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Report

SIMPACT

SIMulation based ship concept imPACT evaluation tool

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Report No:

OC2023 A-040   - Unrestricted

Client(s):

H2020 AEGIS – 859992, H2020 AUTOSHIP - 815012

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VERSION	**DATE**
1	2023-06-05

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CLIENT(S)	**CLIENT'S REFERENCE**
H2020 AEGIS – 859992, H2020 AUTOSHIP - 815012	NA

PROJECT NO.	**NO. OF PAGES**
H2020 859992 and H2020 815012	57

SUMMARY
This report contains the user manual for the SIMPACT tool (SIMulation based ship concept imPACT evaluation tool) for evaluation of novel ship concepts. The tool consists of two sub tools. The logistics analysis tool (LA tool), and the MASS analysis tool (MA tool) for cost and emission analysis. SIMPACT can be used to make an initial design of a waterborne transport system and to evaluate the logistical performance through a set of KPIs. Furthermore, SIMPACT can estimate energy consumption for ships operating in the transport system, transported cargo volumes, emissions, and costs.

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REPORT NO.	**ISBN**	**CLASSIFICATION**	**CLASSIFICATION THIS PAGE**
OC2023 A-040	978-82-7174-454-0	Unrestricted	Unrestricted

Document history

VERSION	DATE	VERSION DESCRIPTION
1	2023-06-05	First version

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1 Introduction

The SIMPACT tool (SIMulation based ship concept imPACT evaluation tool) was developed by the H2020 AEGIS and AUTOSHISP projects. Its intended use is for research and for decision support to investment decisions involving autonomous ships. It can, however, be used for evaluating any waterborne transport system, operated by any ship. Currently, there is an important limitation in that shallow and confined water effects are not accounted for, which means that energy estimation for inland waterways is not supported. This is, however, under development and will be supported in an upcoming version of SIMPACT.

2 User manual

2.1 Introduction

The user manual will in this section both explain the functionality of the SIMPACT tool (which consists of the LA Tool and MA Tool) and how the users can configure simulations and view results. The content of the user manual is aligned with the AUTOSHIP project.

The project view of SIMPACT allows the user to create new projects, or to load previously stored projects. The project view in Figure 1 has three existing projects.
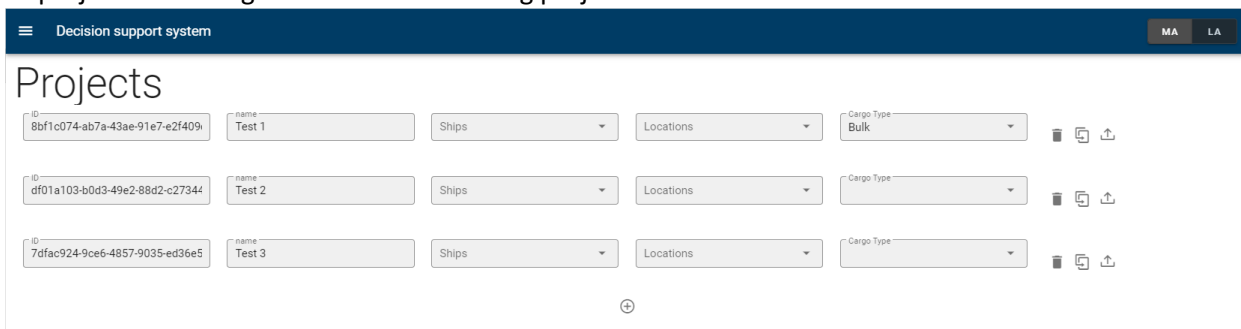

Figure 1: Project view with existing projects

Pressing the ⊕ icon will add a new project, and the user must set a name for the project and choose the cargo type that will be the basis for studying the concept within the project. This can only be done when the project is active, seen in Figure 2 as the *Name* and *Cargo Type* cells being white instead of grey. Currently, it is not possible to study concepts where multiple cargo types are transported within the same transportation system concept. Press ⏏ to load and to set the project one wish to work on as active. In Figure 1, there are no active projects. If the user press ⏏ for project *Test 2*, the project view changes to Figure 2, where the project *Name* and the *Cargo Type* can be altered, and their input cells are white. Press 🖫 icon to store any changes. Pressing 🗑 will delete the project with all its configurations, while pressing ⎘ will duplicate the project and add the duplicate in the *Current project* list.

IMPORTANT Note that if you start to work on detailed configurations of the MA tool and LA tool modules without having an active project, these configurations cannot be stored and will be cleared once a project is set as active. Always choose and set the project you want to work on as active before initiating configurations!

