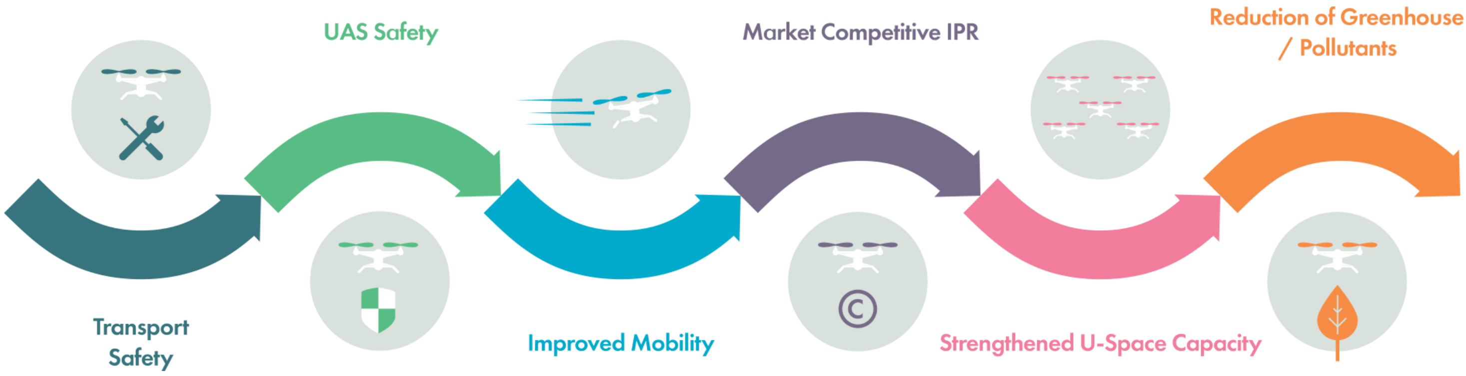
Risk-Aware Automated Port Inspection Drone(s).

# D1.1

## Market opportunities

12 October 2020




The Rapid project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°861211

# Document Context

| | |
|---|---|
| **Project Acronym:** | **RAPID** |
| **Grant Agreement number:** | **861211** |
| **Project title:** | **Risk Aware Port Inspection Drones** |
| **Funding agency:** | **H2020** |
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| **Type of action:** | **Research and Innovation** |
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| **Duration:** | **36 Months** |
| **Project website:** | **https://rapid2020.eu/** |

**Project Summary**

RAPID will save lives by delivering an early warning system that will detect critical deterioration in transport system infrastructure, while also minimising system disruption and delays to critical supply chains. It will achieve this goal by combining and extending state-of-the-art drone technology to deliver a fully automated and safety assured maintenance-inspection (MI) service for bridge inspection, ship hull surveys and more. By combining self-sailing unmanned surface vehicles (USV) with swarms of autonomous unmanned aerial systems (UAS), RAPID will dramatically cut the time and cost of structural condition monitoring. RAPID-enabled MI services will increase efficiency and competitiveness for maritime transport stakeholders – such as ports, shipping companies, and landside transport authorities – and will deliver the safe and seamless operation of supply chain and mobility infrastructures – such as material handling equipment, cargo and passenger ships, and bridges. It encourages prioritisation of safer transport infrastructure where the technology seeks to improve environmental impact. The attractive return on investment will enable RAPID to gain market traction and incentivise commercial proliferation, bringing RAPID into widespread use for the overall benefit of society. By 2028, a newly formed company will generate €124 million and save in the order of 100 lives per year (reaching c. 20% share of the serviceable addressable maritime transport market through strategic partnership with 50 ports). RAPID brings together interdisciplinary partners with the expertise and capacity required to develop and validate this unique service model. The project will develop the consolidated maritime and aviation regulation standard for safe USV / UAS operations and the business model to scale the pilot service. RAPID will validate the high level of digitalisation, automation, and regulation required to support safe, beneficial, and scalable access to U-Space.

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# RAPID Market Opportunities

## 1. Desk research

### Description of the common "Situation" for MI Services and the current state of R&D

Automated maintenance and inspection services are increasingly important topics in the logistics sector. Considering the growing importance of reliable infrastructure of any kind, the exponential growth of Internet of Things (IoT)-supported devices as well as the deployment of 5G communication networks, conditions have never been better to approach the idea of automated drones in maintenance and analysis. Flying drones are already used and tested as a flexible tool for several use-cases: Measuring of bridges and structures from the distance, logistics management and delivery, stocktaking and many more.

Through the establishment of new technologies, more possibilities arise and become technically and economically possible. Regarding maintenance specifically, there are already approaches for predictive maintenance[1] of photovoltaic plants with automatic recharging multirotor drones.[2] Using thermal vision cameras solar panels can be scanned from specific angles and heights to generally identify 99% of defects. A practice which is difficult and inefficient to maintain from the ground due to large surfaces or great heights of the installed solar panels. Compared to human-piloted aircraft, drones are much less expensive, can operate in lower heights and usually provide better resolution images. Moreover, drones have a much better carbon footprint compared to human controlled aircrafts. Within the field of maintenance inspection services drones can either be remotely controlled by humans or automated and fly predetermined routes and scan predefined angles.

Another approach is the preventive maintenance of energy infrastructure using swarms of drones.[3] The energy transmission and distribution network of electricity and gas is considered critical infrastructure and therefore requires constant maintenance of electricity cables, isolators, pipeline tanks and many more parts involved. Manually controlled drones to execute visual inspections have been used for some time already but the high time consumption for such operations are hindering wide adoption. A nationwide 5G communication network, which is currently being established in many parts of the world, will enable a massive capacity of connected devices, close to zero delays, lower energy consumption as well as better security and privacy paving the way for fully automated and connected swarms of drones to operate maintenance in large areas. Such drones can

[1] https://www.readitquik.com/articles/data/using-ai-for-predictive-maintenance/

[2] Predictive maintenance of photovoltaic plants using multirotor drones with automatic recharging system of Li-Po batteries: https://www.e3s-conferences.org/articles/e3sconf/abs/2020/40/e3sconf_te-re-rd2020_02007/e3sconf_te-re-rd2020_02007.html

[3] Preventive maintenance of critical infrastructures using 5G networks & drones: https://ieeexplore.ieee.org/abstract/document/8078465?casa_token=ZLutlHb-14MAAAAA:DS80j0ZSEAodSUHTgSLBpJH71J3IGwZTjPj4yo24BqgSJXfNFbTGcoAAWojp1DZ22twIv4o

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sense their surroundings and avoid obstacles while precisely performing their task using swarm intelligence, reducing the disadvantages of using multiple drones and delay caused by unexpected environmental changes.[4]

According to the World Economic Forum and Accenture, industrial savings on planned repairs amount up to 12%, while maintenance costs are reduced by almost 30%. According to the study, unplanned downtime is reduced by 70%.[5]

A Vanson Bourne study published in 2017 shows that unplanned industrial downtime costs in the UK, US, France and Germany, are around $260,000 an hour across all sectors. "This same study found that 70% of companies lack the ability to determine when equipment is due for maintenance, upgrade or replacement and that 82% of businesses have experienced at least one period of unplanned downtime in the previous three years." [6]

Building on the findings above and consolidating the use of drone technology with data from digital twin models, further highlights the importance of introducing the use of predictive maintenance services. Using digital twins as a living model of the physical system, which continually adapts to operational or structural changes based on the collected online data and forecasts the future of the corresponding physical counterpart, increases the efficiency and brings with it a high savings potential. The modern aerospace industry, which is already undergoing a shift from reactive to proactive and predictive maintenance to extend its useful life and reduce its life cycle costs[7] can help to illustrate the point. Technologies that have proven their worth in an industrial sector such as aerospace, with extremely low fault tolerance, demonstrate the synergy potential for maintenance inspection services within the maritime sector.

Automation will also further shift the industry from preventive (scheduled) towards predictive maintenance models. By only initiating larger maintenance actions and repairs when flaws, cracks or damages are detected, companies can reduce over-maintenance and reduce necessary labour time overall. According to a market research report published in February 2020, the global predictive maintenance industry is estimated to reach $18.6 billion by 2026 (from $2.4 billion in 2018).[8]

Due to their high flexibility and versatile deployment the commercial and civilian drone industry is expected to even surpass the defence industry (~$127 billion) in value over the next half-decade[9] and recent research and development has shown incredible potential for their deployment. Drone usage and technological advancement might alter the maritime industry forever.

