Information System for Monitoring and Planning Maintenance of Offshore Wind Farms

Victoria Vysotska[1], Kirill Smelyakov[2], Nataliia Sharonova[3], Maksym Derenskyi[2], Ganna Pliekhova[4], and Vadim Repikhov[2]

[1] *Lviv Polytechnic National University, Stepan Bandera Street, 12, Lviv, 79013, Ukraine*
[2] *Kharkiv National University of Radio Electronics, 14 Nauky Ave., Kharkiv, 61166, Ukraine*
[3] *National Technical University "KhPI", Kyrpychova str. 2, Kharkiv, 61002, Ukraine*
[4] *Kharkiv National Automobile and Highway University, Yaroslava Mudrogo str. 25, Kharkiv, 61002, Ukraine*

Abstract

The paper is devoted to describing the key aspects of the development and use of a prototype information system for servicing offshore wind turbine farms. The prototype of the information system makes it possible to model organizing of maintenance of offshore wind turbines. Thus, it is possible to place offshore wind turbine farms on a map of the water surface at the required scale, set and change parameters. Model the organization of maintenance of offshore wind farms for different situations and a set of turbines that need to be serviced and lay out the optimal route between port points and a set of turbines. The optimal route building process considers dynamic weather conditions to build the optimal route, which affects the consumption of fuel and maintenance resources. The system has developed not only the algorithm and functionality, but also the interface and visualization system for the optimal route. This allows the prototype to be effectively used for experiments and practical purposes. The information system is fully integrated, that is, it adequately considers all the main influencing factors in the subject area for modeling the organization of maintenance of offshore wind power plants. The prototype is still under active development, it is planned to develop or adopt optimal path planning algorithms and integrate artificial intelligence into the system, which will potentially significantly increase the efficiency of the system.

Keywords

Decision support system, internet of things, offshore wind farm, wind farm, offshore wind turbine, maintenance planning, optimal route, dynamic data, visualization, artificial intelligence, visualization

1. Introduction

In our time of general transition to renewable energy sources, the production of electricity with wind turbines has gained significant popularity. Offshore wind turbines are a key technology to increase the incorporating of green energy into the electricity market [1].

Offshore wind farms are usually located in clusters offshore to form wind farms. To service them, ships with teams of specialists leave the ports to carry out inspection and maintenance of turbines that became faulty, broken or for scheduled inspection.

Turbine maintenance begins with the process of organizing, drafting ships and crews, and drawing up a route on map. It is common for this process to still take place "on paper" that leads to unnecessary spending of extra time. It is also necessary to consider environmental factors, such as weather conditions, routes of other ships, and forecasts for applying necessary changes.

COLINS-2024: 8th International Conference on Computational Linguistics and Intelligent Systems, April 12–13, 2024, Lviv, Ukraine
victoria.a.vysotska@lpnu.ua (V. Vysotska); kyrylo.smelyakov@nure.ua (K. Smelyakov); nvsharonova@ukr.net (N. Sharonova); maksym.derenskyi@nure.ua (M. Derenskyi); plehovaanna11@gmail.com (G. Pliekhova); vadym.repikhov@nure.ua (V. Repikhov)
0000-0001-6417-3689 (V. Vysotska); 0000-0001-9938-5489 (K. Smelyakov); 0000-0002-8161-552X (N. Sharonova); 0000-0003-1539-8018 (M. Derenskyi); 0000-0002-6912-6520 (G. Pliekhova); 0000-0002-1274-4205 (V. Repikhov)

Nowadays, there is no such information systems that would allow effective monitoring of the situation and planning of maintenance of offshore power plants (including data entry and situation modeling, optimization of logistics routes, decision support, etc.). This leads to inefficient use of resources in terms of costs of finance, fuel, and employee time.

Currently, the urgent task is to develop automation systems for production and technological processes that allow performing labor-intensive routine tasks, including calculations, optimization, data exchange, and preparing optimal solutions for the operator, according to the selected criteria and application conditions. Including, for servicing offshore wind turbines, mainly for optimizing time consuming and other types of resources, as well as helping in making decisions during professional activities.

The information system must holistically integrate the functionality of managing the necessary entities, provide their visualization on a real water surface (map), and allow the organization of turbine maintenance, bringing the process as close as possible to the real work of the operator. The information system should provide a convenient interface with all the necessary controls and visualization of ongoing processes to simulate a wide range of situations and relatively quickly give an understanding of the essence of the process. The system must also suggest optimal routes between turbines, considering external dynamic factors affecting the ship's route and avoiding unfavorable factors.

The object of this paper is a developing of a part of complex information system for entering wind turbines related data and organization of their maintenance.

For these purposes, the following problem is solved in this work.

- An analysis of the current state of the issue in the subject area is given.
- Developing of the requirements for a modern decision supporting system for organizing the maintenance of offshore turbines.
- Developing information system model, algorithms, description of implementation technologies used.
- Description of the proposed implementation, experiments, their results interpretation, metrics assessment, recommendations, and effectiveness assessments are given.

2. Related works

Analyzing the latest reviews [2-4], in recent years, technologies for building decision support systems, business automation and processes visualization in robotics, medicine, transport, etc. have been dynamically developing. The use of modern information technologies and computer technologies makes it possible to simulate real situations in the subject area as precisely as possible when creating decision support systems. Some papers regarding methods of positioning and tracking the position of objects on the map were reviewed [5-8]. In this regard, the development and transfer of technologies in the development of information systems to assist decision-making for servicing offshore wind power turbines is relevant [9-11].

In this regard, [5] proposed a model to improve positioning efficiency through collaborative positioning in a partial GNSS environment in ad-hoc networks. The work [6] presents the results of research in the field of positioning based on magnetic location - a new tool for modeling the magnetic field is presented, considering the specification and localization area. The work [7] presents intelligent short-range navigation technologies based on IoT. In paper [8] a new algorithm for short-range vehicle localization to compensate for the GPS distance gap is proposed. Work [9] describes the use of Internet of Things (IoT) technologies to collect data from sensors about the state of machines and robotic systems. Works [10-11] describe the development of a turbine control and maintenance information system, in which the parameters of an individual turbine are controlled and monitored using Internet of Things (IoT) technologies. Such systems have experimentally proven their effectiveness in controlling and maintaining wind turbines, as well as in predicting the remaining turbine life based on condition data from sensors.

A review of materials was also carried out in relation to the process of servicing wind turbines. For example, paper [12] presents a describing of the wind turbine maintenance scheduling problem and presents a nonlinear integer programming model for large-scale wind turbine maintenance scheduling. Paper [13] proposes a multi-level opportunistic maintenance model that allows minimizing turbine maintenance costs. The work [14] proposed a scheme for intensifying the maintenance and inspection of offshore wind energy facilities. A review of preventive maintenance planning for offshore wind power plants was also analyzed [15], which examined the routing of turbine maintenance personnel and proposed a multi-criteria model for its optimization to reduce time and financial costs. The paper presents numerous decision variables, including task assignment, maintenance scheduling, and vehicle routing. A reliability index based on maintenance losses was also introduced and a genetic sorting algorithm was applied to obtain compromise solutions that balance different decision preferences. Work [16] describes the maintenance processes of wave farms. The paper proposes an optimal maintenance strategy for a group of wave farms, leading to adaptive planning of repair time based on the condition of the entire farm. It applies methods to find the optimal compromise between the level of farm performance and the number of devices that fail.

An analysis of the current state of the issue shows significant progress in the field of building a variety of information systems for decision support and the relevance of using the models, algorithms and technologies developed in them, including in the field of optimizing business processes and resource costs, including for servicing wind power plants [17].

The key requirements for such a system are a coordinated comprehensive considering of ongoing processes, entities and influencing factors, a high level of visualization, real-time work on real maps of the water surface, the ability to quickly correct situations, work with different scenarios and sets of entities.

In terms of the development of such simulators, relevant aspects are the implementation of modern image processing systems and computational intelligence [18] to improve the perception, learning and integrity of processing data streams; latest solutions in the field of network optimization [19] and hardware technologies for high efficiency of network communication; modern methods and tools for implementing the interface and visualization of the simulator to ensure a high level of personnel training in e-learning systems according to modern assessment criteria [20].

3. Methods and Materials

This section presents the principles of organization and operation of the developed part of the decision support information system for servicing offshore wind farms, namely the data input subsystem and situation modeling of a promising decision support system.

Decision supporting systems are computer automated systems, the purpose of which is to help people making decisions in difficult conditions for a complete and objective analysis of subject activity. For example, works [21, 22] show an example of the development and implementation of such decision support systems that perform labor-intensive routine functions. Some processes are performed without operator intervention, and for some the system prepares all the necessary data, creates a set of optimal solutions according to the selected criteria, after which the operator only must confirm one of the proposed options.

The basis of the subsystem is a network of offshore power plant farms independent from each other, which consist of wind turbines that have a clear, fixed location. As stated in [23], ships with crews leave ports to service turbines. Crews are formed by the operator in advance for a certain period and include a lot of specialists. Wind turbines can be located quite large distances offshore, which contributes to the planning of long sailing routes.