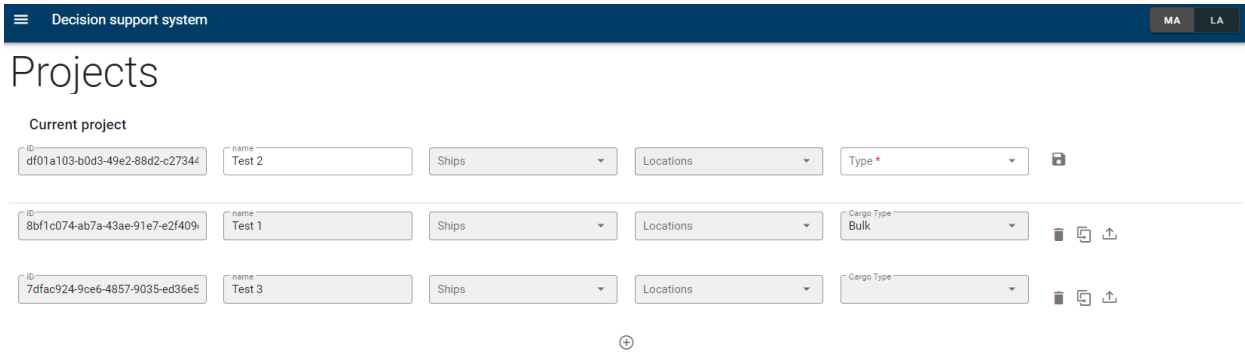**Note** when a duplicate is created, make sure to re-name it.

Figure 2: Project Test 2 is chosen and is active

2.2 LA/MA tool view

In the upper right corner of the logistics analysis tool (see Figure 1), the user can choose which sub-tool to activate by pressing *MA* or *LA*. Upon choosing sub-tool, the side bar menu will change. This is further discussed in subsection 2.3.1.

2.3 Modules

Both sub-tools consist of a set of modules. Each module has its own user interface, or configuration page. The user can move between the modules from the side bar menu, and each module has a common interface for treating data.

2.3.1 Side bar menu

The side bar menu is updated based on which sub-tool is active. It gives access to the various configuration pages for each sub-tool module by pressing the menu items. The LA tool side bar menu is given to the right in Figure 3 and the MA tool side bar menu is given to the left. The details of each sub-tool module are discussed in sections 2.4 and 2.5.

Figure 3: MA tool side bar menu to the left, LA tool side bar menu to the right

2.3.2 Common module interface (create, save, load and delete module, etc.)

All modules share the same interface to create, save, load, or delete data to and from a module, see Figure 4.
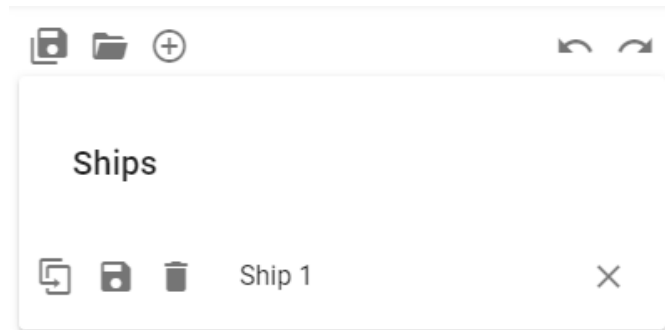

Figure 4: Common module interface

Pushing the ⊕ icon will create a new configuration instance of the active module type. In Figure 4, pressing ⊕ would create a new ship model. The icon saves all configurations in the active module, and the 📁 icon gives a popup to load previously saved configurations of the active module type. Pressing 🗑 will permanently delete the configuration instance. Pressing ✕ will close the configuration instance and, if it has been saved, it persists in the project and can be reopened through the load configuration 📁.

The ↶ ↷ icons (undo and redo) can be used to step configurations in the active module back or forward. These buttons can also be used to undo or redo the deletion of a configuration instance.

To open the configuration page for a configuration instance, press the empty space. As an example, to open the configuration page for *Ship 1* click as indicated in Figure 5.
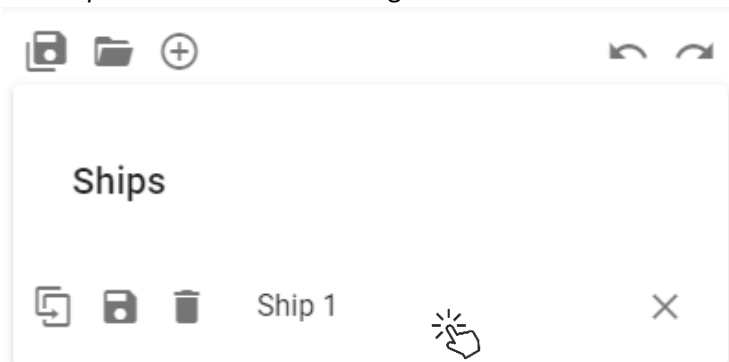

Figure 5: Chose configuration instance and open configuration page

Pressing 🗐 will duplicate the configuration instance, and one should take care to rename the duplicate as it is initially created with the same name as the original.

In addition, all modules have a Name field that the user can set to identify and differentiate each configuration instance, the Name field is set to *Ship 1* in Figure 5.

Note that all required configuration inputs are marked * such as in the example in Figure 6.

Figure 6: Mandatory inputs marked by *

2.3.3 Modules shared by the MA and LA tools

Several of the modules are shared between the MA and LA tools. However, in most cases, not all data is relevant for both tools. Therefore, the configuration pages for the modules only exposes the relevant parameters depending on which tool is active. As an example, Figure 7 and Figure 8 shows the LA tool ship configuration and MA tool ship configurations, respectively. Notice that the LA tool configuration page is significantly simpler. This is because the LA tool does not consider cost or emissions and thus requires considerably less information about the ship to do a simulation.