[4] Formation Maintenance and Collision Avoidance in a Swarm of Drones: https://www.researchgate.net/publication/335751925_Formation_Maintenance_and_Collision_Avoidance_in_a_Swarm_of_Drones

[5] Vorbeugen ist besser als warten: https://industrieanzeiger.industrie.de/management/vorbeugen-ist-besser-als-warten/

[6] Why Companies Are Investing in Automated Maintenance Technology: https://www.distrelec.de/en/knowhow-why-companies-are-investing-in-automated-maintenance-technology/cms/maintenance-and-repair-operations-automated-maintenance-technology

[7] The Role of Data Fusion in Predictive Maintenance Using Digital Twin: https://aip.scitation.org/doi/pdf/10.1063/1.5031520

[8] https://www.fortunebusinessinsights.com/predictive-maintenance-market-102104

[9] How drone technology is improving safety in the maritime industry: https://www.martek-marine.com/blog/drone-technology-maritime-industry/

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## Description of the situation in maritime environments and the current state of R&D

In the maritime context, drones have already been successfully tested in various environments. They have been used in the field of building inspections, bridge inspection, inspections of tanks on cargo ships and vessels, remote structural components and other maritime assets. Dangerous and noxious gases are a big problem regarding these tasks with participating crew members. Commercial overall solutions for hull inspections are available, claiming to be “5x-8x more cost-effective than diver surveys”.[10] By using drones for maintenance and repairs the process can be sped up, reducing the workload and risks for crew members[11]. The use of drones for essential maintenance tasks therefore heavily reduces costs, increases efficiency and most importantly reduces risk to human life.[12] [13]

With the above goals in mind many R&D projects for drones, providing image processing and analysis capacity for inspection and maintenance work, establish their own AI (Artificial Intelligence) infrastructure to significantly improve the reliability of their services as can be seen by a venture of KLine and Mihara Corporation.[14]

In the subsea inspection sector, several suppliers and service providers worldwide have already launched their developments on the market. The European company Aquatic Drones offers robotics-as-a-service (RaaS) on a fully autonomous platform for underwater hydrographic surveys, ship hull inspection and oil spill detection. Aquatic Drones have successfully run a pilot test at the Port of Rotterdam for the Ministry of Infrastructure and Water Management in the Netherlands meeting the high governmental standards on their platform and software.[15]

The US-American company SeaDrone, a Stanford University spin-of, promises an overall time reduction of 10 hours to only 1 hour for the underwater hull inspection and delivers a fully automated certified report in less than one hour based on a mission planning software tool. The process improves efficiency and consistency, adds transparency and thus improves the customer experience.[16]

The future in maritime ship hull inspection and maintenance aims to have fully autonomous systems including drones and data analysis free of human control. [17]

[10] Certified Ship Hull Inspections in 1 hour: https://seadronepro.com/how-it-works#inspector-pro-landing

[11] https://www.flyability.com/news/drones-successfully-tested-to-inspect-maritime-assets

[12] Drones successfully tested to insprect Maritime Assets: https://www.flyability.com/news/drones-successfully-tested-to-inspect-maritime-assets

[13] How drone technology is improving safety in the maritime industry: https://www.martek-marine.com/blog/drone-technology-maritime-industry/

[14] Ship Hull Inspection and Maintenance By A Kline Drone: https://mfame.guru/ship-hull-inspection-and-maintenance-by-a-kline-drone/

[15] Aquatic Drones Builds Data Service for Europe and Beyond: https://www.roboticsbusinessreview.com/energy-mining/aquatic-drones-builds-data-service-europe-beyond/

[16] Ship hull inspections automated: https://seadronepro.com/

[17] Send in the drones: solving inspection and repair challenges at sea: https://www.ship-technology.com/features/drone-inspection-repair/

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## Description of the actual situation in the HPA environment

The HPA manages and is responsible for the infrastructure and facilities in the port of Hamburg. It represents both sovereign and commercial interests. The HPA has a wide range of possible fields of application for drones and can be found in both areas of activity. In order to achieve the goals set: increasing safety, reducing risks and downtimes, and automating standards and routines, the HPA is active in several technology sectors and projects.

In the field of maintenance and inspection services as well as the provision of real-time situation pictures for mission control support, the HPA currently focuses on the use of drones, various sensor units and associated data processing, the development of the digital twin of the port of Hamburg and its control centre software for controlling autonomous systems. HPA are also responsible for services such as artificial intelligence-supported image recognition or swarm intelligence solutions. A differentiation must currently be made between productive Units and research and development systems.

One of the most developed HPA departments using drones is the building inspection unit. For several years now, "hand-held close inspection" has been supported using drones and remotely operated vehicles (ROVs) for the evaluation of the generated sensor data. The systems are used in every phase of the process, during preventive routine inspections, the actual structural inspection or damage assessment, and the subsequent resource planning and implementation monitoring, and the subsequent resource planning and implementation monitoring.

In the "sovereign part " of its tasks, the HPA plans to use drones primarily in the fields of "prevention and management of special events" in order to make existing processes safer, optimise them and introduce new services. Especially in these very time-critical areas, drones represent a significant improvement in efficiency. In the event of a disaster, for example, a video image can be made available much faster in the HPA's very extensive and complex area of responsibility, and it can be provided much more cost-efficiently and sustainably in comparison to a helicopter mission. This is an urgently needed service, especially with regard to the rescue and evacuation of people, which must be introduced immediately. This and other services are to be introduced in the port of Hamburg in the short and medium-term as safety-enhancing measures.

With regard to commercial tasks, the HPA would like to make parts of the infrastructure management more intelligent and sustainable. This also includes the use of unmanned aerial vehicles (UAV), for example, which will be used to automate inspection services in the future. In doing so, the HPA is following a digital strategy on intelligent port infrastructure management. Here, too, the HPA's interests focus on the goals of "increasing safety, for example, by means of maintenance routines in the structural inspection and the resulting possibility of early detection, as well as on more sustainable and efficient infrastructure management.

In order to be able to achieve these goals in the long term with the help of drones, the HPA is planning a two-phase development of its own drone programme. In a first step, a test operation of the in-house infrastructure is to be established in the next two years. At the same time, the HPA continues to participate in research projects in order to participate in the development of port-specific solutions and to be able to put them into practice in the future. During this period, the HPA's drone hardware and software infrastructure is to be completed and all

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licences and process chains are to be developed and created in cooperation with the parties involved and relevant authorities.

To this end, alongside their internal projects, the HPA participates in many national and international research and funding projects in the sector of drones and autonomous systems and focuses on future and highly innovative technology.

The projects listed below are within the thematic scope of RAPID and may contribute to the project in terms of both content and value.

- PORTwings
- RoboVaaS
- Echo.1
- SeaClear
- Digital port twin

## PORTwings

Since the research project PORTwings, a sub-project of the overall project "Digital Test Field Port" funded by the BMVI, which was launched in 2018, the HPA has been working on the implementation and introduction of tele-operated drones in the port of Hamburg. Due to the size of the HPA's area of responsibility, drones in the port of Hamburg are to be controlled and operated out of sight (BVLOS) using control centre software. As planned, the HPA was able to achieve almost all development objectives and prove that both the control centre software and the drone infrastructure created are capable of achieving the expected positive effects on the use case environments "disaster control" and "port infrastructure management" envisaged at the time. Since the end of the project funding, the HPA has continued the development of the program on its own.

A central issue for the sustainable testing of the technology and its profitable use in the medium term is still a "license" for the operation of drones out of sight (BVLOS). The HPA is currently undergoing a safety qualification and assessment process and is endeavoring to establish its own "test field" (U-Space compliant) in the port of Hamburg in cooperation with the federal state aviation authorities.