The main purpose of a decision support system for offshore wind farm maintenance is to assist the operator in organizing the maintenance of these offshore wind farms, which includes entering data into the system, locations of ports, farms, turbines, ships, as well as creating the maintenance itself, adding specialist teams and selecting serviced turbines.

3.1. Information system requirements

The purpose of the information system being developed is to allow enter necessary data and model various situations for organizing the maintenance of offshore wind turbines, input and visualize on a map of all entities involved in the system. This is the first but most crucial subsystem that, in the future, will allow us to work with necessary data to proceed with developing of others part of complex decision support system that gives functionality of building optimal sailing routes between turbines based on dynamic data.

It is planned that the information system will have the following functionality.

- Input and visualization of system entities, which includes ports, farms, turbines, ships, and inspection teams.
- Turbine maintenance organization.
- Dynamic data collection.
- Building optimal routes.

In this work, it is planned to concentrate on the development of a subsystem for input and visualization of entities, as well as the primary organization of turbine maintenance, which includes the creation of maintenance teams and ship selection.

The information system must consistently link entities in a single knowledge base, provide a convenient and responsive interface, and clearly visualize ongoing processes.

3.2. Monolith and Microservices approach

Program interface (API) is a part of the software, which is several small applications that cooperate with each other and send data to the client part. The application principles are based on the microservice architecture of the software.

In papers [26-28] there was given a comparison between two popular approaches of web software development: monolith applications and microservices. The picture of each is presented in Figure 1.

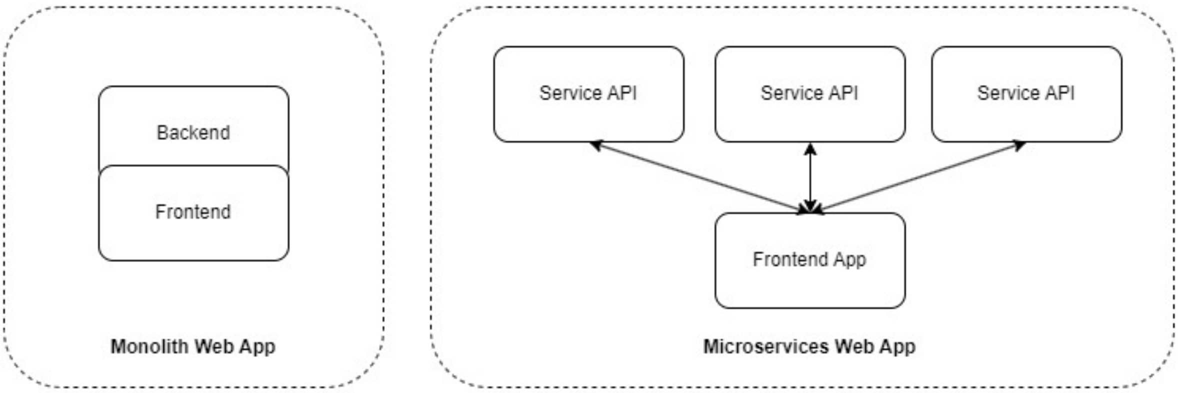


Figure 1: Monolith and microservices architecture scheme

Building applications using the principles of microservice architecture has been used in the construction of large projects for a long time. This approach to application architecture became widespread with the development of agile development practices and DevOps. Now, microservices architecture receives a lot of attention: articles, blogs, discussions on social networks and presentations at conferences. When it comes to ensuring the flexible development and delivery of complex corporate applications, this method of development has significant advantages.

Microservices architecture is an approach where a single application is built as a set of small, self-contained, independent services that are not closely related, which interact with each other using lightweight communication mechanisms such as HTTP, gRPC, AMQP, etc. Such services are built around business needs, where each individual service is responsible for a specific process or business entity and is deployed independently using a fully automated environment. There is an absolute minimum of centralized management of these services. The services themselves can be written in different languages and use different data storage technologies.

One of the reasons for using microservices is that companies want to be able to change things quickly to respond more quickly to changes in business and market requirements. Microservices help developers deliver changes faster, safer and with higher quality, that is, to maintain the speed of product development even when it grows large. After all, services that are not closely related make it possible to make changes with a higher frequency of iterations, minimizing the impact on the rest of the system.

One of the disadvantages of this approach is that it adds additional complexity to the project. Infrastructure maintenance requires DevOps engineers to deploy, monitor, and manage project components, with close relationships and good interaction between them and developers. When working with microservices, it is necessary to deploy more, the monitoring system becomes more complicated, and the number of possible failures increases greatly. Using a microservices approach offers advantages over using a conventional monolithic approach to building projects, and a comparison of the two approaches gives the following results.

The monolith is built as a single entity. Any changes, even the smallest ones, require rebuilding and redeployment of the entire project. Over time it becomes more difficult to maintain a good modular structure, changes to the logic of one module tend to affect the code of other modules. Monolithic applications can also be difficult to scale when different modules have conflicting resource requirements. For example, one module can implement image processing logic and intensive use of the processor. Another module may be demanding on RAM usage. However, since these modules are deployed together, a compromise must be made with the choice of hardware. The entire application must be scaled, even if it is required only for one module of this application.

Microservices on the other hand - each microservice is deployed separately. So, if you change something in one of them, you can deploy those changes without affecting other microservices that can continue to run.

Therefore, now web projects are increasingly being developed as separate services that can be deployed and scaled separately.

3.3. Information system model

To carry out the experiments, there was developed software that allows the placing of such entities as a port, farm, turbines, ships on the map, as well as the organization of turbine maintenance. In the process of organizing maintenance, the operator selects the turbines that should be serviced, creates one or several teams and selects a ship on which the team will go to sea. The optimal route is also determined using dynamic data. To do this, information is periodically collected from the weather data provider.

The information system was developed using Web technologies according to the principles of “client-server” architecture. The system architecture scheme is shown in Figure 2.

The information system consists of two subsystems.

- Wind turbines maintenance organizing and entities placement system.
- Collecting and accumulating dynamic weather data system.

In this paper there will be concentration on developing of wind turbines maintenance service that is the main subsystem that provides functionality for maintaining turbines of offshore power plants and assisting in decision-making when organizing maintenance. The functionality provided by this subsystem allows operator perform placement of entities such as wind turbines, offshore wind farms, ports, ships, and teams. Based on the entities data operator can create wind turbines inspection. Service consists of the following basic elements.

- Backend API – system operation logic.
- Frontend Application – user interface.
- DB – database.

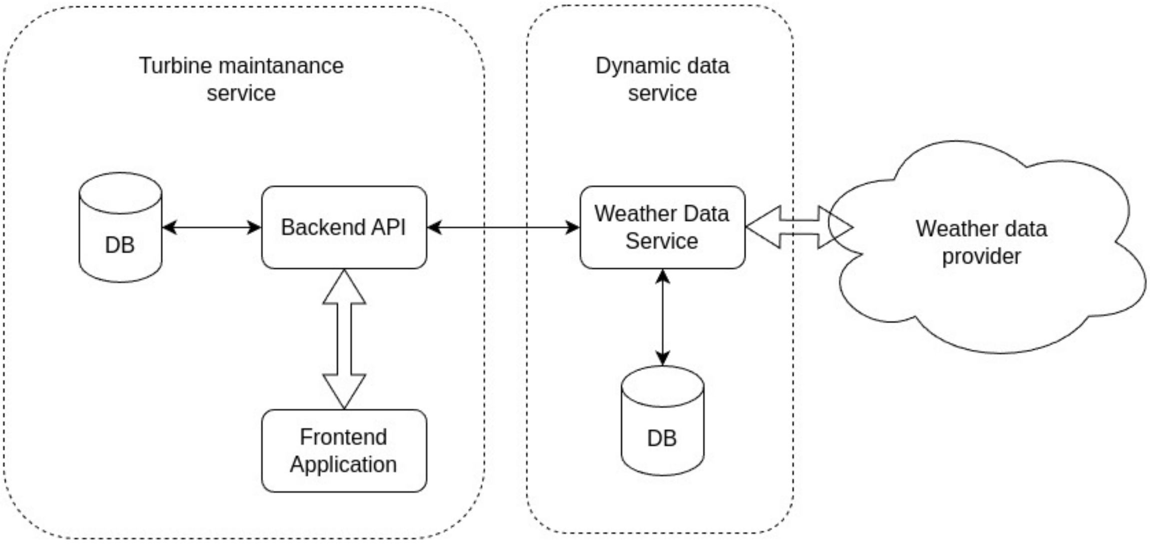


Figure 2: System architecture scheme

The Backend API is built as a single API, divided into logical parts, resources for processing port entities, farms, turbines, ships, teams, and turbine maintenance management. The application uses Node.js runtime environment to run the application. The code is written using TypeScript, which is a strongly typed superset of JavaScript. The Express library is used, which provides components for the basic server logic. The PostgreSQL relational database management system is used as a database.

The Frontend Application is a web single page application that provides user interface for performing of work to operator. It provides convenient map view, necessary controls and placement visualization of ports, farms, turbines, and vessels. It is written with TypeScript and uses React library for building user interface. As a data management approach there was chosen separated app state and Recoil as a library that provides it. In paper [29] there is said that data is an essential part of most web applications, and complex applications also have additional state to manage. State management is a significant part of complex frontend application, and it may impact the application performance, even on a small amount of data and in these terms even though Redux is more popular library to use but it is not preferred for applications with high performance requirements.