Figure 7: LA tool ship configuration page

Figure 8: MA tool ship configuration page

2.4 Logistics Analysis tool

2.4.1 Introduction

The SIMPACT logistics analysis tool is intended for developing the logistics concept and for analysing the capacity of the logistic system and its components. It enables trade-offs between number of ships, routes, cargo handling equipment capacity, ship size, and the ship sailing schedules. The goal is to design a logistic system that results in a satisfactory cargo flow, given a cargo transportation need.

Locations are a central model component for the LA tool. Locations can be of type consumer, producer, or terminal. The key features for the location types are:

- Producer: a location where cargo enters the supply chain. It can be a location with a factory that

  produces the transported cargo, or simply the point where the limit for the logistic system model is

  drawn, and where cargo enters the logistic system model. E.g., a terminal where cargo is transported

  to the terminal by truck. The producer model is simply based on an amount of cargo that is produced

  at a certain frequency, and which have a certain end destination. Each produced set of cargo is called

  an order, and the order has an origin and destination.

- Consumer: a location where cargo exits the supply chain. It can be the customer/end destination for

  the cargo, or simply the point where the limit for the logistic system model is drawn, and where

cargo exits the logistic system model. E.g., a terminal where the further transportation after delivery to the terminal is not part of the logistic system model.

- Terminal: a location where cargo is transferred between ships, and intermediately stored.

Note that the locations form a sort of property inherence hierarchy where a terminal has all the properties of the consumer plus the terminal property, and where a producer has all the properties of the terminal plus the producer property. That is, all can receive cargo, terminal and producers can act as terminal, producer is the only one that can produce cargo.

The following sub-section will discuss each module of the LA tool, how it is configured, and key functionality.

2.4.2 Ship configuration

Creating a ship model instance is done in the same way as discussed in subsection 2.3.2, note that multiple ship model instances can be created and configured.

The ship configuration is quite simple as the LA tool only needs the ship cargo capacity, the ship cargo handling rate, and the number of hours that the ship will wait at a location if there is inbound cargo. The latter is modelled to avoid strict schedule keeping where minor disturbances results in a ship leaving minutes before another ship delivers cargo that the ship should have loaded. This is configured by entering the *Max waiting time.* The LA tool is designed with a future expansion in mind where the separation of orders in different cargo holds is required, such as for the AUTOSHIP SSS demonstrator ship which carries different feed orders in different feed silos. The cargo holds are configured by pressing *Add Cargo Hold.*
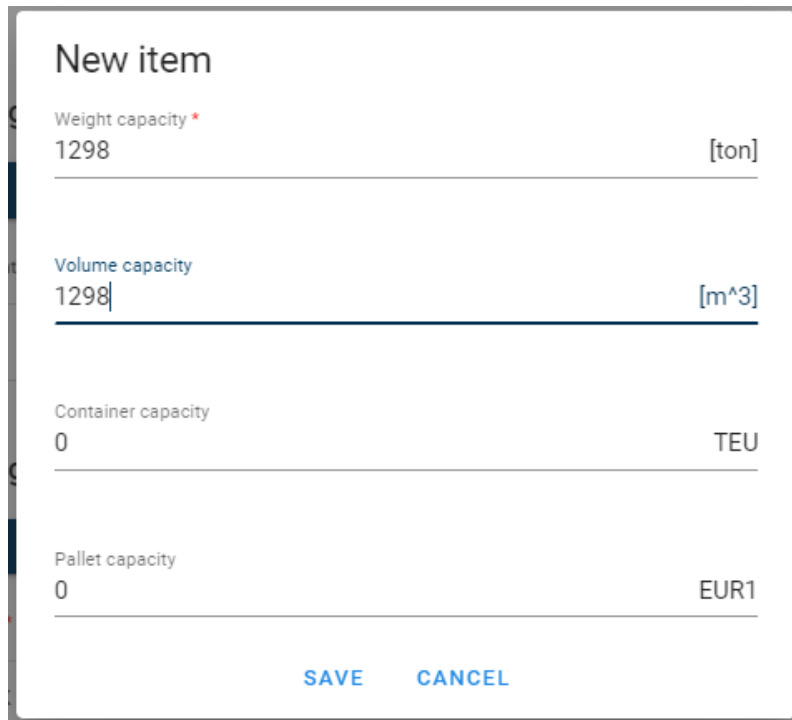
Figure 9: Ship configuration