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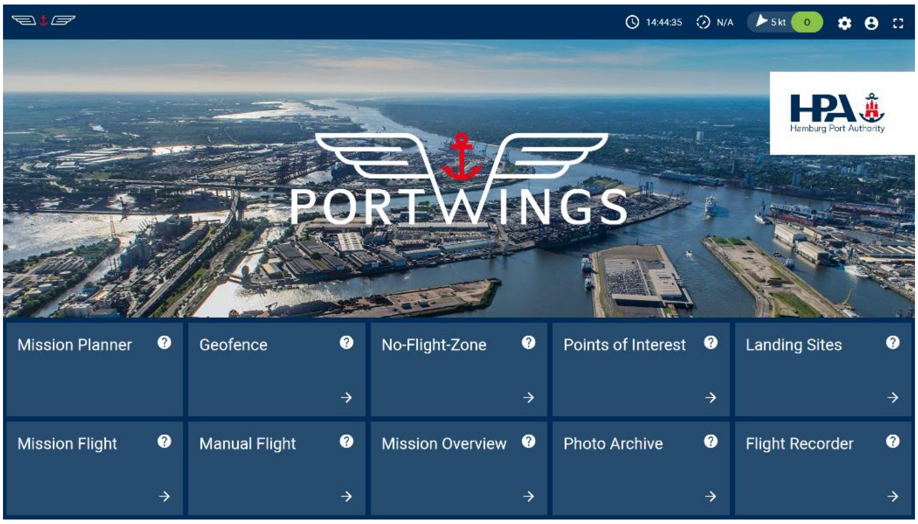


*Figure: PORTwings GUI*


*Figure: PORTwings GUI*

*Figure: PORTwings drone*

*Figure: PORTwings drone*

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The PORTwings drones and control centre software developed by the HPA is an application specially adapted to the needs of the HPA and port environments. It is possible to control drones via planned missions as well as manually via flight sticks. The control centre supports various individually editable functions to ensure safe operation in a complex infrastructure such as the port of Hamburg.

| Thematic intersections of the project |
| --- |
| - ground control / tele operation (VLOS, eVLOS, BVLOS)<br>- Mission planning & monitoring<br>- Services: AI, Swarm intelligence<br>- legal framework, standards and licensing<br>- routing & autonomous navigation<br>- intelligent vessel control |

## RoboVaaS

The Robotic Vessels as-a-Service (RoboVaaS) intends to revolutionise shipping and near-shore operations by offering on-demand robotic aided services via small unmanned vessels (UVs) such as unmanned underwater vessels (UUVs) and unmanned surface vessels (USVs).

The RoboVaaS vision is facilitated by interconnected UVs equipped with specialised sensor technology, a reliable data transfer cloud network for over- and underwater communication, a monitoring station and a real-time web-based user interface. The vision is expected to have a high level of autonomy by using autonomous surfaces vessel (ASVs) and autonomous underwater vessels (AUVs); however, some operations still involve human control through, e.g. remotely operated vehicles (ROVs). The disruptive concept has the potential to improve maritime and human safety, to increase flexibility and accessibility of European waterways and to reduce costs for a multitude of maritime stakeholders. The project concept targets services for the waterborne transport sector but the vision itself is highly transferable to other sectors such as offshore, maritime security, oil & gas and aquaculture.

The project aims at validating the high-level RoboVaaS vision via a selection of identified services by addressing near-shore maritime operations that have a strong benefit on automation and digitisation: The anti-grounding service allows a ship to book an USV that travels ahead for safe guidance through shallow water. The inspection service can be ordered by ships to get a robotic hull and propeller inspection via USV and ROVs while e.g. loading or bulking in port. The data collection service has a wide range of application such as measuring ship emissions or cost-efficient autonomous bathymetry survey of waterways with an USV. RoboVaaS will perform

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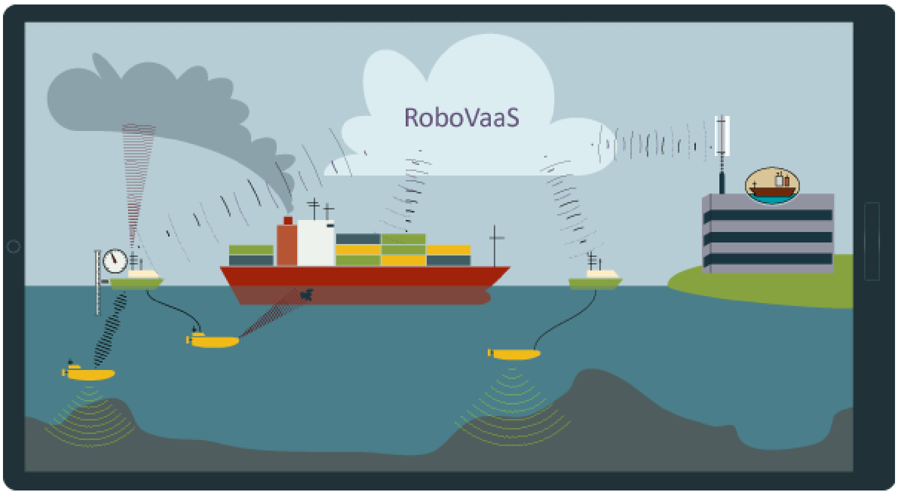
necessary scientific and technological developments to validate these services on three levels in real (small- and large-scale) and virtual (full-scale) demonstrations.[18]




*© RoboVaaS project*

| Thematic intersections of the project |
| --- |
| - Ship emission monitoring<br>- autonomous surveys with USV<br>- legal framework, standards and licensing<br>- routing & autonomous navigation<br>- intelligent vessel control<br>- Mission planning & monitoring |

## Echo.1 – ASV Hydrography Drone

After several months of successful test operation, the HPA's hydrography department operates its first depth sounding surface drone echo.1. Like the HPA's sounding vessels, echo.1 is equipped with an AIS transmitter

[18] Project information RoboVaas

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and receiver, an echo sounder and carries out depth measurements of the water bottom. It is used as a stand-alone unit or as an assistance vessel for the sounding vessels “Deepenschriewer”. Currently, this drone is not yet allowed to be operated autonomously according to the requirements of the harbour master department. The pilot must keep it in sight at a distance of 500m and be able to disengage the autopilot and take over manual control at any time. The degree of automation will be reviewed and extended at regular intervals so that the drone can participate autonomously in port operations in the coming years.


*Hydrographic surface drone echo.1*

| **Thematic intersections of the project** |
|---|
| - ground control / tele operation<br>- autonomous navigation & collision avoidance<br>- mission planning & monitoring<br>- legal framework<br>- interface to internal workflow |

## SeaClear

The **Se**arch, Identific**a**tion and **C**ollection of Marine **L**itt**e**r with **A**utonomous **R**obots (SeaClear) project brings together ultimate aerial and marine technologies into a highly disputed social, economic, and environmental

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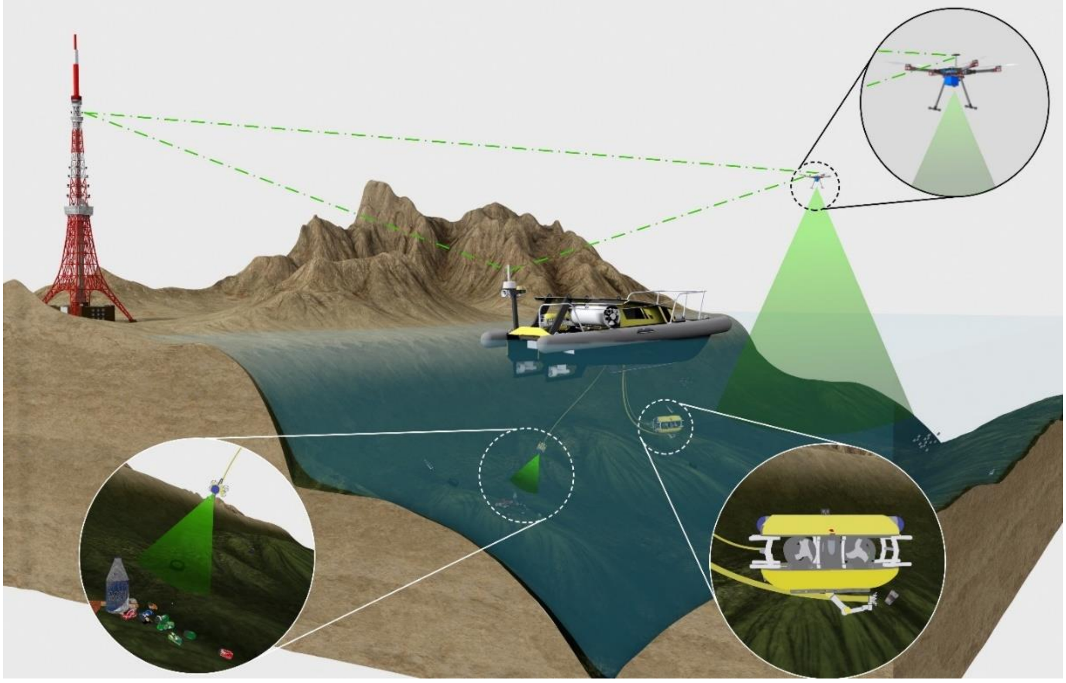
issue, namely ocean pollution. A multidisciplinary team is seeking to exploit its natural synergy for overcoming the technological barriers of designing and implementing an autonomous solution for searching, identifying, and collecting marine waste. The concept is based on the fact that a significant amount of debris is located in coastal areas, sinking to the floor, and thus being unreachable to simple manual labour skimming the surface or automating this process with process with surface vehicles (see the Motivation section). In SeaClear's vision, a group of interconnected unmanned aerial and water borne vehicles with specialised sensory equipment and/or end-effectors, running complex digital image processing algorithms, reliably connected to a data exchange network, and interfaced by an interactive web-based application, are working together towards autonomously fulfilling the task of cleaning marine litter in a predefined coastal area; see Figure1.8 for a graphical illustration of the system. Multiple robots will be employed to efficiently handle the tasks happening at different timescales (mapping, classification, collection). This disruptive concept has the potential to improve maritime safety and human health, to overcome one of the greatest effects of humans (that is, ocean pollution), to reduce costs for a multitude of maritime stakeholders and to help local economies regain their tourism potential.[19]



