, and whether it is on land or on sea, the position estimate may change as time passes, forcing the JRCC to dynamically make new estimations of the current search area.

The JRCC can request any nearby vessel to help with the search and rescue operation and all vessels are obligated to help if they have the possibility. This means a combination of different resources are available: emergency responders (rescue services, police, and emergency medical services) and the coast guard, as well as civilians and the military. In Sweden, the voluntary Swedish Sea Rescue Society (SSRS) also performs search and rescue in a majority of the cases. The JRCC have SAR-helicopters

and pilot boats as their own resources, so most of the necessary resources come from other organisations. A search and rescue operation proceeds until a rescue has been successfully performed, or when there is no probability of finding a person alive anymore. In a man-over-board incident during the winter, with the missing person not wearing appropriate clothing to survive in cold waters for extended periods of time, this probability quickly decreases with time.

DATA

Search and rescue operation data was obtained from the SSRS and complemented with the data from the Swedish Maritime Administration. SAR incidents during the year 2023 have been used, including coordinates and time stamps for incidents. The data also includes time stamps for when the first resources from SSRS reaches the coordinate, making it possible (in most cases) to calculate the historical response time.

The data for maritime traffic that has been used for the analysis is AIS data. The International Maritime Organization (IMO, n.d.) states that all passenger ships (regardless of their size) and international cargo ships with over 300 gross tonnage (500 gross tonnage if not international) are obliged to use AIS. Other types of ships and vessels that are not required to use AIS, may also carry AIS transponders; their use is increasing by vessels not covered by the regulation (Swedish Maritime Administration, 2023).

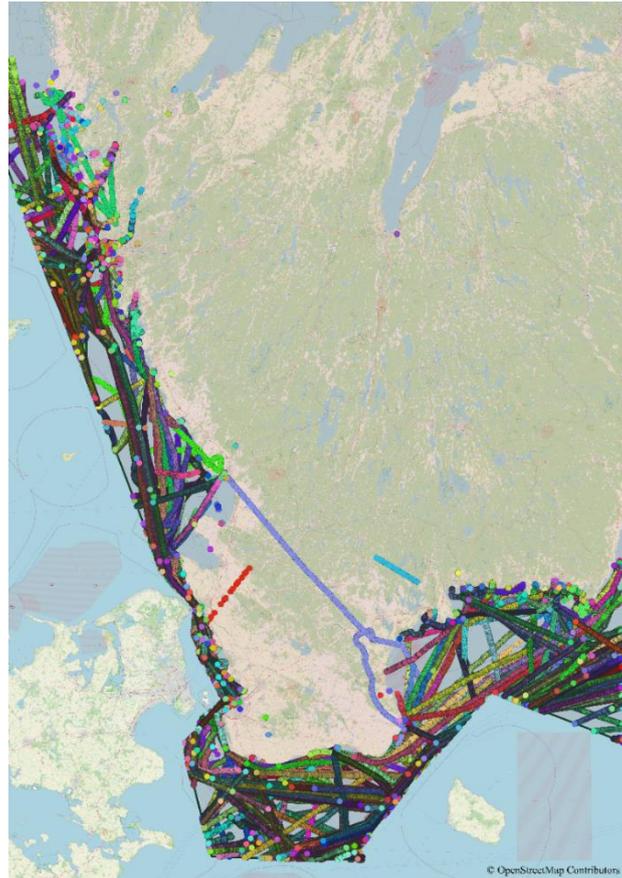


Figure 2 - AIS data in the studied area. Each dot represents an AIS position for a ship/helicopter, with individual colors for each unique ship. The data in the picture corresponds to all registered traffic for 24 hours within the studied area.