Pressing *Add Cargo Hold* opens the popup menu given in Figure 10. The cargo hold is configured by entering the *Weight capacity,* the *Volume capacity*, the *Container capacity* if the ship is a container ship, and the *Pallet capacity* for ships such as the AUTOSHIP IWW demonstrator Pallet Shuttle Barge.
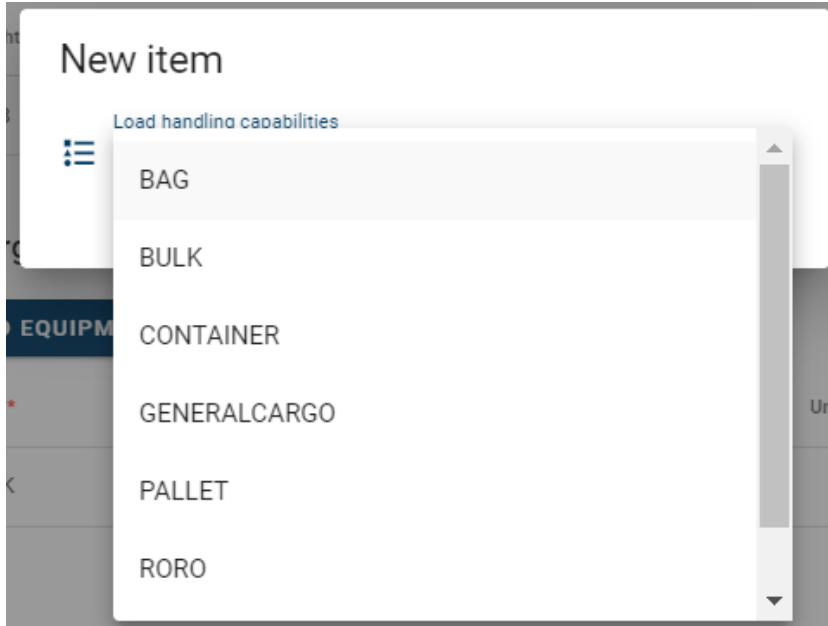
Figure 10: Cargo hold configuration popup

Pressing *Add Equipment* in Figure 9 opens a popup menu for configuring the cargo handling equipment installed on the ship. The first step is to choose the cargo type that the cargo handling equipment can load and unload by choosing from the *Load handling capabilities* dropdown list, see Figure 11.

Figure 11: Configure cargo handling - choose cargo type

Once the cargo type is chosen from the *Load handling capabilities*, the *Loading rate* and the *Offloading rate* is configured, see Figure 12.

Figure 12: Configure cargo handling - loading and offloading rate

Ship models are shared with the MA tool, which means that configuration changes done in the LA tool for parameters that are also used in the MA tool, will apply to both tools.

Once configuration is completed, remember to save.

Note the configuration view in Figure 12 changes depending on chosen cargo type.
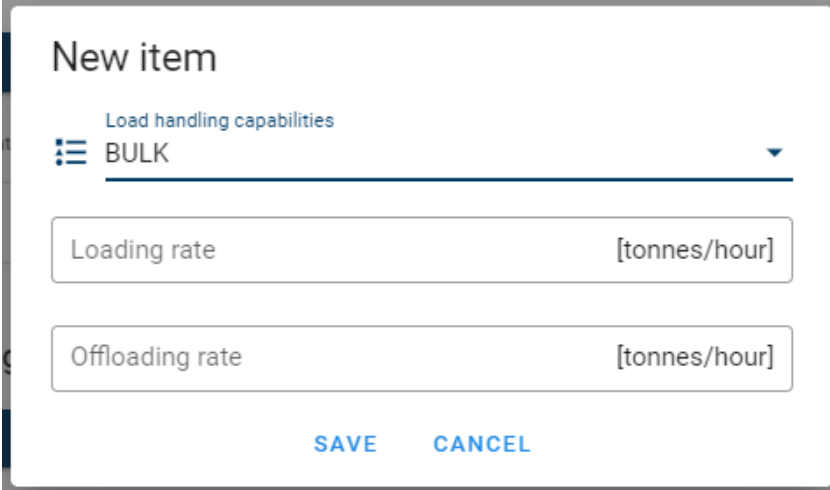
2.4.3 Location configuration

Locations are shared between the MA tool and the LA tool configuration is done in the same way as described in section 2.5.5 where the MA tool location configuration is discussed in detail, however, a bit simpler. This is because the LA tool do not need the Charging configuration, and *Port cost scheme* configuration, which are described in section 2.5.5. All other configurations are the same.

2.4.4 Route configuration

Creating a Route model instance is done in the same way as discussed in subsection 2.3.2, note that multiple Route model instances can be created and configured.

The route configuration inputs are given in Figure 13. If the user would like the ship to sail from location A to location B, and back to A, this must be explicitly defined here. The ship will sail from location to location as defined by the location sequence in Figure 13. New locations are added by pressing the ⊕ icon in Figure 13, and the location is chosen by selecting from the Location dropdown. The Location sequence can be altered by dragging and dropping the ✛ icon.

Figure 13: Route configuration

When the location sequence configuration is done, press the *Generate Route* button, and the route will appear in the map, see Figure 14. Route generation and manual editing of the route is discussed in more detail in section 2.5.7.

Figure 14: Generated route

2.4.5 Ship schedule configuration

Creating a Ship schedule model instance is done in the same way as discussed in subsection 2.3.2, note that multiple Ship schedule model instances can be created and configured.

The ship schedule ties the ships to routes and specifies when and how often the ship will sail along the route, and at what speed. The ship schedule configuration page is given in Figure 15. The ship which is to be scheduled is chosen from the *Ship* dropdown list, where all configured ships are available. The ship sailing speed is entered in the *Speed* configuration box. The schedule is made by setting the *Epoc size* which is the number of days that the schedule applies for, selecting the route from the *Route* dropdown list, setting the *Scheduled start* which is the day within the schedule duration (or epoc) that the ship will start sailing along the route, and by setting the *Scheduled stop* which is the day within the schedule which the ship shall have

completed the route. The ship will repeat this schedule as many times as possible within the simulation horizon, which will be discussed in subsection 2.4.7.