There is also the idea to make a service that will be gathering data from open APIs of weather data following approaches described in papers [30-31]. Thus, there will be used IoT technologies of sensors that performs data gathering. There are different open APIs that provides variety of data. The weather data service will be calling weather data by coordinates of farms centers and paths points and saving it into the storage.

4. Experiment

This section discusses the principles of operation of a decision support information system for maintaining wind turbines, describes main software features, preparation for conducting experiments, the experiments themselves in various operating modes and the interpretation of the results obtained.

4.1. Software functionality overview

The interface of the Frontend Application editor page is shown in Figure 3. Operator can see the interface that consists of map of the earth's surface, which displays ports, ships, farms, and turbines, and interface elements, controls using which operator can perform entities management.

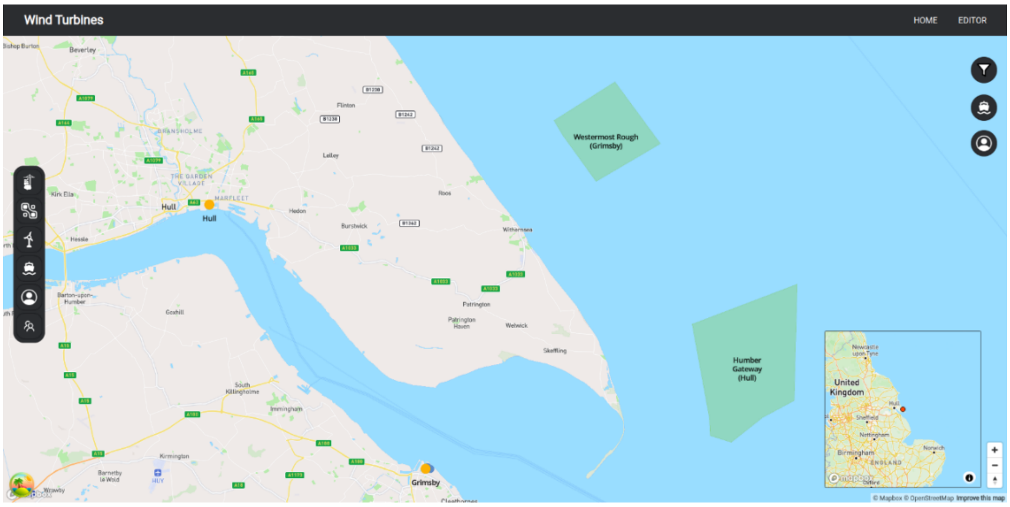


Figure 3: Editor page user interface

On the entity editor page, the operator can perform placing of entities on the map using the entities side menu on the left. The entity editor is necessary to enter the system initial information about ports, farms, turbines, ships, teams so that the system has data with which it can work. Since this is a decision supporting system, all data must be as close to reality as possible for further experiments to be successful, and the process of adding it reflects the actual work of the operator in a production environment.

Initially, the operator enters information about the port to which farms and ships will be linked in the future. To create a port, the operator selects the appropriate item in the entities menu and enters information in the form shown in Figure 4 in such fields.

- Name - port name.
- Description - description of the port.
- Coordinates - port location coordinates.

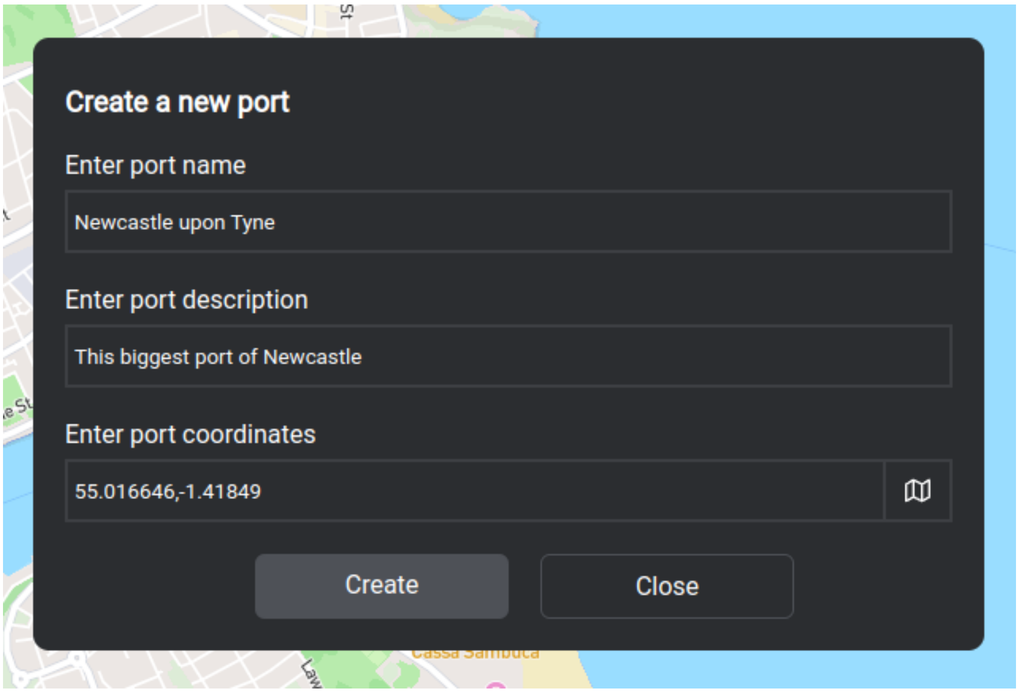


Figure 4: Port creation form

The coordinates of the port location can be specified visually by clicking the button to the right of the input field and clicking on the required location on the map. The coordinates will be automatically written into the input field. Once created, the port will appear on the map as an orange circle with the port name below it, as in Figure 5.

Figure 5: Displaying of created port on the map

Next, the operator can create a farm that will be assigned to any of the existing ports. To create a farm, the operator selects the appropriate item in the entities menu, fills out the information in the form shown in Figure 6 in such fields.

- Port - the port to which the farm is assigned.
- Name - name of the farm.
- Description - text description of the farm.
- Color - farm color.
- Transparency - opacity of the farm polygon.
- Polygon - farm area polygon.

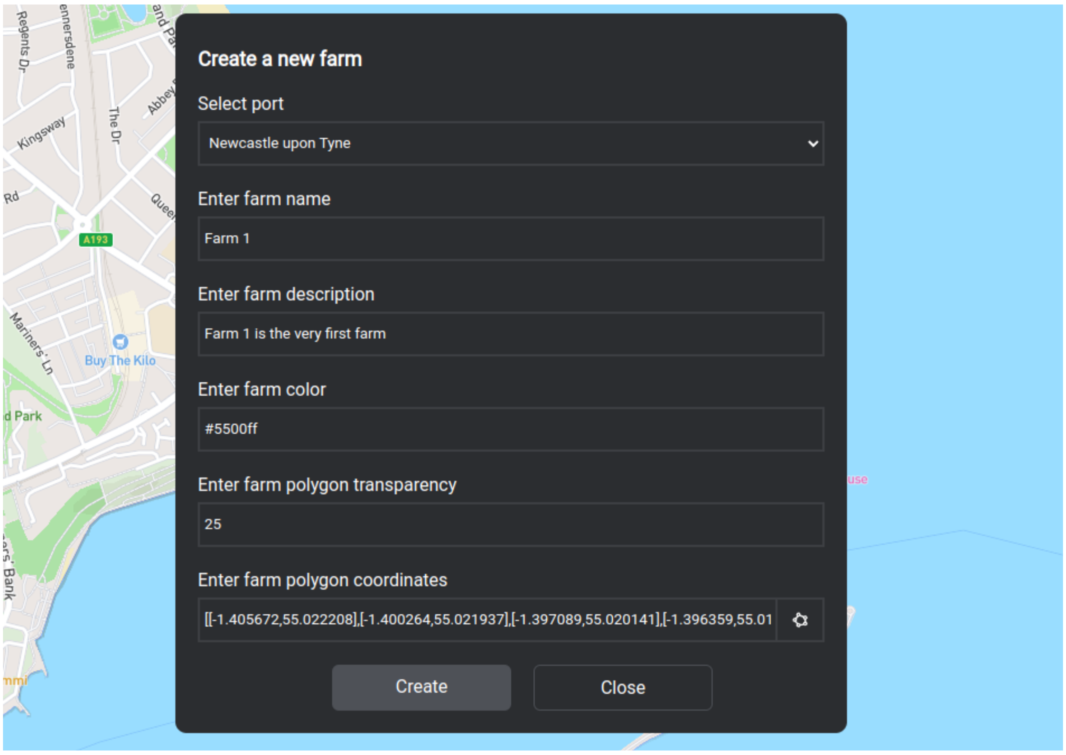


Figure 6: Farm creation form

During farm creation, the operator can designate a farm area by drawing a polygon. After saving, the new farm is immediately displayed on the map.

After creating a farm, the operator can add turbines by selecting the appropriate option in the entities menu. The operator will see a turbine creation form in the same was as for farm like in Figure 7, where the operator fills in the following information.

- Farm - select the farm to which the turbine is assigned.
- Name - turbine name.
- Description - text description of the turbine.
- Type - turbine type.
- Coordinates - coordinates where the turbine is located.