*The proposed SeaClear concept with SeaCat USV, Guardian observation UUV (left), Tortuga collection UUV (right) and UAV. (Source & ©: project proposal)*

| **Thematic intersections of the project** |
| --- |
| - Ship emission monitoring |

[19] SeaClear project information / proposal

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| |
|---|
| - autonomous surveys with USV<br>- legal framework, standards and licensing<br>- routing & autonomous navigation<br>- intelligent vessel control<br>- Mission planning & monitoring |

## Digital Port Twin

*Digital Port Twin of the Hamburg Port Authority*

The core of the Digital Port Twin is a 3D model of the entire port of Hamburg in a VR environment based on the Unreal Engine. It contains building models, the terrain model and water depths. Data from various weather stations and other sensors are also connected. The Port Twin is currently mainly used by the construction department to integrate and assess BIM[20] projects. The Digital Port Twin is constantly being expanded under the direction of the Chief Digital Office in a wide variety of projects and is to be extended to the entire Hamburg city area in the coming year.

| **Thematic intersections of the project** |
|---|
| - Digital twin simulation |

[20] What is BIM (Building Information Modeling): https://constructible.trimble.com/construction-industry/what-is-bim-building-information-modeling

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- Predictive services
- Real time interfaces
- Low latency interaction
- IoT integration
- 2D / 3D Mapping
- Real world positioning

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# 2. Needs and experience

## General method description

The HPA consulted internal and external stakeholder and reviewed results from other projects and literature. The internal and external stakeholders were introduced to the RAPID project through workshops. During the workshops, the needs and requirements of the stakeholders were surveyed, the most societally beneficial use cases for autonomous maritime vehicles in transport infrastructure MI were identified, and experiences with the use of drones of any kind were gathered and discussed with the project partners.

The stakeholders were asked in detail about any of the four use cases services:

- how they would take value from the particular RAPID service?
- if they were already using a comparable service and what their budget for that service is?
- what kind of specific data do they need as an output from the RAPID process?
- what information, data or interface they could provide for the use case?
- how often they would need the output from the particular RAPID service?
- how often they would use a particular RAPID service?
- what effect the service would have on their daily business?

They were generally asked to assess in which environment they saw the greatest potential tor the RAPID service and to point out their top five criteria that need to be considered today in order to use the RAPID service productively in 2023.

In a further section, stakeholders should state how important the RAPID service would be in their environment in different configurations: VLOS, eVLOS, BVLOS and integration of the service in their own infrastructure or as a bookable service.

Lastly the stakeholders were asked if they would like to be kept informed about RAPID or even would like to see a real demonstration and what their demands would be for a live demonstration and what they could contribute to it.

The workshops will not be considered as completed but will be continued with all interested stakeholders every 6 months in order to be able to react to changing requirements and to take the stakeholders along in the learning process of the project. A cross-sectoral and interdisciplinary Expert Advisory Board will also be established comprising leaders of transport, insurance, regulatory, shipping, and port organisations.

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# Display of requirements and options

## a) From the perspective of the HPA

### Building inspection

For several years, the building inspection has been dealing with the possible use of ROVs as support and extension of ongoing inspection services.

The following core objectives are thus pursued:

1) To reduce the risks for the inspecting personnel as far as possible.

2) To make non-testable areas testable

3) Increasing efficiency during inspections

4) Minimise downtime of heavily used traffic lines

1) Every year fatal accidents occur during building inspection processes. These are caused by rear-end collisions with work vehicles, equipment failure or operating errors. The use of ROVs can be particularly useful in these areas to reduce the risks for personnel. An example in the port of Hamburg would be the rope inspection of the Köhlbrand Bridge (German: Köhlbrandbrücke). Various concepts have already been tested here, all involving a considerable risk potential. In addition to other tests, a rope access under running traffic (rope-based test) or the use of a 70 m elevator standing on the roadway were also tested.

2) There are areas of several structures in the port of Hamburg that cannot be tested without technical support. With the use of ROVs, these areas can now be inspected at least with the help of images and thus the informative value can be increased with regard to the external condition of these structures.

*Prototype of surface vessel for inspection*

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Of course, there are still areas that cannot be inspected (e.g. the foundation). An example of how the non-testable areas can be reduced is the pile foundation of the Hansa Bridge which we can now inspect with our ROV test vessel. The time window of the tide in which an inspection by a diver is possible is only 20 minutes on average and the entire inspection process is associated with a very high risk due to the flow. Therefore, only the first row of piles could be inspected by a diver from the outside. Therefore, no statement could be made about the remaining piles. With the help of the ROV test vessel, the entire pile grid can now be reached and tested.

Pfeiler Nord (Südansicht)

*Bridge construction scan*

3) With ROVs, the structures can be flown over or driven over without any major effort. Depending on the combination of the technology used, focal points for the physical inspection can be identified. The efficiency of the inspection process can thus be increased by identifying in advance the areas where more time and attention is needed. In the future, it will also be possible to identify entire areas that can be completely excluded from the physical inspection if they have already been inspected and evaluated in advance using automated maintenance inspection techniques. An example of this is the use of lasers in tunnels. These can be used during operation and in addition already fulfil parts of the required test specifications and are legally partly accepted.

4) Particularly when using underfloor equipment or lifting platforms, large safety areas must be created and, for example, individual lanes must be closed. For example, when using a 70m lifting platform on the Köhlbrand bridge, the entire bridge must be closed. The installation of scaffolding on only one pier of the Köhlbrandbrücke costs around 350.000€. Here, ROVs can reduce the use of such equipment in the future and thus significantly reduce the negative consequences for infrastructure operation and the associated costs.

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*Manual bridge inspection*

*Manual bridge inspection*

Currently all bridges and engineering structures are subject to a major inspection every 6 years. Here, all structural elements have to be inspected close to the hand. Every 3 years, a simple inspection is carried out, in which the entire structure is inspected and areas that were identified as requiring special inspection in the main inspection are inspected again here. In addition, an annual inspection of all structures is made without technical aids. In addition, there are special cases in which special tests with different intervals are specified for certain components.

At present, the applicable regulations, DIN 1076 and VV WSV 2101, do not provide for the use of ROVs as testing instruments. However, there are already studies that investigate in which areas ROVs can support the tests in the future and should be accepted as an aid. (e.g. study of the Bast of 2014[21]) If it becomes possible in a timely manner, e.g. to optimise interim inspections and thus reduce the associated costs, a clear added value is achieved. The HPA building inspection determines in parallel to what extent these techniques can be used in a supporting way.

All public inspection authorities present their results within the framework of the biennial annual construction inspection meeting. Some of the results are incorporated into the regulatory structures.

21 Martin Sperber, Rainer Gößmann, Corinna Reget, Jörg Müller, Jürgen Nolden, Ralf Köhler,TÜV Rheinland,Köln Lukas Kremkau, Spectair, Meerbusch: Unterstützung der Bauwerksprüfung durch innovative digitale Bildauswertung –Pilotstudie, 2014

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The fundamental interest of the building inspection is to record the condition of a building as comprehensively as possible in order to obtain a statement about the:

1) Stability

2) Durability

3) Operational safety

Furthermore, the building inspection has a considerable interest in the damage progression, e.g. how does a damage develop, and which factors affect it.