The Maritime Authority of Denmark openly provides historical AIS-data (Danish Maritime Authority, n.d.). As the analysis is performed on Swedish rescue cases, the accuracy of the AIS data for Swedish SAR areas cannot be guaranteed for areas too far from Danish coast. The range of an AIS transmitter and receiver is dependent on the type of transponder used, as well as weather effects on the signal. Therefore, in consideration of these error sources, the data was limited to include only the incident and AIS-data west of longitude 16.09 and within the Swedish SRR. The latter also functions as the westly coordinate breaks, while a northern break was not considered based on the visual evaluation of the data. An example with data from one day is presented in Figure 2.

The coordinate breaks were evaluated visually in the Geographic Information System (GIS) software QGIS, to ensure that there is enough coverage of received AIS-data for the data points within the geographic limitations, by setting a limit before the receiving rate fades. This limits the analysis to only include rescue cases in the west and south coast areas of Sweden, which were filtered through QGIS, summing up to a total of 370 cases (out of a total of 790 for Sweden as a whole). There were some cases with a zero minute response time for the SSRS, and those were also filtered out from the set of incidents, giving a remaining 362 cases for the analysis.

ASSUMPTIONS AND LIMITATIONS

The main assumption in the analysis is that there will be future infrastructure and services ready for commercial actors to operate UAS beyond visual line of sight, with regulations and authorisations adapted to civilian use of UAS. The results are based on ideal conditions for all scenarios, meaning that factors that may negatively affect the UAV's performance, such as the weather, will not be included explicitly in the analysis. This means that the capacity of a UAV is always expected to be the maximum in terms of speed and flight duration. A UAV may need to avoid flying above populated areas, but this has not been accounted for in this analysis. The UAV type that will be used for the analysis is a multi-rotor type UAV, as this type is more likely to have multiple purposes on a large ship (such as inspections and deliveries).

All ships that are categorised in the AIS dataset as fishing, cargo, passenger, tanker or high-speed craft (HSC), are considered commercial traffic and assumed to have an UAS when performing the analysis. The closest ship within Euclidian distance from the incident is selected as the resource to dispatch a UAV. The maximum flying

distance in the analysis is defined as half of the total maximum distance the UAV can cover given its speed and flight duration. The UAV is expected to take-off within 3 minutes and 10 seconds after the incoming emergency call, based on the measured mean times in real life situations for UAV carrying automatic external defibrillators (Schierbeck et al, 2022). The SAR helicopter of the JRCC can, if dispatched, take-off within 15 minutes (Swedish Maritime Administration, 2024). In the analysis, the historical time from reception of alert until reaching the incident coordinates (the response time) for the SSRS resources, is compared to the calculated time for the UAV to reach the same incident coordinates.

The capacities for a smaller UAV intended for local search and rescue are based on the average specifications from the different UAVs used in the project by the Swedish Maritime Administration (Swedish Maritime Administration, 2024). The specifications are summarised in Table 1.

Table 1. UAV specifications of speed and flight time used for the scenarios.

UAV type	Speed (m/s)	Flight time (min)	Max distance (total) (km)
Multi-rotor	20.5	50	61.5

RESULTS

The analysis of the data was made in PostgreSQL with PostGIS queries (spatial tools) to a database and verified with QGIS.

The basic scenario assumes dispatch of a UAV from the closest ship to the incident position, which is decided based on the ships in the vicinity geographically (i.e., within reach of the UAV), and temporally, within 2 minutes before or after the call. Thus, only ships close by, at the time of the incident, are considered. The reason for an interval is to not restrict the matching of nearby ships by requiring exact timestamps. Other scenarios are considered in a sensitivity analysis, with two scenarios increasing the take-off time for the UAV to either 5 or 10 minutes, one scenario using a UAV with a 20% speed reduction and one scenario with a UAV with 20% reduced speed and flight time (duration/capacity). The scenarios with longer response time will affect the total response time for the UAV, while the speed and flight time reductions will affect the response time and reach of the UAV. In Figure 3, an example of the results (from 15 July 2023, the day with the greatest number of incidents in the data set) is presented, where the blue triangles represent ships that at the time of an incident are the closest within the UAV maximum flying distance to a specific incident. The red rhombi represent incidents with no ship fulfilling the criteria of time and space to dispatch a UAV. The numerical results are presented in Table 2, Table 3, and Table 4, with Table 3 giving confidence intervals for the different scenarios.