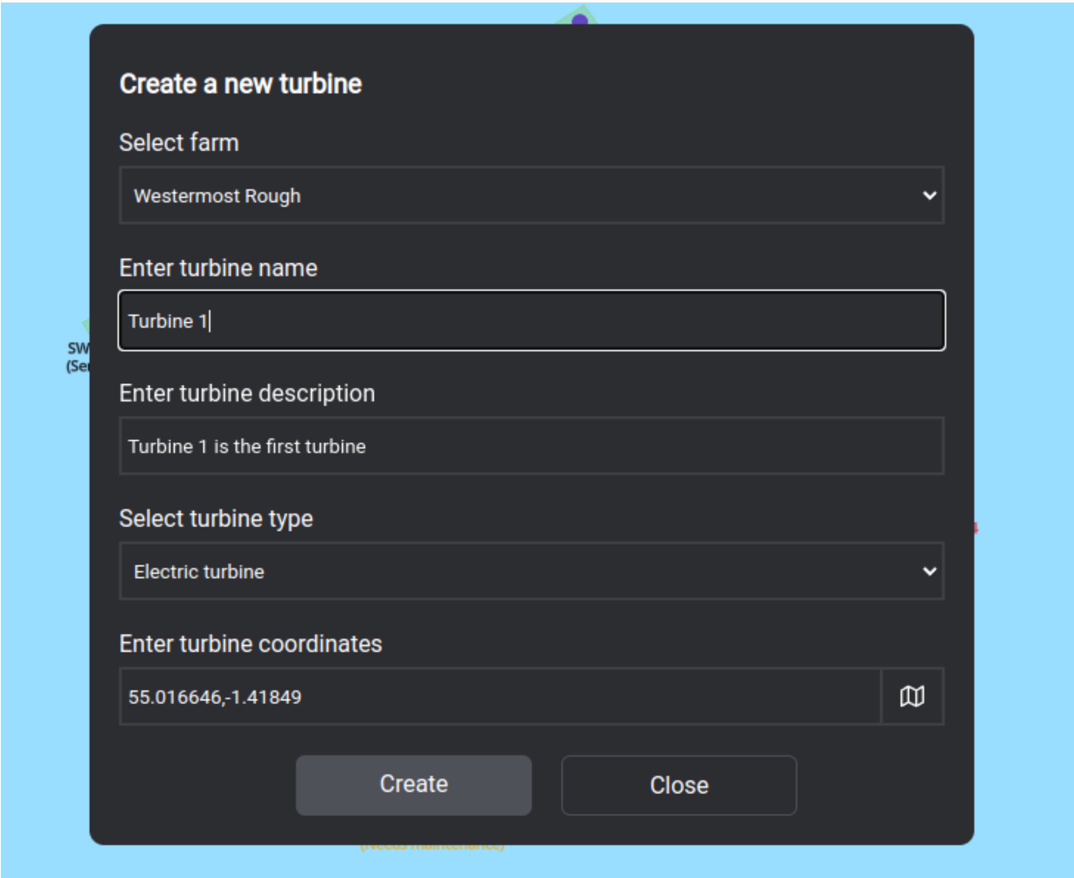


Figure 7: Turbine creation form

After creating the farm and placing the turbines, the operator can see the result as in Figure 8. The map displays the polygon of the wind farm area. Turbines that belong to the farm are displayed inside the polygon. If necessary, the operator can make additional changes, since all information of existing entities can be edited, and the entities themselves can be deleted. The operator can also add new turbines and change the polygon of the farm area. The operator can create different sets of ports, farms, turbines to simulate different service scenarios.

Each turbine has a status, a turbine state, that can be one of the following.

- In service - operational.
- Need maintenance - requires maintenance.
- Faulty – broken.

Depending on the status, the turbine is painted with the corresponding color on the map.

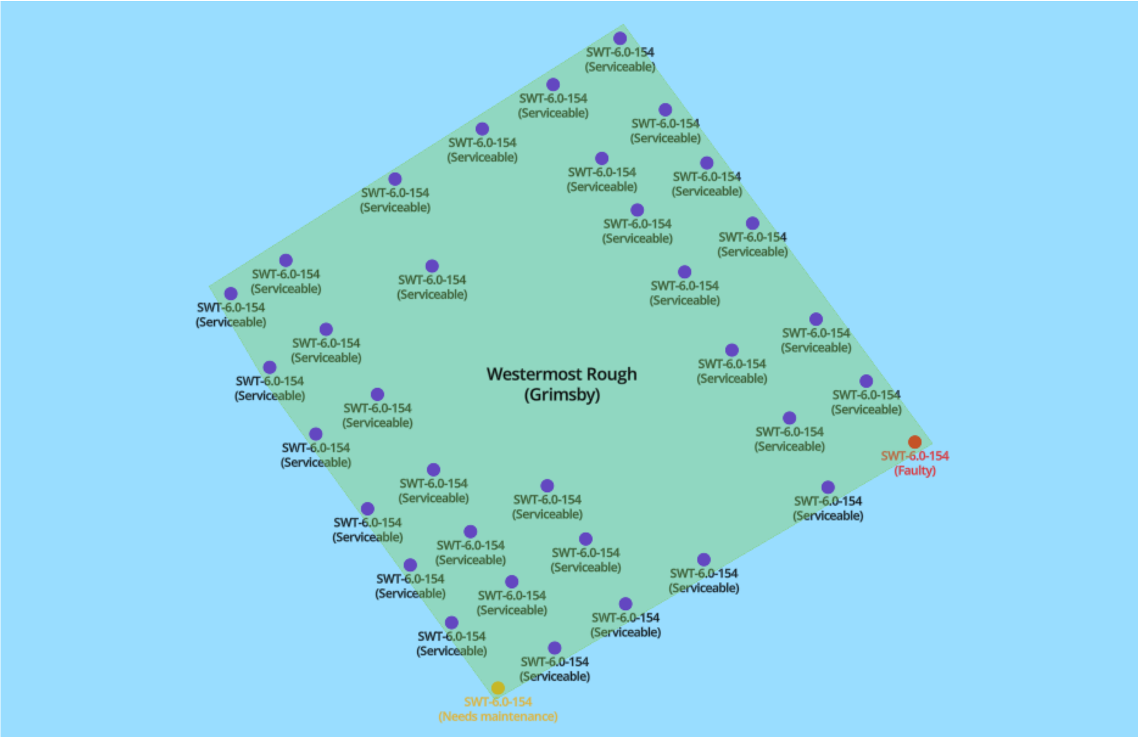


Figure 8: The result of creating a farm and turbines

When operator clicks on a farm, he can get information about the farm in the farm menu that appears, as shown in Figure 9. In the displayed window, operator can see the name of the farm, a description, the port to which the farm belongs, and a list of turbines. From this window he can edit information about the farm. In the list of turbines, operator can change existing turbines or delete them. Changing the turbine status is also available.

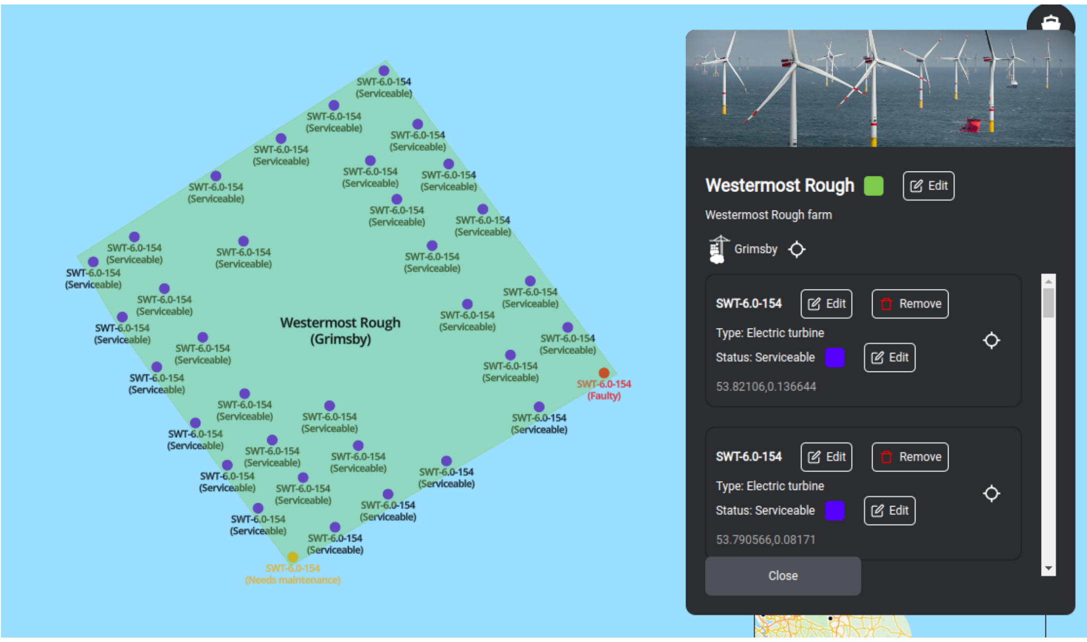


Figure 9: Farm information

When you click on the focus icon next to the port name, the view is redirected to the port to which the farm is assigned. This opens a window, as in Figure 10, with information about port, that displays information about selected port and a list of farms assigned to the port. Port information can also be edited.