Image-based systems can be used, for example, to detect cracks (from 0.2mm) and structural displacements (from 1mm) automatically. The systems must be able to deliver these accuracies with a high hit rate. Therefore, these systems are usually very suitable for damage detection.

*Bridge damages*

Point clouds are particularly interesting for the damage progression, but if structural conditions change due to external influences, these can be better captured in these three-dimensional models. When standing in the building, the building inspector in person does not have a view of the entire building but only a momentary section, models can help here.

The point cloud should be able to show significant changes (from about 2cm).

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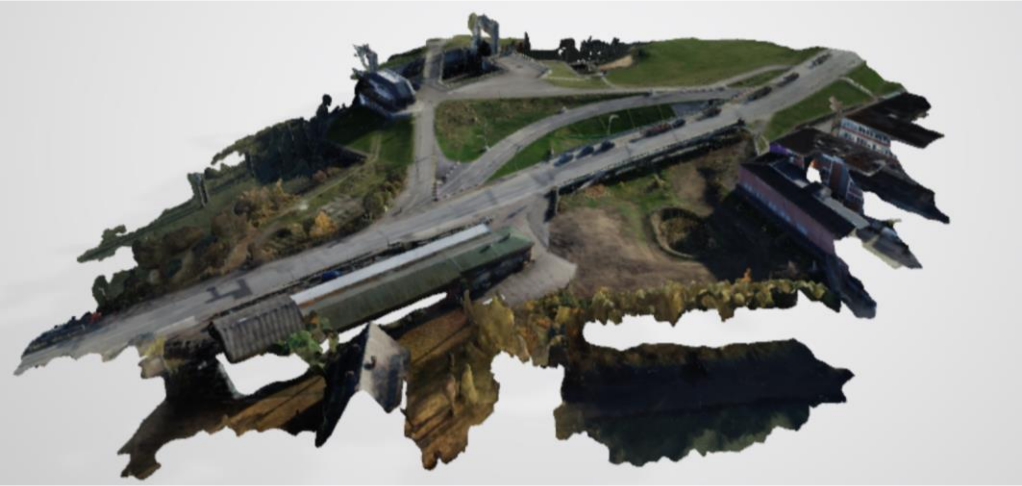

*Point cloud*

### Fleet

The Hamburg Fleet is the full-service provider where vehicles and equipment can be chartered in bareboat charters or with qualified personnel.

Since July 2017, the Hamburg fleet has been bundling the city ships in a comprehensive fleet management system. By establishing its own fleet, Hamburg has created added value for the city and the port. Hamburg's municipal fleet currently comprises around 50 ships. The majority of these are inland waterway vessels with very different functions - from fire-fighting and police vessels to sounding vessels, pilot transfer vessels, transport ships and icebreakers. The fleet also operates dredging equipment, a barge suction station and 40 barges.

The joint fleet management creates synergy effects. Ships can be maintained, repaired and newly procured in a standardised way. Clever pooling and multifunctional deployment options ensure that the vessels are operated cost-efficiently. The fleet finances newbuildings and other investments independently.

The team consists of around 130 employees. The largest share is made up of the crews, i.e. skippers and on-board mechanics. These employees work around the clock 365 days a year to keep the port of Hamburg running. A small, efficient staff takes care of scheduling, maintenance management, newbuilding projects and administration.[22]

[22] Hamburg fleet management: https://www.hamburg-port-authority.de/de/tochtergesellschaften/flotte-hamburg/unser-unternehmen/

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GREEN FLEET

On the basis of its business model, which is unique in Germany, and the specifications of the Hamburg parliament, the Hamburg fleet is implementing a consistent environmental strategy. As a result, the urban fleet has become an innovation driver, testing and implementing solutions for low-emission shipping in Hamburg. The Hamburg fleet sees itself as a role model for other municipal companies as well as for private ship operators. The aim is to achieve a sustainable reduction in emissions of air pollutants that are harmful to the climate and health, such as carbon dioxide (CO2), nitrogen oxide (NOX), sulphur oxide (SOX) and soot particles (PM), through environmentally conscious use of the ships. The Hamburg fleet has therefore developed a consistent environmental strategy based on a practice-oriented 5-pillar concept.[23]

In line with the business segment and the sustainability strategy, the fleet's focus is primarily on the project results of the use case environments 1 and 3. Even though the majority of ship classes can currently be checked directly on sight, the focus of interest in this environment is primarily on the technical and sensory procedures for damage assessment and prediction.

[23] https://www.hamburg-port-authority.de/de/tochtergesellschaften/flotte-hamburg/gruene-flotte/

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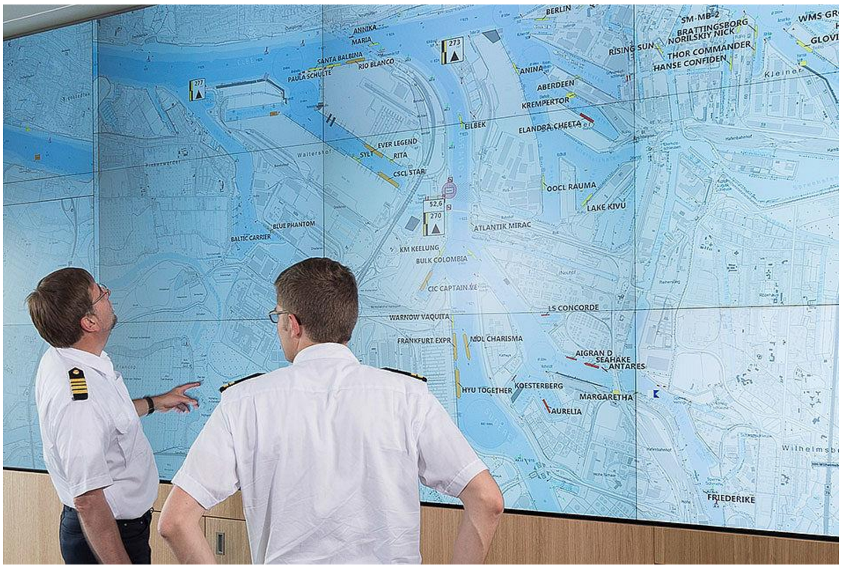
### Harbour master

The port of Hamburg has a high daily volume of sea, inland, traditional and sports shipping. At this hub, the HPA and its Nautical Information Centre ensure safety and smooth traffic. It uses one of the most modern IT-based control systems for coordinating shipping traffic. The port authority also ensures shore protection, takes care of bridges and locks and provides flood protection. With its strong fleet, it secures and protects the future of the port and the river Elbe.

One of its main tasks is to provide advice on nautical matters that need to be taken into account in shipping traffic, construction planning or approval and licensing procedures. In this field, the Harbour Master is recognised as a competent contact and knowledge carrier for the port of Hamburg and is therefore regularly consulted within the HPA as well as by the port industry. The Harbour Master is responsible for:

- *9,000 calls of sea going vessels per year*
- *10,000 inland ship´s calls*
- *43 km quay walls*

The central task of the Harbour Master is the preventive performance of its duties: to recognise foreseeable disruptions in time and to take appropriate measures before anything happens - this contributes significantly to the productivity of the port of Hamburg.



*Nautical Information Centre*

Since drones will now also be used as traffic participants in the port of Hamburg, the Harbour Master Department is interested in working on safe integration solutions. Research projects like RAPID offer a unique opportunity to participate in the development of system solutions at an early stage.

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Prospects of the Harbour Master Department must take the following points into account from the outset:

- *Process integration*
- *Communication*
- *Security*
- *Legal conformity & responsibility*
- *technical maturity level*

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## b) From the perspective of the Port of Hamburg

Located in Hamburg there are already various very advanced automated drone services. From organ transportation and document transport to fully automated maintenance and inspection services. In addition to productive units at the police, fire and rescue services and various service providers, the companies HHLA Sky and Beagel Systems in particular, as well as the Medifly project, offer very mature BVLOS services.

Beside various services, the HHLA Sky provides his own drone control centre service. The HHLA Sky's range of services covers almost every relevant full-service area.

The system allows the safe operation of drones out of sight (BVLOS) and they offer the industrial drones for special use in industrial environments. With the integrated control station, it is possible to operate more than 100 drones in parallel for a wide variety of service tasks.