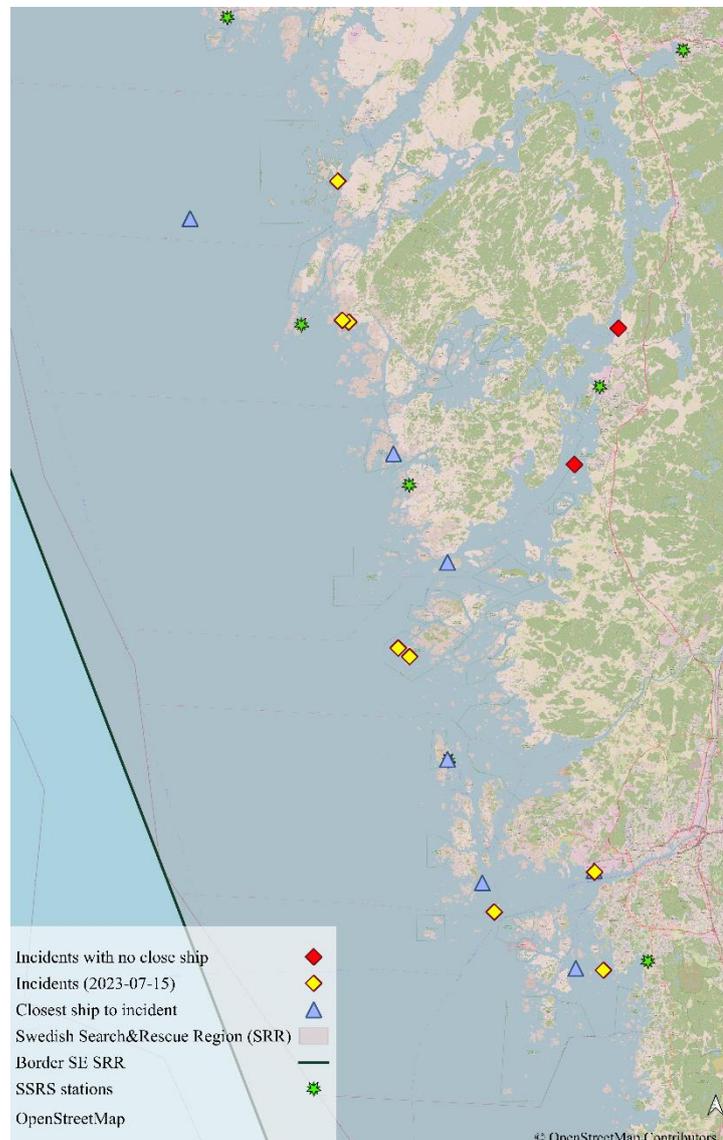


Figure 3 - Visualisation of results, showing both incidents with a close-by ship eligible for sending a UAV and incidents with no eligible ship.

Table 4 contains the confidence intervals for the SSRS response times, which remain basically the same for all five scenarios since their time is based on real data from the incidents, the small variation is due to fewer incidents compared due to the reduced reach of the UAV.

Incidents where ships were out of range (not close enough at the right time) to dispatch a UAV to the incident could not be compared to the response times of the SSRS. Therefore, the results in

Table 2 are showing both the share of cases where the UAV arrived before the SSRS based on the total number of incidents, as well as the share of only the cases where there was an actual dispatch of a UAV. Note that the response times of the SSRS do not significantly change in any of the scenarios, (see Table 4) as these are based on the historical data of the SSRS, and their response time is not affected by the scenario changes.

Table 2. Results from the scenarios compared in the analysis. The incidents included are in total 362.