Figure 15: Ship schedule configuration

Remember to save the configuration.

2.4.6 Production schedule configuration

Creating a Production schedule model instance is done in the same way as discussed in subsection 2.3.2, note that multiple Production schedule model instances can be created and configured.

Each location that has been configured as a producer must also have at least one associated production schedule. The production schedule is where the cargo transportation need is modelled. It is based on a simple model where a certain amount cargo, organised in an order, is generated at a specified frequency. Each order has one delivery location, however multiple orders can be configured for the production schedule of each producer location, see Figure 16. First the *Producer* location is selected from a dropdown list that holds all locations configured as producers. Next, orders are added by pressing the ⊕ icon at the bottom of Figure 16. Then, each order is configured by entering the *Delivery location* by selecting from a dropdown list, the first simulation day that the order is generated by setting *Initial spawn*, the frequency with which the order will be generated by setting the *Spawn frequency*, and by configuring the cargo that the order consists of and the route(s) the order shall be transported by. One producer may generate orders for multiple consumers. Orders are generated binary, which means that the full order appears at the same time. For an order of 10 containers, this means that all 10 containers appear at the same time. An example of this functionality is given below:

- Producer: Location A

- Delivery location: Location B, Initial spawn 1

- Spawn frequency 7

- Cargo: Type – container, amount 10, weight of each container – 10 tons

- Route: A-B

In this case, an order of 10 containers, each weighing 10 ton, with destination location B, will appear at producer A storage at simulation day 1, and then again every 7th day (that is simulation days 8, 15, 22, etc.).

Figure 16: Production schedule configuration

The configuration inputs for the cargo that the order consists of is accessed by pressing as indicated in Figure 16. This expands the cargo configuration view as given Figure 17. The cargo must be given a *Name,* while the cargo *Type* is fetched from the project cargo type and is not configurable in this view. The user can choose between configuring the cargo within the order as a percentage of the vessel max capacity, or by entering the *Weight* and *Volume* of the cargo.

Figure 17: Configuring the cargo within the order

If the *Use vessel max capacity* is chosen, the cargo configuration view changes as given in Figure 18. In this case, the user must enter the *Weight in percentage of vessel maximum capacity.*

Figure 18: Configure cargo by vessel max capacity

At the bottom of the page, there is a map that visualises the configuration of each order by indicating the producer as a green circle, the consumer as a red circle, and the routes that the order will travel along, see Figure 19. This visualisation is updated by selecting the different orders in Figure 16.

Figure 19: Visualisation of configured order with production location as green circle, consumer location as red circle, the routes the order travel, and the terminal where it is transferred from one ship to another

Remember to save the configuration.

2.4.7 Simulations and results

The logistics analysis tool can run two types of simulations, the first is the logistics analysis for designing and dimensioning the logistics system, the second is a set of MA tool simulations based on the logistics analysis results, and which combines the results from the generated MA tool simulations to give cost and emission estimates for the transportation network.

2.4.7.1 Simulation – Logistic analysis

Simulations for logistics analysis must be done over a sufficiently long simulation horizon such as a year. The simulations are quite quick, in the order of seconds to a one or two minutes depending on the size of the logistics system, so longer simulation horizons are also possible.

Simulations for logistics analysis are configured by setting the *Simulation horizon,* choosing the *Ship schedules* from the dropdown, and the *Production Schedules* from a drop down, see Figure 20.

Figure 20: Configuring logistics analysis simulations

The simulation is run by pressing the ▶ icon. Upon completion, a status is indicated next to the ▶ icon. The different statuses and what they indicate is given in Table 1 in subsection 2.5.9.

2.4.7.2 Results – logistic analysis

The logistic analysis results page has a set of controls which is used to pick which result that is displayed, see Figure 21.

Figure 21: Results page controls

Ticking off the *Schedule keeping* check box in Figure 21 opens the plot given in Figure 22. The figure shows the schedule keeping for the ships "Test 1" and "Test 2". Positive values indicate the number of hours ahead of schedule that the ship completed the route. In this example, the scheduled duration of the period for completing the route is more than enough, and it would be possible to introduce extra voyages and still be robust against disturbances from e.g., bad weather.
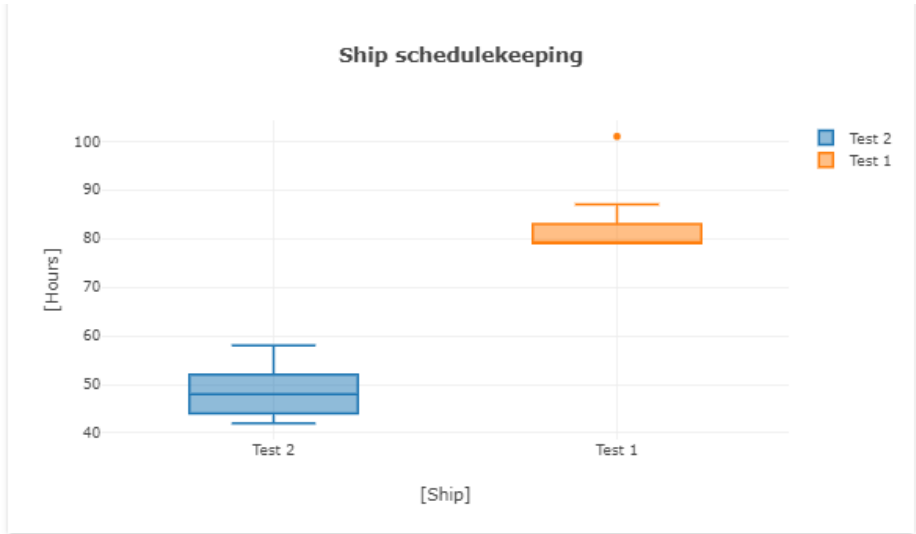
Figure 22: Schedule keeping per ship