The offer provides for the purchase of the control stations and the associated software licences for operation or the leasing of a complete service package from HHLA Sky.

Each of these displayed programmes has one thing in common. They rely on a high degree of automation and an operation of the systems beyond visual line out of sight.

These, as well as the HPA's own programme PORTwings, have not yet been finally approved for regular operation. However, within the scope of special approvals and extensive test series, these programmes have repeatedly proven their maturity and approval can be expected in the near future.

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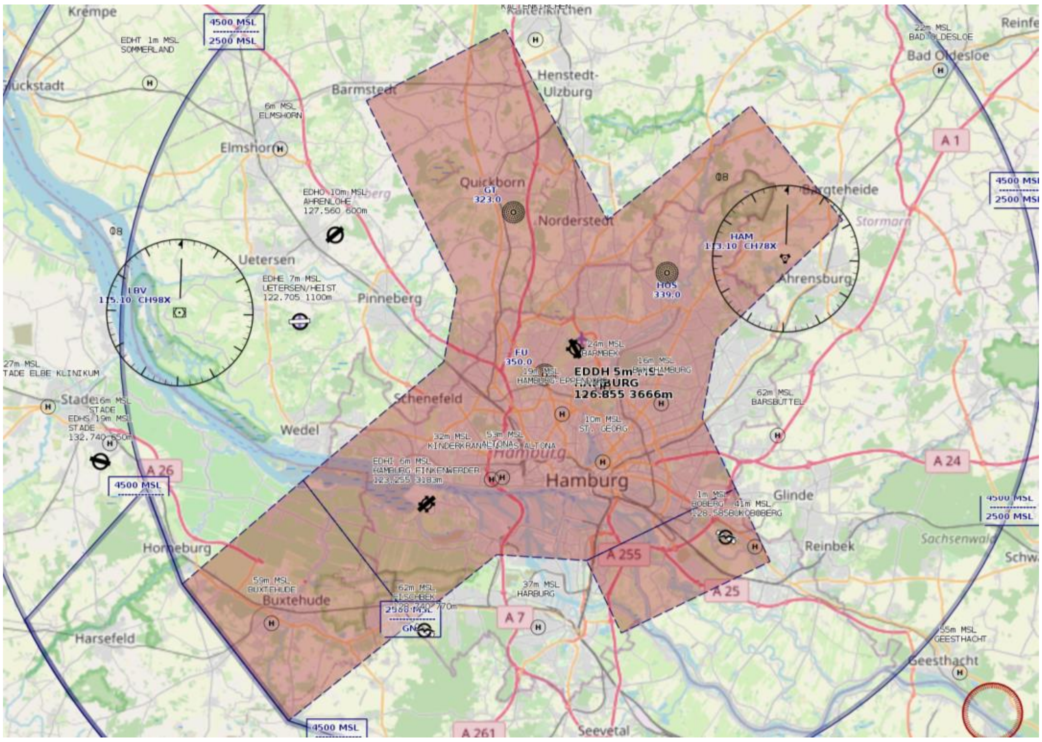
## German air control (DFS) & Air control (BWI)

While the area of the Port of Hamburg is considered an industrial area with complex operational structures anyway, this upcoming system expansion poses additional challenges for all parties involved. Due to the fact that the majority of the port of Hamburg is located in controlled airspace, the operation of fully automated or autonomous systems poses additional challenges.



*Hamburg controlled airspace*

Currently, drone operations, regardless of the control mode and purpose, are only carried out with a large number of approvals. The pilot's qualification, possible irritation of shipping traffic, and contacts with federal waterways are examined in the same way as the safety assessments of the mission, the hardware to be deployed or special circumstances in the context of ground interests and installations.

Future solutions and approaches should simultaneously take into account all the circumstances and interests of the port area in a multi-perspective manner and optimise the required operational procedures.

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### c) From an offshore perspective

Offshore operations, by their nature, occur in extreme and hostile environments which drives a movement among marine asset owners and service providers to reduce personnel required offshore. This alone yields the demand for autonomous vehicles that can provide data collection and asset inspection services with lower risk to personnel, lower emissions and lower cost.

Marine infrastructure is expected to continue to increase at a rapid pace with the onset of offshore wind and the continued demand for green energy driving data collection services through their lifecycles. As more industries aim to pursue the transfer of these services, drone technologies will need to be able to fulfill inspection and service activities beyond those intended by RAPID.

### d) From the perspective of maritime industries

There is an extensive demand for automated maintenance and inspection services in the maritime environment. This is confirmed both by the market analysis we have carried out and by the feedback we have received from external stakeholders.

The large number of technical key topics and the very early participation of industrial companies in the most diverse research and service topics impressively underline the given demand. The feedback from the Bernhard Schulte Group also shows that companies are prepared to engage in very closely coordinated project developments in order to obtain a product that is as specific as possible to their needs.

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# 3. Analyse collected data to identify and proof the requirements and needs

The requirements and needs of the project stakeholders listed above are analysed and summarised. The needs are considered separately from the stakeholders, if the context to the stakeholder is not relevant for the respective requirement, in order to enable bundling. The requirements and needs are listed in tabular form and prioritised by the MoSCoW[24] method. This prioritisation also results from the statements of the stakeholders and project partners.

Missing a requirement with a “must” prioritisation could lead to a fundamental failure of the technology implementation, while the "should" reflects the importance of the requirement for a successful deployment of the technology in the market for the particular use case. The "could" stands for requirements that are addressed by stakeholders as desirable but not essential. The fulfilment of a requirement with the prioritisation with "won't" is not explicitly addressed within the project, as it either goes beyond the scope of the project or is almost irrelevant for the established use cases.

| **Requirement** | **MoSCoW** |
|---|---|
| Output provides a 3D model or pointcloud where detected in infrastructure or ship hull damages can be located. | S |
| Output combines a 3D model with a report | S |
| Images of an incident contain coordindates of the pictured content | M |
| Heat maps of the incident | M |
| Image transmission from an incident can be provided continuously over a period of at least 1 - 2 hours | M / S |
| Situation picture transmission starts within approx. 15 min after receiving the flight order | M |
| RAPID service offers comparation of successive acquisitions | S |

[24] Clegg, Dai; Barker, Richard (1994). Case Method Fast-Track: A RAD Approach. Addison-Wesley. ISBN 978-0-201-62432-8.

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| | |
|---|---|
| Output contains high quality raw images | S |
| Defect detection is IFC compatible | S |
| Output can be imported to software *SIB Bauwerke 2.0* | C |
| Scan format is LAS and xyz | S |
| 3D model format is OBJ | S |
| Pollution measurement of SOX, PM and airborne noise plus visual check for signs of water pollution | S |
| Ships are qualified as within environmental protection margins or not | S |
| Ship inspection for hull and propeller fouling evaluation | S |
| Ship hull inspection includes check for oil pollution from Stern tubes, bow thrusters, sewage overboard | S |
| Ship hull and propeller inspection can be combined with autonomous hull cleaning and propeller polishing service | C |
| Ship hull inspection includes cracks and deformation | S |
| UAV operation follows the common law | M / M |
| Defect detection has little to no tolerance | S |
| Simple to use mission planning | S / S |

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| | |
|---|---|
| Search for missing persons in an accident | C |
| The Drone control within the RAPID Service need to be done VLOS? | S / C / S |
| The Drone control within the RAPID Service need to be done eVLOS? | C / S |
| The Drone control within the RAPID Service need to be done BVLOS? | M / C / M |
| The integration of the RAPID Service in your own infrastructure? | M / S / M |
| Using the RAPID Service as a bookable product? | C / M / S |

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# 4. Comparison with the objectives

In the previous chapter the requirements of the designated stakeholders and project partners were analysed and prioritised. According to the prioritisation, the MUST requirements are compared with the objectives of the RAPID application in the following table, in order to determine whether the previous objectives of RAPID meet the demands of the stakeholders and fulfil the criteria for satisfying the requirements. The table also shows whether certain objectives formulated at the time of the project application are now obsolete.

The requirements have been established by the stakeholders in relation to the use cases, but at this point they are considered globally for the whole project. The assignment of the requirements to the individual use cases is carried out in Deliverable 1.2.

**The RAPID objectives are:**

O1. Improve planned operational safety by Digital Transformation of UAS risk management [WP2].

O2. Minimise UAS collision risk in complex BVLOS survey flight by developing swarm robustness [WP3].