Scenario	Cases with no UAV dispatch (#)	UAV first (all cases, incl. no dispatch of UAV) (#)	UAV dispatch, SSRS first on site (#)	UAV dispatch and first on site (#)	Mean difference (min) SSRS - UAV	SD (min) difference SSRS - UAV	Mean time (min) UAV response time	SD (min) UAV response time
Basic scenario (avg. specs UAV)	26.0% (94)	68.8% (249)	7.1% (19)	92.9% (249)	20.62	22.63	9.36	5.41
Take-off time 5 minutes	26.0% (94)	66.3% (240)	10.4% (28)	89.6% (240)	18.79	22.63	11.20	5.41
Take-off time 10 minutes	26.0% (94)	58.0% (210)	21.6% (58)	78.4% (210)	13.79	22.63	16.2	5.41
20 % reduced speed	27.3% (99)	64.4% (233)	11.4% (30)	88.6% (233)	19.15	22.74	10.51	6.15
20 % reduced speed & flight time	32.0% (116)	61.6% (223)	9.3% (23)	90.7% (223)	19.99	22.94	9.48	4.91

Table 3. Confidence intervals (99 %) for UAV dispatch cases (minutes).

Scenario	Lower bound	Mean time (min) UAV response time	Upper bound	Lower bound	Mean. Difference (min.) SSRS-UAV	Upper bound
Base scenario (avg. specs UAV)	8.51	9.36	10.21	17.06	20.62	24.18
Take-off time 5 minutes	10.35	11.20	12.05	15.23	18.79	22.35
Take-off time 10 minutes	15.35	16.2	17.05	10.23	13.79	17.35
20 % reduced speed	9.53	10.51	11.49	15.54	19.15	22.76
20 % reduced speed and flight time	8.67	9.48	10.29	16.22	19.99	23.76

Table 4. SSRS response time (minutes). Confidence intervals (99 %)

Scenario	Lower bound	Mean	Upper bound
SSRS response time ALL cases	26.10	29.31	32.52
SSRS response time UAV dispatch cases (base scenario)	27.02	29.99	32.96
SSRS response time UAV dispatch cases (5 min take-off)	27.02	29.99	32.96
SSRS response time UAV dispatch cases (10 min take-off)	27.02	29.99	32.96
SSRS response time (20 % reduced speed)	26.74	29.66	32.57
SSRS response time (20 % reduced speed and duration)	26.51	29.48	32.45

Equipping UAS on commercial ships and assuming they would be able to dispatch a UAV for a search and rescue call is shown to potentially reduce the time to first response at the incident position with around 20 minutes, as is shown in Table 2. The distribution of the difference between SSRS and the UAV is shown in Figure 4 where most of the cases have a time reduction of 10 minutes or more.