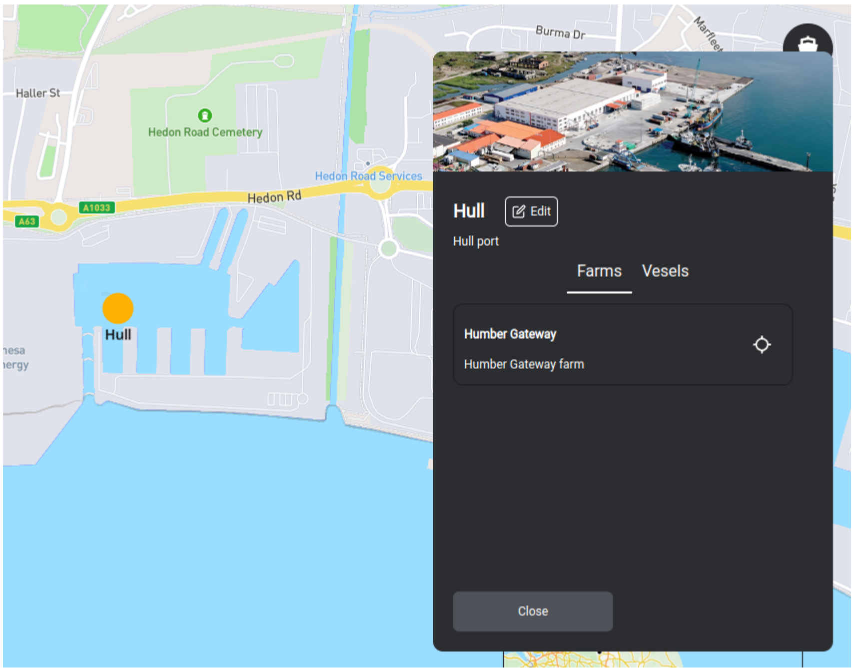
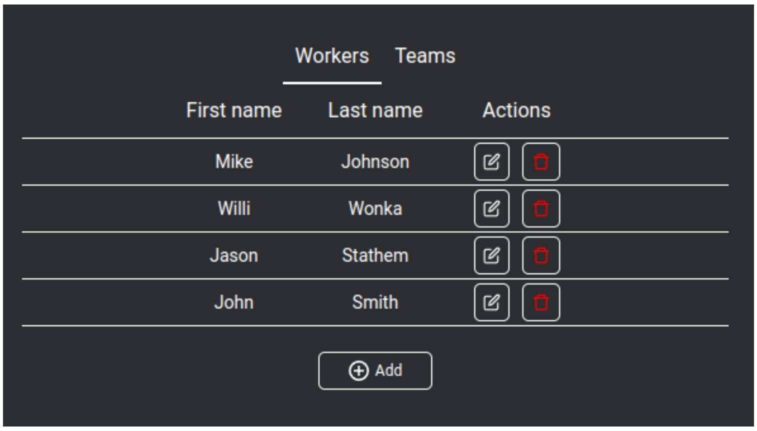


Figure 10: Port information

The next step is the creation of ships and inspection teams. The interface contains lists of teams and the people that are involved in these teams. These lists are shown in Figures 11 and 12. Clicking on the add button at the bottom of the list allows you to add new entries.



First name	Last name	Actions
Mike	Johnson	
Willi	Wonka	
Jason	Stathem	
John	Smith	

Figure 11: Workers list

Name	People	Actions
Team 1	2	
Team 2	2	
Team to mai...	3	

Figure 12: Teams list

When adding a new worker, the operator enters information in the form shown in Figure 13 in the following fields.

- First name – worker's first name.
- Last name - worker's last name.

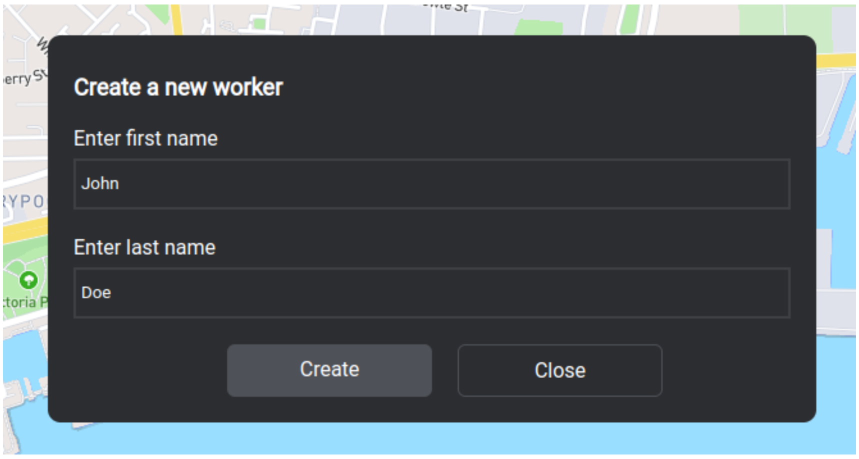


Figure 13: Worker creation form

The new worker will be displayed in the list of workers.

When creating a command, the operator enters information in the form shown in Figure 14 in the following fields.

- Name - the name of the team.
- Vesel - the ship on which the team will go to sea.
- Start date - the beginning of the time for drafting a command for inspection.
- Finish date - time of completion of drafting a command for service.

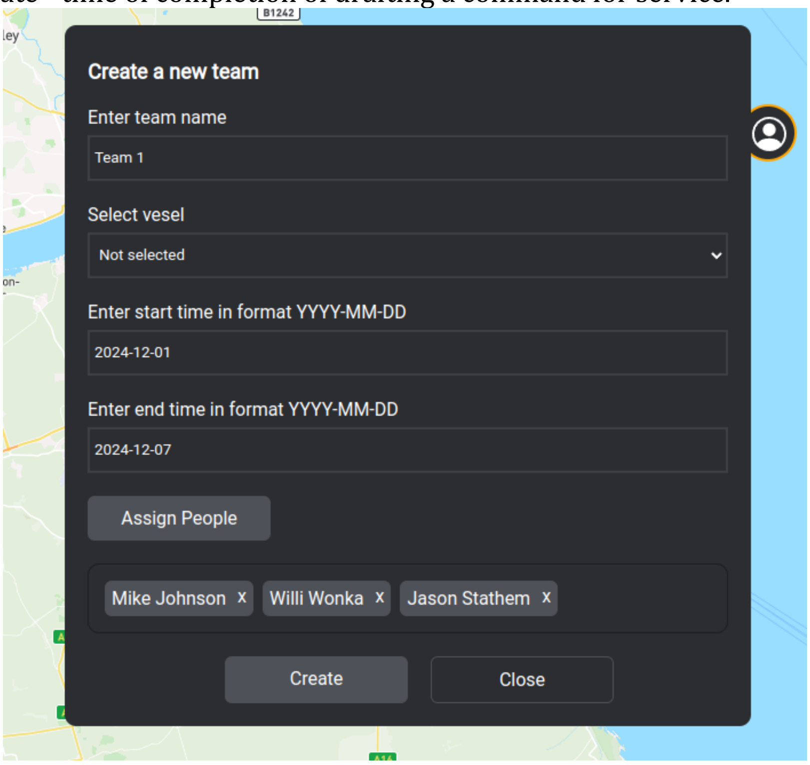


Figure 14: Inspection team drafting form

The Assign People button allows you to select people from the list of workers who will be drafted for service. It is considered, that if certain employee is already in another team and that team is also drafted for selected period, then worker cannot be available for selection to this team. In the list of teams, you can see how many people are assigned to a particular inspection team.

If you need to create an empty draft, then when creating an inspection team, you can leave the vessel field to be not selected and not select people for the team. You can later change this information and add a ship and people from the teams list menu. If you need to delete a record about an employee or team, this can be done from the list of teams and employees.

The final stage of entity creation is the creation of ships. To do this, the operator selects the corresponding item in the entities menu or clicks on the add button in the list of ships shown in Figure 15.

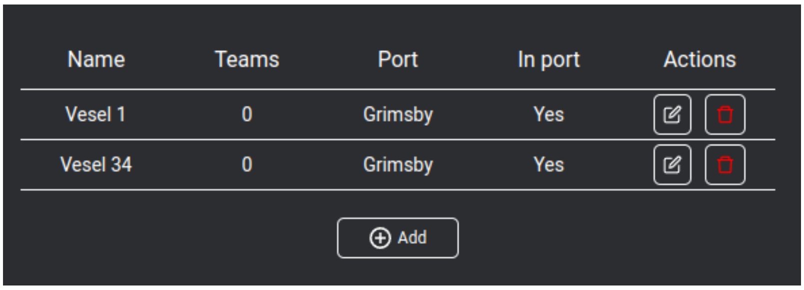


Figure 15: List of vesels

The operator enters information into the appeared vessel creation form shown in Figure 16 in the following fields.

- Name - the name of the ship.
- Description - text description of the ship.
- People quantity - number of people, ship crew.
- Port - ship's home port.
- Is vessel in port - is the ship in port.
- Coordinates - current ship position in coordinates.