O3. Extend UAS reach, duty cycle, and power reliability by developing Smart Energy Management [WP4].

O4. Improve efficiency, accuracy, and insight of structural condition monitoring by equipping the maintenance-inspection workflow with smart automation [WP5].

O5. Overcome resistance to adoption and inform legal regulations by clarifying and contributing to the development of laws and standards for USV / UAS operations [WP6].

O6. Integrate and validate the pilot UAS / USV enabled asset inspection service in Hamburg Port [WP8] to demonstrate societally beneficial UAS services and improve public perception and acceptance.

O7. Fast track the outcomes and technologies developed by RAPID by formulating the business model to replicate and scale the pilot service built upon the Hamburg demonstrator [WP8].

| Stakeholder requirements | RAPID objectives |
|---|---|
| Drones operate in accordance with the law. | O1, O5 |
| Drones operate BVLOS. | O2, O1 |
| RAPID service is integrated in the own infrastructure. | O6, O7 |

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| | |
|---|---|
| RAPID is a bookable service | |
| Image transmission of an incident starts 15 minutes after flight order. | O1, O4 |
| Continous image transmission over 1 - 2 hours. | O3. |
| Beyond cracks paint defects and other defects should be monitored. | O4. |
| Detected damage should be locatable e.g. in a 3D model or pointcloud. | |
| Incident image transmission contains coordindates. | |
| Heat maps of the incident | |

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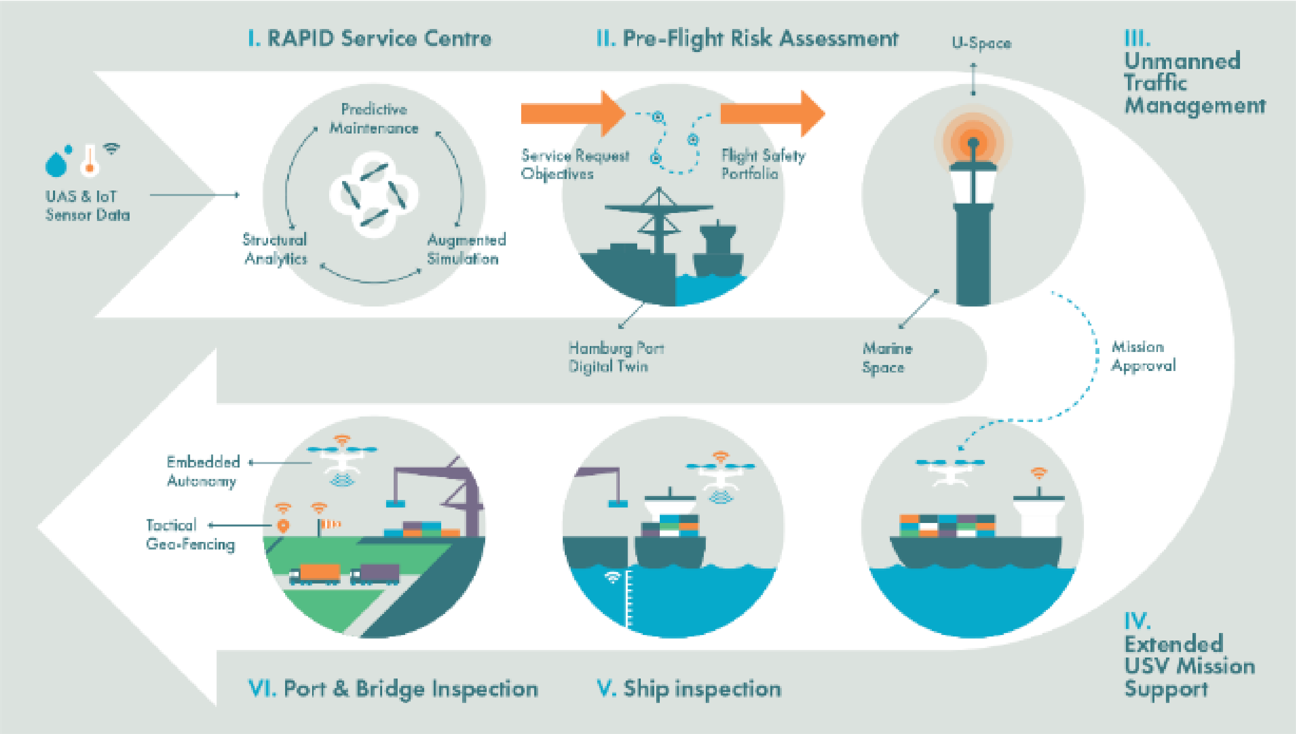
# 5. Concept Infrastructure

To achieve ground-breaking impact on UAS adoption for ensuring safety in transport, RAPID brings together critical attributes of MI workflow automation, safe UAS delivery, and service innovation. The MI service is realised as a digitally transformed survey, with a typical use-case mission profile executing as shown in the following figure:




*The RAPID mission cycle*

I) Service Level Request (O6): The customer interface is simplified to a web transaction, whereby the customer submits an inspection service request (e.g. ship hull survey) and receives an augmented reality presentation of identified structural faults (deformation and cracks, etc.) when the survey has completed. The web interface consists of a Geographical Information System with AIS ship location and static bridge and equipment assets within the port service area. Handling of service requests will prioritise incident response. The Port will host the resident service command and control centre. This comprises the augmented UAS simulator, which will leverage an existing Port Digital Twin[25] that is synchronised with the Port reality by a stream of distributed Internet of Things sensor data, such as weather and Port traffic activity. The subsequent services stages II-V are automated and transparent to the customer. The RAPID Safety by Design approach embeds a hierarchy of safety controls to safeguard transport system users and inspection personnel. Scaled UAS data collection will enable the elimination of unknown points of structural failure by enabling more frequent condition surveys

[25] Saxe, Sebastian. "SmartPORT traffic hub–the prospects for an intermodal port of the future." Digital marketplaces unleashed. Springer, 2018. 417-426.

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without budget strain. Substitution of manual MI workflows with automated temporal tracking of potential points of failure will enable early preventative maintenance. Engineering controls such as augmented reality fault visualising will isolate inspection personnel from the hazard of physically marking structural faults. End-user informed KPIs for accuracy and precision of fault detection and morphological change sensitivity will adhere to administrative engineering rules such as DNI 1076 used by HPA.[26] The inspection-survey sub-concept is detailed further in sub-section E below.

II) Mission Planning (O1): Software for automatic generation of survey plans will be developed to optimise mission safety. The risk profile will be evaluated against real-time and expected conditions using the Port Digital Twin, and refined through exhaustive simulator evaluation (WP2) of potential situational scenarios to identify perception sensor responses (WP3) and power system states (WP4) that present safety threats to the UAS flight plan. For example, detectable abnormal LIDAR conditions (e.g. poor signal to noise ratio) caused by multipath and occlusion lead to undesirable states such as loss of target recognition. If redundant navigation systems, such as positioning GNSS and satellite ADS-B tracking are simultaneously denied (for instance beneath a large structure), a single point of failure will occur. Alternatively, a change in wind speed and direction can drastically reduce the flight endurance requiring earlier than scheduled return to the USV for energy recharge. These situations will be detected in advance and avoided through strategic mitigation (at the control and command centre) to adapt the flight plan, while realtime live assessment during flight (using the USV compute hardware) will enable tactical risk mitigation for resilient mission corrections. Traceability of test scenarios to the use case needs elicitation will define the pool of conceivable flight profiles, with context-aware verification and validation incorporated to minimise the occurrence of unknown theatre situations. The simulator environment will enable early testing of UAS software prototypes to virtualise the risk of failure. The concept is also transferable to USV mission planning as USV sensor-driven collision avoidance has many parallels with the UAS paradigm. Through repeat use, RAPID will generate data to improve performance prediction and test case generation and the real-world evaluation data will feed into the development of urban-industrial BVLOS Standard Scenarios to reduce uncertainty in UAS flight.

III) Mission Approval (O6): RAPID will perform a digital transformation of UAS flight approval to enable safe, automated, and compliant service delivery (WP2). Flight approval of lightweight commercial UAS, termed "Specific Category", involves the production of a Comprehensive Safety Portfolio (CSP) that details the flight safety objectives, operational risk assessment, and mitigation and containment measures. The operation-centric authorisation regulations are provided by EASA and operators submit approval requests to their competent national authority. They are the EASA mechanism to alleviate the administrate burden of U-Space flight approval and they will be defined by stakeholders. RAPID also incorporates a USV, with the added complication of maritime legal instruments (UNCLOS[27], COLREGS[28], MARPOL[29], SOLAS[30]) and safety compliance rules (e.g.