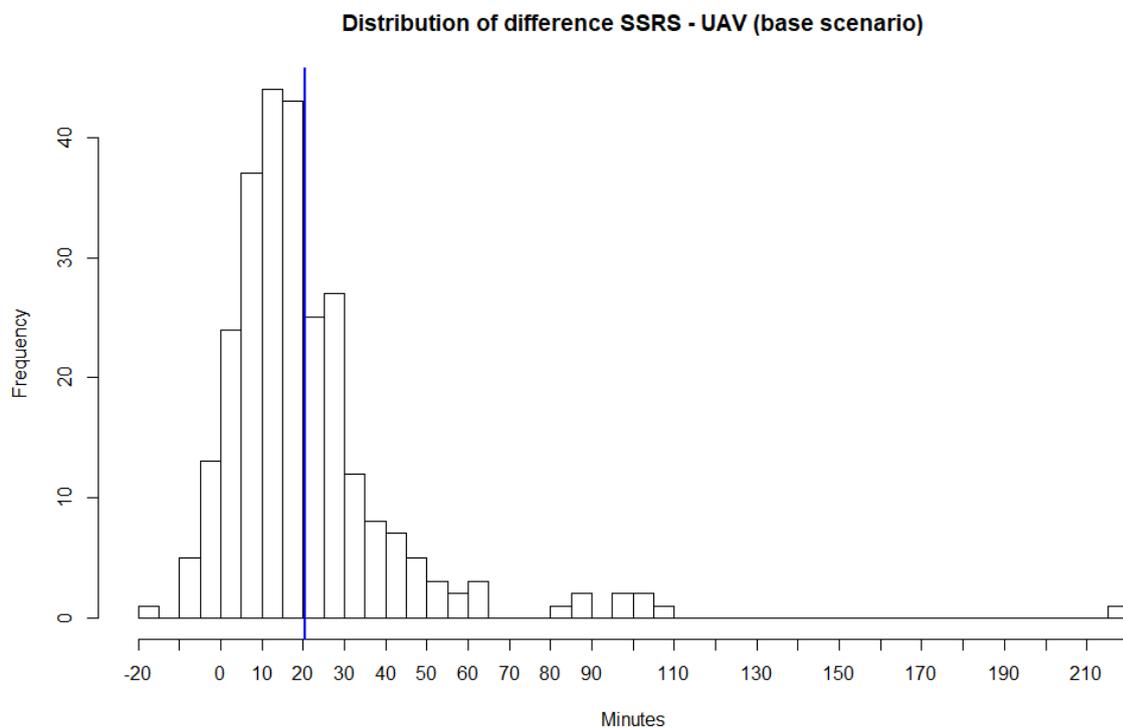


Figure 4 - Distribution of the time difference between SSRS and the UAVs. The mean is highlighted by the blue line.

However, in the data set studied, there were 94 incidents when no UAV was dispatched, which accounts for 26.0% of the total cases analysed. In those cases, there was no ship sufficiently close to the incident position at the right

time (given that the distance is half of the maximum distance that can be flown) to dispatch a UAV, or the closest ship was outside of the Swedish SRR. In the worst-case scenario, the take-off time for the UAV is 10 minutes, but still reaches the incident position in 58.0% of the cases before the SSRS. The mean response time in that scenario is 16.2 minutes, with a lower limit on the confidence interval being 15.35 minutes, which is more than the take-off for the search and rescue helicopters (but not including flight time for the helicopter). Thus, even with pessimistic assumptions, equipping commercial ships with UAS, might have a significant impact in maritime search and rescue.

The mean time difference of response times between the UAV and the SSRS are 18.47 minutes. The early first response of a UAV might give valuable insights to SSRS and other responding units, e.g. by confirming that the position is indeed where the ship in distress, or man overboard, is located. In Table 5, the total average response time of all cases is compared between the scenario with the current system (no UAV) and with the scenarios including UAVs as resources. For the basic scenario, the reduction in time is around 15 minutes, and for the worst-case scenario (10-minute take-off) the reduction is 10 minutes.

Table 5. Total response time (minutes). Confidence intervals (99%).

Scenario	Lower bound	Avg.	Upper bound
SSRS only (no UAV)	26.10	29.31	32.52
Base scenario (avg. specs UAV)	11.85	14.26	16.68
Take-off time 5 minutes	13.12	15.48	17.85
Take-off time 10 minutes	16.30	18.56	20.82
20 % reduced speed	12.77	15.18	17.60
20 % reduced speed and flight time	13.13	15.61	18.10

In the cases where a UAV is dispatched (i.e., is in flying reach of the incident) it also arrives first to the position in a majority of the cases. With a take-off time of ten minutes, it will still be first in 78.4% of the cases, and has an average potential time gain of 13 minutes. The performance of the UAV in terms of speed and flight time affects the number of cases where a UAV is dispatched, as those factors determines the range of the UAV. However, for those cases where a slower and shorter ranged UAV is dispatched, it will still reach the incident site first in more than 88% of the cases, according to the results in Table 2.