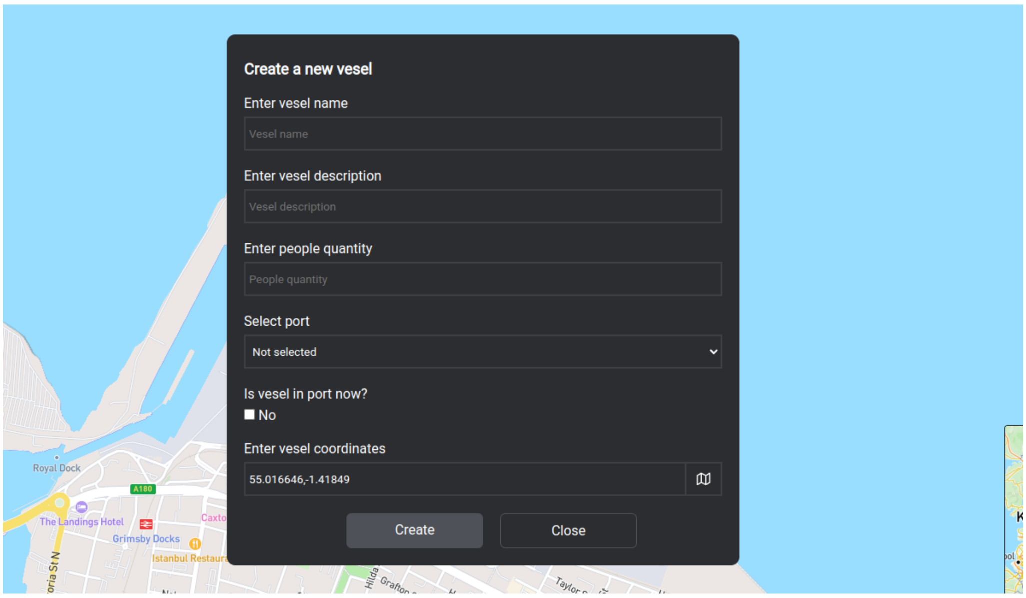


Figure 16: Vessel creation form

The operator may not specify the current home port of the ship but add it later when editing the ship. Also, the mark "is vessel in port" can change. In the future, it is planned to automatically change the current coordinates of the ship using GPS tracking and automatically change the status of the ship in the port.

It is also planned to provide functionality for full export and import of entities to be able to simulate different arrangements of ports, farms, turbines, and ships. Also, the export and import functionality will be useful if several people test or learn how to use the software on their personal computers.

4.2. Experiment planning

The main way to conduct experiments in an information decision supporting system is to simulate the real work of an operator. The actual work of the operator includes creating and managing entities with which system interacts, that is, ports, farms, turbines, ships, and teams. Experiment also consists of simulating the organization of maintenance of a set of turbines as close as possible to reality.

Several experiments are planned to demonstrate the operation of this information system. Such experiments are planned.

- Close to reality work of operator in managing of basic entities.
- Export and import of entities.
- Organization of turbine maintenance close to reality.

Before carrying out the experiment, it is necessary to carry out several preparation steps.

- Preparing data on known farms for input into the system.
- Deleting previous test entities.
- Preparing a .json file for importing entities into the system.

Data preparing consists of preparing in advance all the data related to the system entities and gradually introducing them into the system. Data should be taken from real farms, for example from open-source data sets where these farms exist.

For the purity of experiments, it is necessary to remove all existing test data to obtain an empty system without outdated or irrelevant data. This is done by clearing the database or manually deleting all existing entities.

Preparing a .json file for importing entities is like preparing data for manual entry, only you need to combine everything into one file. The format must match the format of the entity fields in the database. The list of fields is shown in Table 1.

Table 1
Entities Fields

Entity	Key	Data type	Value example	Description
Port				
	name	String	Grimsby	Port name
	description	String	Grimsby port	Port description
	coords_lat	String	53.578137	Latitude coordinate
	coords_lng	String	-0.064571	Longitude coordinate
Farm				
	name	String	Grimsby farm	Farm name
	description	String	Grimsby farm	Farm description
	coords_lat	String	53.578137	Latitude coordinate
	coords_lng	String	-0.064571	Longitude coordinate
Turbine				
	farm_id	Number	1	Assigned farm id
	status	String	In service	Turbine status
	type	String	Wind turbine	Turbine type
	name	String	Turbine 1	Turbine name
	description	String	Turbine 1	Turbine description
	coords_lat	String	53.578137	Latitude coordinate
	coords_lng	String	-0.064571	Longitude coordinate

Vesel				
	name	String	Vesel 1	Vesel name
	description	String	Vesel 1	Vesel description
	people_quantity	Number	50	Max people quantity
	in_port	Boolean	true	Is vessel in port
	coords_lat	String	53.578137	Latitude coordinate
	coords_lng	String	-0.064571	Longitude coordinate
	port_id	Number | null	1	Assigned port id
Worker				
	first_name	String	John	Worker's first name
	last_name	String	Doe	Worker's last name

Arrangement of entities can be carried out in any of the above methods. The result of the arrangement of entities is shown on the next page in Figure 17.

For already created entities, you can change information through editing forms. If necessary, the operator can add new entities or delete existing ones.

After entering the necessary data into the system, you can carry out experiments to create inspections for turbine maintenance. Turbine inspection implies that the operator will select a list of turbines that are subject to inspection or repair, draft a team for a certain period (usually several days), and select a ship on which the team will go into sea. The diagram of entities that are included in inspection is shown on the next page in Figure 18.

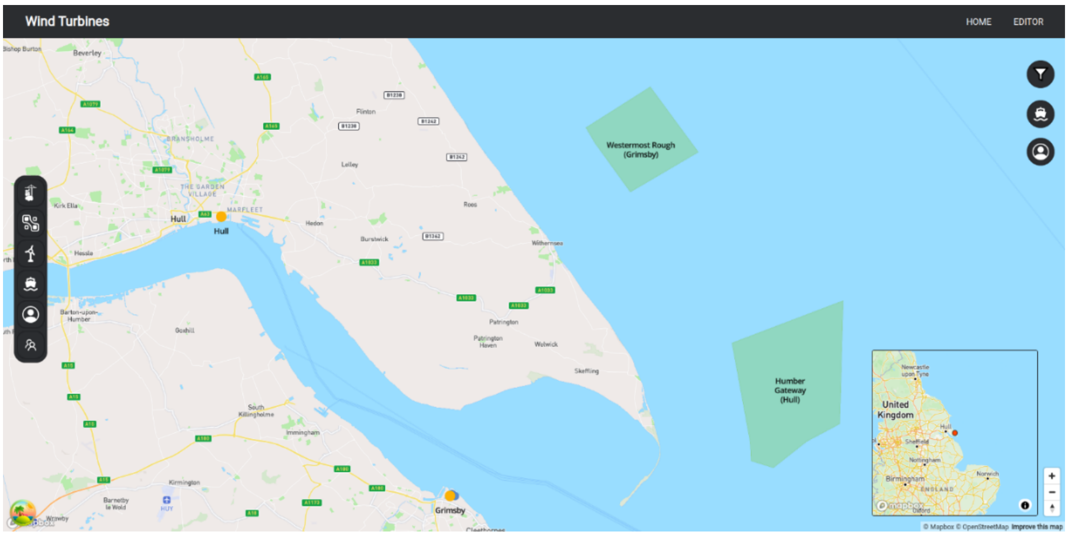


Figure 17: Arranged entities on map

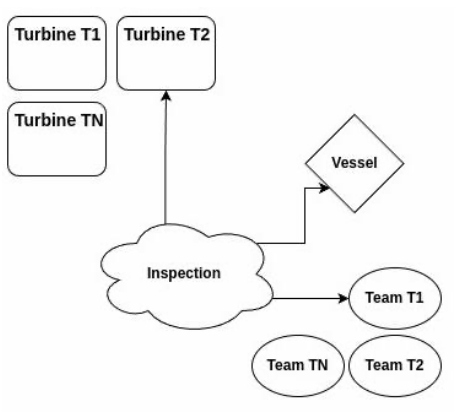


Figure 17: Inspection entities scheme

5. Results

Experiments were carried out simulating the actual work of a system operator. Several sets of ports, farms, turbines entities were created, and several inspections were created to inspect a different set of turbines. To select turbines for inspection, you need to change their status to "Need maintenance". In this case, such turbines are colored orange on the interface and their status is displayed below their name. A wind turbine farm prepared for inspection is shown in Figure 19.