Ticking off the *Shipment departure frequencies* in Figure 21 opens the plot given in Figure 23. The figure shows the frequency at which shipments are picked-up at locations and loaded onto ships. In this example, only locations A and C have cargo that is loaded onto ships. This can be used to investigate if requirements related to frequency of service is satisfied. The same goes for *Shipment arrival frequencies.*

Figure 23: Shipment departure frequency
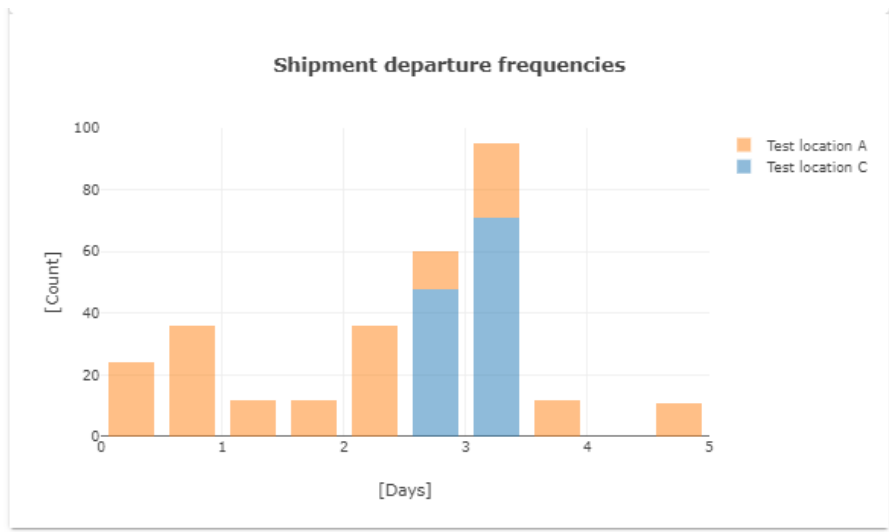
Ticking off *Shipment arrival frequencies* in Figure 21, opens the plot in Figure 24. The figure shows the frequency at which shipments are delivered to locations. In this example, shipments are only delivered to locations A and B. This can be used together with *Shipment departure frequency* to investigate if requirements related to frequency of service is satisfied.
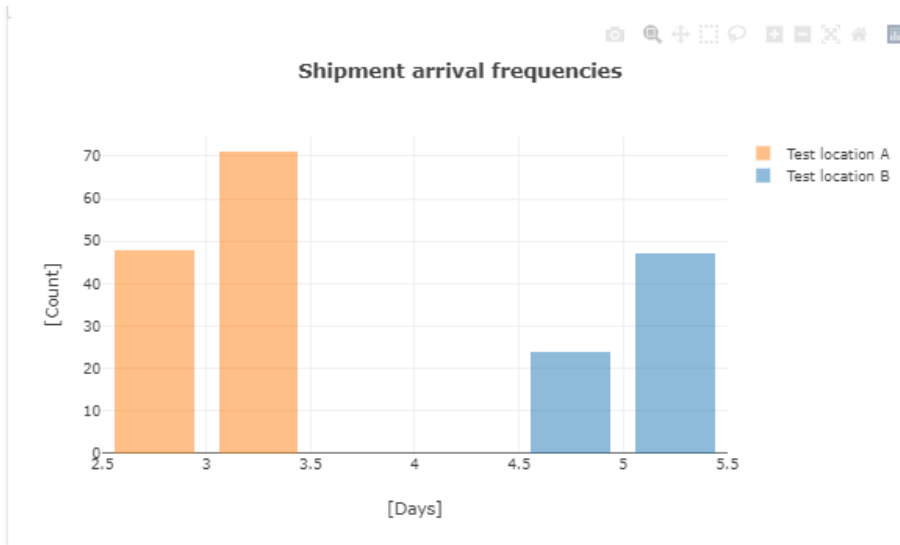
Figure 24: Shipment arrival frequencies

The lead time for sending an order from a producer to a terminal or a consumer, or from a terminal to a terminal, etc., can be investigated by the *Order lead time*. This is done by picking *From* location and *To* location, see Figure 25. Doing so opens the plot in Figure 25, which is a histogram of how many orders have the same number of days lead time. This is useful for investigating if the logistics system capacities, ship sailing speeds and schedules, results in transportation time (lead times) that are acceptable relative to requirements. This should also be seen in relation to the frequency KPIs.