It can be observed that even when using a UAV with poorer performance in terms of flight duration and speed, there may be a potential time gain of 19 minutes in average for reaching the incident position. The range of the UAV and the take-off time are factors that affect the gains of introducing this type of resource into the system. With a shorter range, the UAS was not dispatched in almost a third of the total number of cases. According to the confidence intervals in Table 3 and Table 4, the differences between the SSRS and the UAV response times are statistically significant (no intervals are overlapping). Furthermore, the confidence interval for the difference of the time is not covering 0 minutes or less, which both confirms the significant difference between the scenarios, and also means that the response time of the UAV is significantly shorter than that of the SSRS. However, a more elaborate analysis needs to be made to examine the time differences between the different scenarios.

DISCUSSION

The results show a positive impact on the time from an incoming emergency call to the arrival at an incident position when incorporating UASs in maritime SAR. There are however assumptions and simplifications made that should be taken into consideration before introducing these types of resources. The weather is not considered in the analysis, which of course can affect both the performance of a UAV as well as the possibility of take-off. The type of UAV is assumed in this analysis to be the same for all ships, but it will most probably differ in reality, and some ships may have a UAV that can fly in all weathers while some may not. Furthermore, the wind direction might affect the range of the UAVs. The scenario with reduced flight time and speed can be thought of as leaning towards a scenario with colder or wetter weather conditions, reducing the capacity of the UAV. When considering multiple equipped ships, several ships may be sufficiently close to the incident to dispatch the UAV, making it

more likely that at least one UAV is able to take off and reach the incident site. If assuming that the ships dispatching the UAVs also start to travel towards the incident site, the UAV range will also increase, since the way back to the ship will be shorter.

In a search mission with a rough position estimate, having more than one UAS covering a search area may reduce the search time. The time gains in terms of the UAV reaching the incident position first means that if the position is incorrect, the UAV may perform a search around the area and confirm the real position of the incident. With an accurate or confirmed position by airborne resources before the waterborne resources arrive, the driving time of the rescuing resources may be reduced as the need for searching will be eliminated. However, it is not possible to determine how big that impact may be based on these results alone, as details, such as the length of search part of the rescue operation, are not included in the data set. For an incident with people being in the water, depending on the season (e.g., winter or summer), this potential time gain could be of great importance for their survival.

CONCLUSIONS

Including UAS in emergency response has great potential, as previously stated in the literature and also as shown by the results in this study. Introducing UAS as a search resource in maritime SAR results in time gains—often reaching the position of an incident before land-based resources. The development of the technology needed for the use of UAS in SAR is progressing, and the need for establishing safe regulations for the use of UAVs by civilians is required for the system to be of practical use.

Introducing unmanned resources into existing rescue systems, not only from official search and rescue organisations, but also from other organisations (e.g., shipping companies), raises the question of how to develop a functioning and efficient methodology for the implementation of these systems. This includes how the collaboration between technology and humans is developed (human-computer interaction), as well as the planning of the search mission. These two areas may be explored with regards to the potential gains of using these types of resources by further quantitative analysis such as mathematical modelling and simulation.

The initial analysis was carried out with a limited set of cases, registered by the SSRS, and covering the southern part of the Swedish search and rescue region. The analysis should be expanded to cover all emergencies of the Swedish region. One future study could be to analyse the effect of equipping all SSRS coast-stations with UAS and compare to the equipping of commercial ships as well. To further explore the different possibilities of introducing UAS as a search resource in maritime SAR, an extensive statistical analysis of the results to find the significant differences of different scenarios should be made, including a more thorough analysis of the distribution of the times. An expansion of the analysis would also include all ships, regardless of being inside or outside the Swedish SRR. Expanding on this, there will be a need to study how a future system with both conventional SAR resources and new resources such as UAS should be organised and how a response should be planned to use all resources in the best possible way. Mathematical modelling such as optimisation could be a useful method for this. Human factors research on the interaction between the UAS and the humans in the search and rescue process are also topics to be further explored, as those are enablers for an efficient use of resources.

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