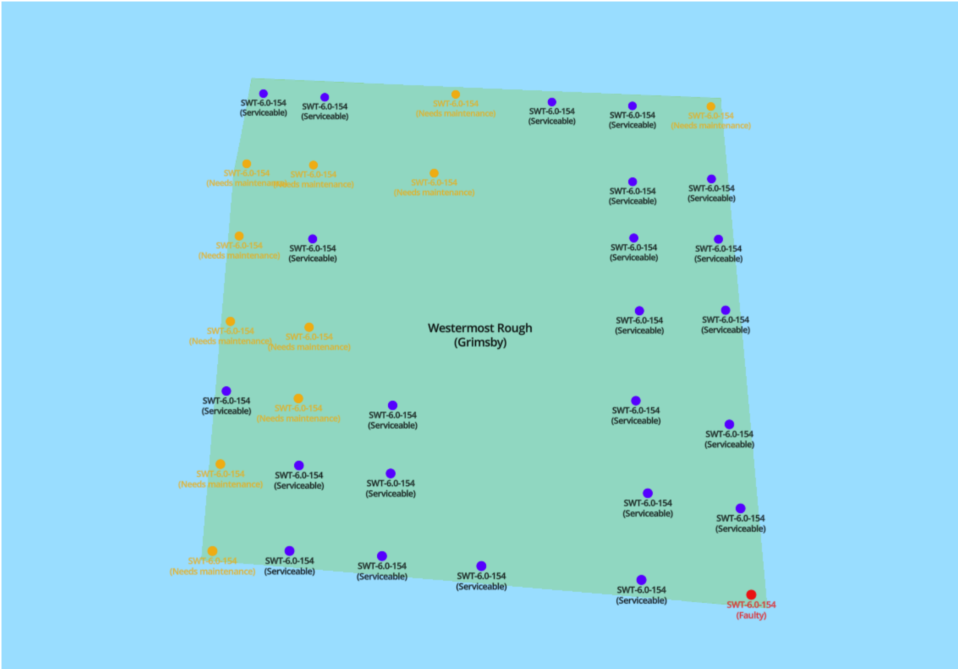
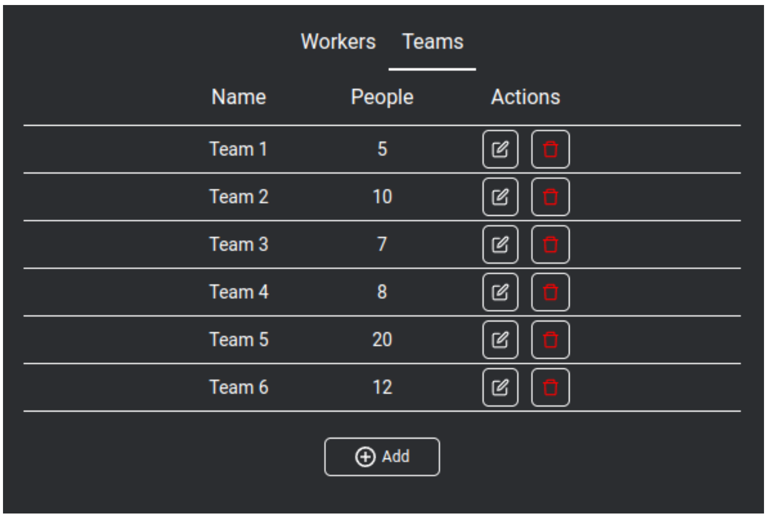


Figure 19: Turbines prepared for inspection

Further preparation for the inspection includes creating of maintenance teams. Maintenance teams consist of specialists, people who will be involved in servicing of turbines. In practice, a team is drafted for a certain period, during which they are offshore in sea servicing turbines, so setting clear dates for drafting of a team is very important. There were created several teams with draft dates ranging from 2024-03-01 to 2024-03-08. The list of created inspection teams can be seen in Figure 20.



Workers Teams

Name	People	Actions
Team 1	5	
Team 2	10	
Team 3	7	
Team 4	8	
Team 5	20	
Team 6	12	

Add

Figure 20: Maintenance teams drafted for inspection

The rest of the inspection preparation for the turbines is finding a suitable vessel and adding inspection teams to it. For example, there is a ship in the port that has been added inspection teams to available team slots.

Thus, several experiments were carried out on organizing turbine inspections. The performance metric used was the time it took an operator to organize a turbine inspection under different scenarios and data sets.

6. Discussions

The main purpose of the software is to optimize resource costs for servicing wind farms, helping the operator in organizing turbine maintenance, to reduce costs and time spendings. It also eliminates the need to conduct full-scale experiments with real expensive equipment, which is not always available. Also, using the information system, it is possible to train future or existing system operators.

The development work and experiments have shown that the decision support system allows operator to organize the maintenance of wind turbines quickly and efficiently, based on the data stored in the system about the location of ships, ports, farms and turbines, as well as data on the teams drafted for services, while being able to control individual parameters of entities at any time. A convenient and simple interface, as well as extensive software capabilities, allow you to quickly simulate different service scenarios and arrange entities on the map.

The system is as close to reality as possible and provides fine-tuning of parameters, allowing you to simulate different situations for organizing certain turbine maintenance scenarios.

The results of the experiments showed that the software produces results close to reality in terms of accuracy in visualizing the location and parameters of entities that the operator creates, and significantly reduces the time for organizing turbine maintenance compared to paperwork. The software has received high praise among subject matter experts.

Further development of the system consists of a subsystem for collecting weather data, which will act as dynamic data and subsystem for building optimal inspection paths among sets of inspected turbines. This dynamic data will influence the construction of ship routes. For example, if there is currently a storm warning in some region, then this area should be bypassed along a safer, but still optimal route. It all depends on the demand for the technology in the subject area of which the information system works and includes the deployment of the system in a production environment as an MVP to begin real testing by users who will use the software in their professional activities. By collecting feedback on the operation of the system and requests for additional functionality, a further list of functional elements can be generated that can be added to the decision support information system.

For now, we can offer the following functionality for development:

- Development of subsystem for weather data gathering.
- Introducing optimal path planning algorithms.
- Including AI models for predicting optimal inspection teams and path finding.

Separately, it can be noted as an idea for development, in close cooperation with experts in the aviation field, to implement support for streaming signals from the sensors of real ships, which determine its position on the map, speed and course, their further processing, for example, displaying these parameters on dispatch equipment or creating turbine maintenance records. The same can be addressed for getting real time data from turbines by demand and visualizing on user interface the state of turbines during their work and during maintenance.

7. Conclusions

An analysis of the current state of information systems for automation of technological processes was carried out, including algorithms and operating technologies, network capabilities, interface implementation and visualization. On this basis, requirements were formed, and an information system was developed to assist in intelligent solutions for the maintenance of offshore wind farms.

The principles of organization and most of the maintenance processes of offshore wind power plants are considered. In the future, greater focus was shifted specifically to the organization's service process and transferred to electronic form.

In the "Methods and Materials" section, there were described principles of wind turbines maintenance. Processes that are constantly used in the preservation of offshore turbines were reviewed, the principle of organizing such maintenance was considered. Based on this there were arranged requirements for the decision support information system. The popular approaches for building of web applications were reviewed and the model of software architecture was developed. The architecture and component descriptions provide a brief explanation of the safe operation of the software and the use of technology.

In the "Experiment" section, there were developed a part of software for data input and turbines maintenance organizing was developed with which it is possible to simulate the real work of an operator in his professional activity in organizing the maintenance of turbines on the farms of offshore power plants. The envisaged stage of experiments was described, where the main capabilities of working with operator system software in the process of creating sets of entities and their arrangement were shown. The experiments were accompanied by a description of the capabilities of the system, which display all the necessary information, and the measurements themselves were carried out with sufficient confidence, which is the main effectiveness of the software, which makes it possible to transform the organization of wind turbine maintenance into a more efficient form.

The next milestone is to continue developing other parts of complex system that includes weather data gathering system and optimal routes building based on this dynamic data.

References

[1] T. Balachandran, A. Yoon, D. Lee, J. Xiao and K. S. Haran, "Ultrahigh-Field, High-Efficiency Superconducting Machines for Offshore Wind Turbines," in IEEE Transactions on Magnetics, vol. 58, no. 2, pp. 1-5, Feb. 2022, Art no. 8700805, doi: 10.1109/TMAG.2021.3094163.

[2] S. Maglio, C. Park, S. Tognarelli, A. Menciassi and E. T. Roche, "High-Fidelity Physical Organ Simulators: From Artificial to Bio-Hybrid Solutions," in IEEE Transactions on Medical Robotics and Bionics, vol. 3, no. 2, pp. 349-361, May 2021, doi: 10.1109/TMRB.2021.3063808.

[3] R. M. Viglialoro et al., "Augmented Reality to Improve Surgical Simulation: Lessons Learned Towards the Design of a Hybrid Laparoscopic Simulator for Cholecystectomy," in IEEE Transactions on Biomedical Engineering, vol. 66, no. 7, pp. 2091-2104, July 2019, doi: 10.1109/TBME.2018.2883816.

[4] D. Jung, "A Minimally Configured Hardware-In-the-Loop Simulator of Electrical Power Steering System for Human Driver Interaction on Crosswind Effect," in IEEE Access, vol. 9, pp. 60470-60481, 2021, doi: 10.1109/ACCESS.2021.3073989.

[5] Y. Yan, I. Bajaj, R. Rabiee and W. P. Tay, "A Tightly Coupled Integration Approach for Cooperative Positioning Enhancement in DSRC Vehicular Networks," in IEEE Transactions on Intelligent Transportation Systems, vol. 23, no. 12, pp. 23278-23294, Dec. 2022, doi: 10.1109/TITS.2022.3208257.

[6] L. Ferrigno et al., "Magnetic Localization System for Short-Range Positioning: A Ready-to-Use Design Tool," in IEEE Transactions on Instrumentation and Measurement, vol. 70, pp. 1-9, 2021, Art no. 6002309, doi: 10.1109/TIM.2020.3035397.