Figure 25: Order lead time for sending orders from location C to location B

The amount of cargo at locations, or the location stock, and how this develops over time, is investigated by choosing the *Location* from the dropdown list in Figure 26. This is an important measure of the logistic system capacity, if the location stock grows over time, this is an indication of insufficient ship capacity (size

and number of ships), too infrequent sailings, etc. The example in Figure 26 shows that Location A is serviced sufficiently well such that cargo flows through the Location and does not build up.
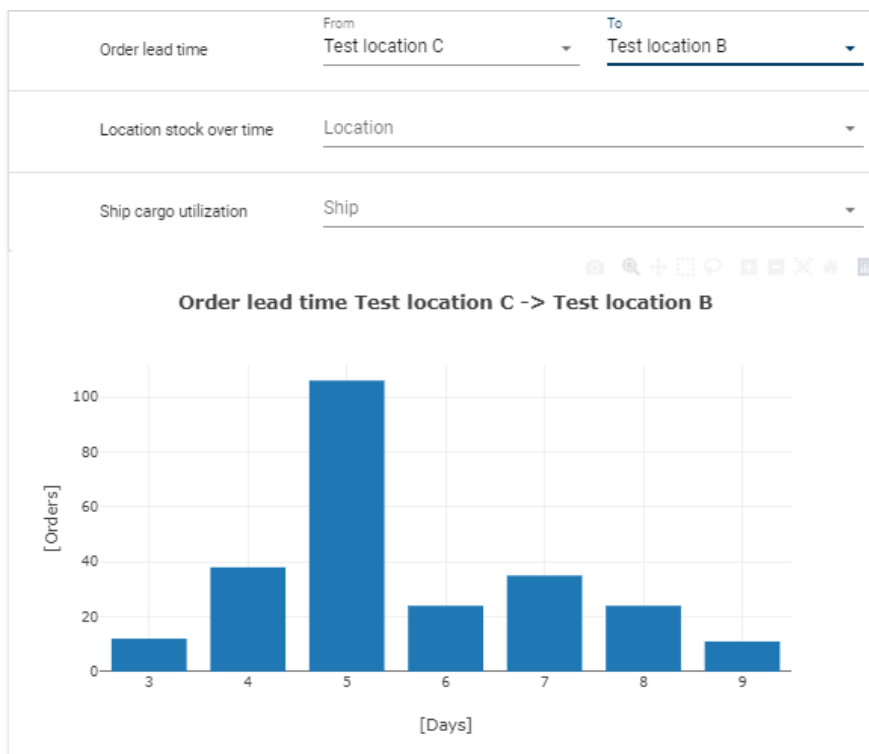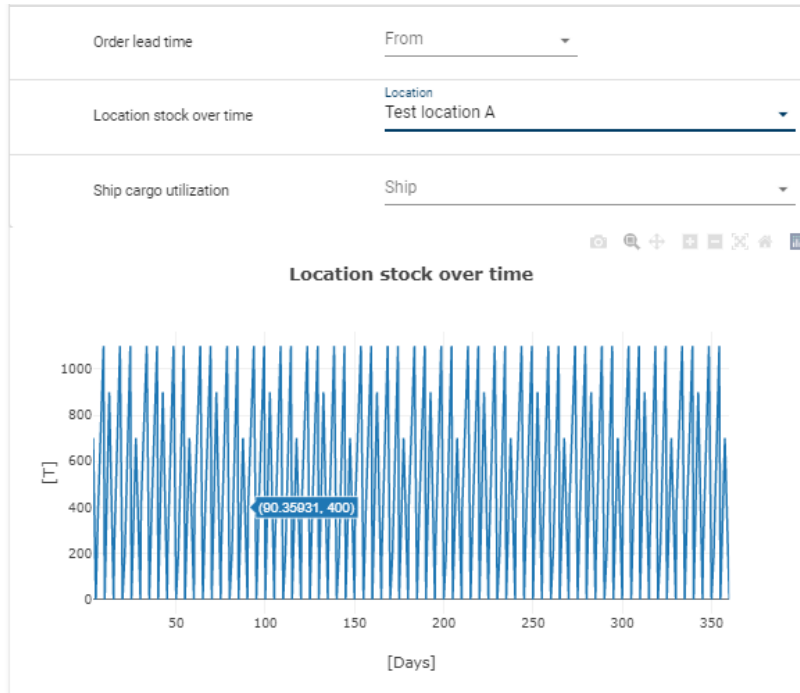

Figure 26: Location stock in cargo units, per day

The ship capacity utilisation is studied by choosing *Ship* from the dropdown in Figure 27. This is another important indication of how well the logistic system capacity is utilised, and thus how well the logistic system is dimensioned. The example in Figure 27 shows that the capacity utilisation of ship "Test 2" is varying, and that for the trip between Location A and C, it is always empty, while for the trip from Location C to A it is between 30 and 70 % utilised. This indicates over-capacity that could be utilised by adding cargo sources, or that the capacity could be reduced somewhat.