[26] Highway structures - Testing and inspection, Deutsches Institut fur Normung E.V. (DIN), 1999 Edition

[27] The 1982 United Nations Convention on the Law of the Sea.

[28] Derived from the 1972 Convention on the International Regulations for Preventing Collisions at Sea and published by the IMO.

[29] The 1973 International Convention for the Prevention of Pollution from Ships, as modified by the Protocol of 1978.

[30] The 1974 International Convention for the Safety of Life at Sea.

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NAVSAC[31], MASRWG[32], SARUMS[33]). Encompassing underdeveloped aerial and maritime legal landscapes in relation to unmanned platforms, a consolidated RAPID "Standard Scenario" is required to unlock UAS land/sea services (WP6). As digital toolchain technologies for UAS (and USV) mission approval does not yet exist, compliance is achieved through a series of manual complex processes and procedures including a Specific Operational Risk Assessment (SORA[34]). RAPID will digitalise the SORA workflow to enable automatic generation of CPS information using the Digital Twin simulator for VLOS, BVLOS, and automated BVLOS flight. The RAPID Risk Management platform will improve pre-flight decision-making by identifying the safest flight path(s) and optimal risk-reducing mitigations by deep data mining the CPS information. The RAPID framework will optimise the simplicity (user experience), efficiency (process time), and accuracy (prediction) of the UAS flight approval workflow and complete the approval process on behalf of the customer (and service provider) (WP3).

IV) Service Deployment - Unmanned Surface Vehicle (O3): Once the mission request is approved by the maritime and aviation traffic control, the USV will be used to ferry the UAS swarm to the safest dispatch location within flight range of the remote asset (ship, bridge, etc.), as determined at Stage II. The USV navigation system will integrate with the port Vessel Traffic Management System to assist collision avoidance. With the USV support, extended reach locations will encompass 10s of kilometres of quay terminals, accessible upstream bridges, and seaward to port approach lanes, which is far beyond the reach of SoA mission configurations. An automated UAS take-off and recovery (TOAR) guidance system will be developed (UL) to enable missions in moderate sea swells and wind. As the inspection survey is executed by several autonomous UAS and the USV, swarm coordination strategies and methods will be developed to enable collaboration and task execution in a cooperative, efficient, robust, and scalable way (WP3). The coordination will be developed to handle heterogeneous systems including agents with very different capabilities (UAS and USV) allowing also to include several variations of UAS embedding with different kinds of sensors with different accuracies. The USV dynamic positioning will adapt the UAS Return to Home (RTH) location according to a hierarchy of safety behaviours (such as ship traffic avoidance, TOAR shelter, viewpoint for swarm observation, and optimal solar harvesting) (WP4). The USV will be equipped with marine refined solar energy harvesting, battery recharge, and UAS battery hot-swap capability to extend the UAS utilisation by eliminating downtime due to battery recharging (WP4). As RAPID is decoupled from the electric grid it has the resilience to power network outage (such as during fire outbreak). When a UAS battery reserves are depleted, it will return to the USV for battery hot-swap. The USV will maintain a collection of batteries on recharge to eliminate the battery recharge time from the UAS duty cycle. The USV will host a power system (and perception) Digital Twin to monitor and predict the UAS energy budget envelops and prevent unexpected power failure. The novel USV coordination concept enables remote UAS transport, *in-situ* high-performance computing, and swarm force multipliers. The concept enacts a stepping-stone to long-term impact objectives of residential unmanned platforms to support autonomous passenger ferries, border surveillance, and search and rescue response.

V) Service Survey, Input-Process-Output (O4): The preceding mission stages (II, III, & IV) safety bring the UAS survey capability to the remote asset. RAPID automates the inspection survey workflow into an innovative four-

[31] U.S. Navigation Safety Advisory Council.

[32] U.K. Marine Autonomous Systems Regulatory Working Group.

[33] Safety and Regulations for European Unmanned Maritime Systems (Belgium, Finland, France, Germany, Netherlands, Italy and Sweden).

[34] See http://jarus-rpas.org/sites/jarus-rpas.org/files/jar_doc_06_jarus_sora_v1.0.pdf.

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stage process to convert multi-sensor structural condition data into a 5D augmented reality (AR) overlay of surface shape, appearance, and temporal changes. The output will be available to the customer immediately following completion of the survey and viewable by AR glasses or screen display. Geo-referenced virtual tags of potential points of failure will be displayed as a layered visualisation over the real-world structure, with supporting analysis information such as crack morphology or structural deformation.

U-Space projections of 20,000 UAS flights per city per hour by 2035 highlight the need for a digital system to automate UAS service provision. The RAPID service concept is needs-driven and informed by end-user partners HPA and XOCEAN. RAPID will embed Safety by Design into UAS flight control to prevent risk transfer of improved transport safety at the expense of utilising unproven UAS. The USV swarm-ferry enables elimination of high-risk UAS long-baseline transit to remote urban-industrial assets. Solar energy generation enacts an emission free solution, augmented with onboard ship emissions monitoring. Embedded perception based localisation eliminates reliance on uninterrupted GNSS and adds redundancy to U-Space ADS-B tracking. The substitution of cloud computing with edge computing will minimise the vector for cyber-attack by reducing possible telecommunication pathways. Engineering controls will be designed to isolate in-flight UAS from hazards and people to minimise collision risk and protect privacy. Intelligent digital twins will be used to virtualise risk identification. Embedded perception sense-and-avoid and machine-learning battery management will be designed to minimise collisions due to loss of situational awareness or battery depletion. The interdisciplinary concept is made possible by codifying and augmenting EASA administrative controls, which introduce procedural UAS compliance changes to limit people's exposure to UAS hazards. Public/societal engagements on issues related to the project are described in Section 2.2.c and WP9 (Communications).

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# 6. Opportunity Assessment

The results achieved within the framework of the RAPID project can be diverse, but their direct usability at the end of the project cannot yet be finally assessed. It is equally conceivable that the results will result in fully usable services or basic developments on which to build on. However, given the diversity of developments, this should be seen as an advantage rather than a disadvantage.

As a prospective user of an inspection and maintenance service, it is conceivable and, from the HPA's point of view, also desirable to use the RAPID service - or sub-products - profitably within the framework of intelligent port infrastructure management.

For the HPA it is of secondary importance whether the result is a coherent system or various individual solutions to cope with specific challenges. Each of the infrastructure maintenance tasks is extensive and costly, and each partial service is correspondingly helpful in optimising the handling of inspection and maintenance tasks.

What is certain from the HPA's point of view is that there is a serious interest and a real need for automated maintenance and inspection services. The HPA is prepared to use new services or to complete the basic developments that have been created in cooperation with other industrial partners.

In the future, the fourth use case “collision accident response” could be extended to include parts of use cases 1 and 3. In the event of an accident or disaster, this would make it possible to determine environmental data and the condition of the ship's hull in addition to providing a situation picture. In further more, persons in the water or persons requesting help could be identified via an AI and also transmitted to a rescue team. Beyond noted use cases, the RAPID developments could be extended to meet the needs of offshore asset inspection and increased environmental monitoring needs of offshore infrastructure operators and service providers. Significant demand will be driven by offshore wind developments and their need for cean data throughout their lifecycles.

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# Version history

| Version | Changes | Responsible | Reviewed by |
|---|---|---|---|
| 23.10.2020 | First Version | HPA | UWS, XO |
| | | | |

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# Risk-aware Automated Port Inspection Drone(s) – RAPID

RAPID will save lives by delivering an early warning system that will detect critical deterioration in transport system infrastructure, while also minimising system disruption and delays to critical supply chains.

RAPID will save lives, minimise system disruption and delays to critical supply chains.

What is RAPID - Risk-aware Automated Port Inspection Drone(s)?

The EU-funded RAPID project will combine and extend drone technology to deliver a fully automated and safety-assured maintenance inspection service for bridges, ship hull surveys, and more. Specifically, the service will combine self-sailing unmanned surface vehicles with autonomous unmanned aerial systems. The aim is to reduce the time and cost of structural condition monitoring of maritime transport infrastructures such as material-handling equipment, cargo and passenger ships, and bridges. RAPID's new system will also facilitate the prioritisation of safer transport infrastructure.

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