[7] M. Fazio, A. Buzachis, A. Galletta, A. Celesti and M. Villari, "A proximity-based indoor navigation system tackling the COVID-19 social distancing measures," 2020 IEEE Symposium on Computers and Communications (ISCC), Rennes, France, 2020, pp. 1-6, doi: 10.1109/ISCC50000.2020.9219634.

[8] J. Zhang and Y. Zhang, "WAVE-Based Short-Range Vehicular Localization Through Vector Match," in IEEE Transactions on Industrial Electronics, vol. 67, no. 1, pp. 592-600, Jan. 2020, doi: 10.1109/TIE.2019.2893828.

[9] H. A. Raja, T. Vaimann, A. Rassõlkin, A. Kallaste and A. Belahcen, "IoT Based Tools for Data Acquisition in Electrical Machines and Robotics," 2021 IEEE 19th International Power Electronics and Motion Control Conference (PEMC), Gliwice, Poland, 2021, pp. 737-742, doi: 10.1109/PEMC48073.2021.9432553.

[10] R. Issa, M. S.Hamad and M. Abdel-Geliel, "Digital Twin of Wind Turbine Based on Microsoft® Azure IoT Platform," 2023 IEEE Conference on Power Electronics and Renewable Energy (CPERE), Luxor, Egypt, 2023, pp. 1-8, doi: 10.1109/CPERE56564.2023.10119576.

[11] S. -J. Lee, C. Kim, I. -K. Yu, M. -T. Ngo, M. -C. Dinh and M. Park, "Recent Progress and Performance Analysis on Durability Evaluation and rRemaining useful life Prediction Technology Development for the Life Extension of Wind Turbines in Korea," 2023 12th International Conference on Renewable Energy Research and Applications (ICRERA), Oshawa, ON, Canada, 2023, pp. 339-343, doi: 10.1109/ICRERA59003.2023.10269432.

[12] L. Liu, Y. Zhou, B. Yan and J. Liu, "Large-scale Maintenance Scheduling of Wind Turbines," 2019 Prognostics and System Health Management Conference (PHM-Qingdao), Qingdao, China, 2019, pp. 1-5, doi: 10.1109/PHM-Qingdao46334.2019.8943053.

[13] H. Luo and C. Su, "Multi-Level opportunistic Maintenance optimization of Offshore Wind Turbines Based on Rolling Horizon Approach," 2020 IEEE International Conference on Mechatronics and Automation (ICMA), Beijing, China, 2020, pp. 478-483, doi: 10.1109/ICMA49215.2020.9233524.

[14] Y. Yao, J. Liu, Z. Wu, X. Tang, S. Li and Z. Zhang, "Implementation Scheme and Feasibility Analysis of Intensification of Maintenance and Inspection for Offshore Wind Power in Guangdong Province," 2022 IEEE 5th International Electrical and Energy Conference (CIEEC), Nangjing, China, 2022, pp. 1139-1144, doi: 10.1109/CIEEC54735.2022.9846614.

[15] J. Cai, Y. Liu and T. Zhang, "Preventive maintenance routing and scheduling for offshore wind farms based on multi-objective optimization*," 2022 First International Conference on Cyber-Energy Systems and Intelligent Energy (ICCSIE), Shenyang, China, 2023, pp. 1-6, doi: 10.1109/ICCSIE55183.2023.10175291.

[16] P. Pradhan, S. Kishore and B. Defourny, "Optimal Predictive Maintenance Policy for an Ocean Wave Farm," in IEEE Transactions on Sustainable Energy, vol. 10, no. 4, pp. 1993-2004, Oct. 2019, doi: 10.1109/TSTE.2018.2877437.

[17] M. Pape and M. Kazerani, "Turbine Startup and Shutdown in Wind Farms Featuring Partial Power Processing Converters," in IEEE Open Access Journal of Power and Energy, vol. 7, pp. 254-264, 2020, doi: 10.1109/OAJPE.2020.3006352.

[18] K. Smelyakov, A. Chupryna, D. Sandrkin and M. Kolisnyk, "Search by Image Engine for Big Data Warehouse," 2020 IEEE Open Conference of Electrical, Electronic and Information Sciences (eStream), Vilnius, Lithuania, 2020, pp. 1-4, doi: 10.1109/eStream50540.2020.9108782.

[19] S. Bielievtsov, I. Ruban, K. Smelyakov and D. Sumtsov, “Network technology for transmission of visual information”, Selected Papers of the XVIII International Scientific and Practical Conference “Information Technologies and Security” (ITS 2018), Kyiv, Ukraine, November 27, 2018. In CEUR Workshop Proceedings, Vol-2318, 2018, pp. 160-175. https://ceur-ws.org/Vol-2318/

[20] K. Smelyakov, D. Karachevtsev, D. Kulemza, Y. Samoilenko, O. Patlan and A. Chupryna, "Effectiveness of Preprocessing Algorithms for Natural Language Processing Applications," 2020 IEEE International Conference on Problems of Infocommunications. Science and Technology (PIC S&T), Kharkiv, Ukraine, 2020, pp. 187-191, doi: 10.1109/PICST51311.2020.9467919.

[21] J. R. N. de los Santos, J. R. Suyom, M. B. Comora, G. N. de los Santos, M. G. de los Santos and R. C. Aruy, "Imbentaryo App: An Intelligent Inventory and Decision Support System," 2021 25th International Conference on Information Technology (IT), Zabljak, Montenegro, 2021, pp. 1-5, doi: 10.1109/IT51528.2021.9390123.

[22] C. Nicodeme, "Build confidence and acceptance of AI-based decision support systems - Explainable and liable AI," 2020 13th International Conference on Human System Interaction (HSI), Tokyo, Japan, 2020, pp. 20-23, doi: 10.1109/HSI49210.2020.9142668.
[23] P. Papadopoulos, D. W. Coit and A. A. Ezzat, "Seizing Opportunity: Maintenance Optimization in Offshore Wind Farms Considering Accessibility, Production, and Crew Dispatch," in IEEE Transactions on Sustainable Energy, vol. 13, no. 1, pp. 111-121, Jan. 2022, doi: 10.1109/TSTE.2021.3104982.
[24] W. Yin, X. Peng and Y. Hou, "A Decision-dependent Stochastic Approach for Wind Farm Maintenance Scheduling Considering Wake Effect," 2020 IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe), The Hague, Netherlands, 2020, pp. 814-818, doi: 10.1109/ISGT-Europe47291.2020.9248768.
[25] M. Hasani, M. K. Sheikh-El-Eslami and H. Delkhosh, "A Linear Model for Wind Farms Preventive Maintenance Scheduling Considering the Wind Speed Uncertainty and Electricity Market Conditions," 2022 9th Iranian Conference on Renewable Energy & Distributed Generation (ICREDG), Mashhad, Iran, Islamic Republic of, 2022, pp. 1-7, doi: 10.1109/ICREDG54199.2022.9804559.
[26] O. M. Bakhriddin uali, A. J. Samadilla ugli and Z. S. G'olib ugli, "Microservice Approach In Designing A Scalable Architecture On The Example Of An Electronic Invoice System," 2021 International Conference on Information Science and Communications Technologies (ICISCT), Tashkent, Uzbekistan, 2021, pp. 1-3, doi: 10.1109/ICISCT52966.2021.9670337.
[27] I. A. Kautsar, M. R. Maika, A. N. Budiman, A. B. Setyawan and J. Y. Awali, "Microservice Based Architecture: The Development of Rapid Prototyping Supportive Tools for Project Based Learning," 2023 IEEE World Engineering Education Conference (EDUNINE), Bogota, Colombia, 2023, pp. 1-6, doi: 10.1109/EDUNINE57531.2023.10102884.
[28] K. Adrio, C. N. Tanzil, M. C. Lianto and Z. E. Rasjid, "Comparative Analysis of Monolith, Microservice API Gateway and Microservice Federated Gateway on Web-based application using GraphQL API," 2023 10th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI), Palembang, Indonesia, 2023, pp. 654-660, doi: 10.1109/EECSI59885.2023.10295809.
[29] Kyrychenko, I., Pronina, D., "Comparison of Redux and React Hooks Methods in Terms of Performance", 2022 6th International Conference on Computational Linguistics and Intelligent Systems (COLINS-2022), 2022. – CEUR-WS 3171, 2022, ISSN 16130073. - Volume I: Main, PP. 791 - 800.
[30] M. S, B. N M, S. N, M. H N, P. S and D. B L, "An Efficient Big Data Gathering in Wireless Sensor Network using Reconfigurable Node Distribution Algorithm," 2022 Fourth International Conference on Cognitive Computing and Information Processing (CCIP), Bengaluru, India, 2022, pp. 1-6, doi: 10.1109/CCIP57447.2022.10058620.
[31] C. Minghua, L. Xiangqiang, Z. Fuxiao, Y. Dongchuan and L. Hua, "Application of remote sensing big data technology in refined urban management," 2020 International Conference on Big Data, Artificial Intelligence and Internet of Things Engineering (ICBAIE), Fuzhou, China, 2020, pp. 397-400, doi: 10.1109/ICBAIE49996.2020.00089.