Figure 27: Ship capacity utilisation ship "Test 2"

2.4.8 Cost and emission analysis in LA tool – Generated MA tool simulations

When a logistic system has been designed in the LA tool, with satisfactory logistical performance, the simulation results can be used to generate a set of MA tool simulations for evaluating costs, emissions and external costs (societal costs) for the logistic system concept. To do this, one must first complete some configurations in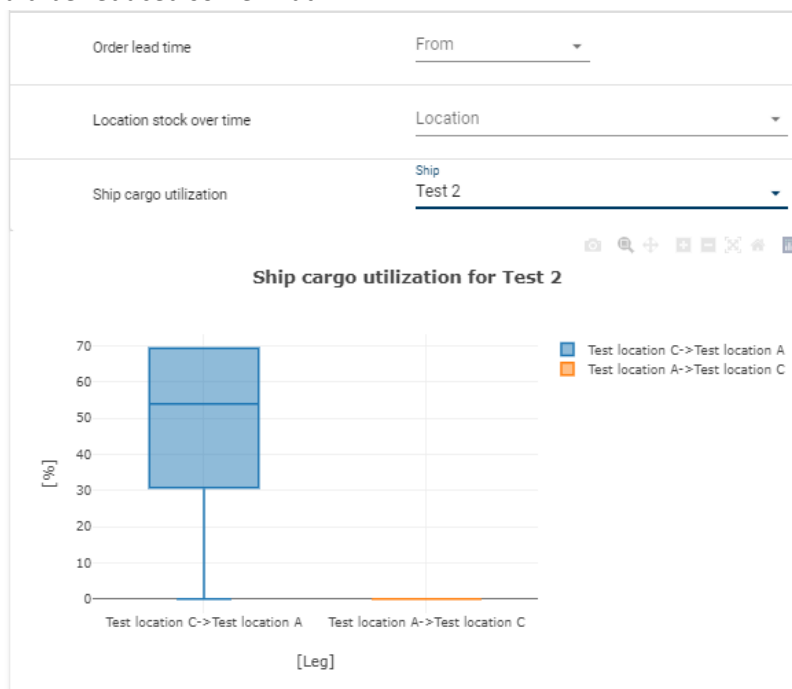 the MA tool, such as modelling a ship concept in more detail. This process is described in subsection 0. When MA tool configuration are ready, the LA tool generated MA tool simulations described in this sub-section can be done.

Note: Comparison to truck transportation as elaborated in 4.4.8.1 is not required for LA tool generated MA tool simulations. This is an optional functionality that can be used in addition to the ship cost and emission estimation in case the waterborne logistic system concept is an alternative to road transportation.

2.4.8.1 Truck comparison

In many cases, it is interesting to evaluate the autonomous ship based logistic system concept against truck transportation. SIMPACT supports such evaluations by providing simple truck transport cost estimation, and by estimating the external cost impact of moving the transportation from trucks to the waterborne logistic system concept.

External cost calculation

The external cost calculation is done according to the method given in [1] and is an estimate of the change in external costs. The result is a Euro value where a positive value indicates that the analysed waterborne logistic system gives an increase in external costs, while a negative value indicates that the analysed waterborne logistic system gives a decrease in external costs, compared to truck transportation.

Truck transportation cost calculation

Truck transportation cost is estimated in the same way as in [2] as a sum of time costs, distance costs, and tolls.

External costs

External costs are defined as costs incurred by a third party that is not part of the transaction. In our context, which is transportation, this means that if one pay someone for transporting e.g., a container, then this transaction also has an impact on society, and this impact can be quantified as costs incurred by society. This is an established way of quantifying societal impact of transportation because transportation will cause several costs for the society within the main categories: accidents, air pollution, climate, noise, congestion, well-to-tank, and habitat damage. The monetary cost incurred by society within each category is estimated in a comprehensive study [3] that has collected statistics from the EU28 countries, on behalf of the European Commission. The publication is called the Handbook on the external costs of transportation [3], and therein, one can find average numbers for each category for the EU, and for each member state. As an example, accident statistics, including number and type of injuries and number of deaths, are used with factors that estimates the societal cost of injuries and deaths, to find how much each truck ton-kilometre transportation causes in monetary costs for society.

Another example is that the estimated average cost of transportation for the society for truck transportation is 4.2 eurocent per ton-kilometre, while for maritime ships 0,66 eurocent per ton-kilometre.

In [1] we show how external cost estimation can be made dependent on ship concepts and that for a case where approximately 100 containers were moved from road to sea for the transport between Stavanger and Bergen, for one trip with an autonomous hydrogen powered ship, the societal savings is approximately 12 000 Euro. SIMPACT functionality related to external costs is intended for doing such comparisons between waterborne logistic concepts and truck transport and gives an estimate of the yearly impact of replacing trucks with the configured waterborne logistic system concept.

Configuration of truck comparison

The Truck comparison configuration page is found to the right in Figure 3. This configuration page has two purposes: Estimating truck transportation costs and estimating the external cost impact for replacing truck transport corresponding to the simulated cargo flow in the LA tool.

The Truck comparison configuration page is given in Figure 28. At the top of Figure 28 there is a check box "Calculate truck KPIs" and ticking of this check box populates the configuration page with the parameters that must be configured for comparing the logistic system KPIs to truck transport. The parameters are sorted under three headlines: "External costs conversion factors", "Truck capacity" and "Truck trip configuration".

External costs conversion factors

The external cost configuration consists of a set of conversion factors taken from the handbook [3], and the default value for each factor corresponds to the European average given in [3].

Since the default values are averages for Europe, they can be overwritten by the user, e.g., if conversion factors for the specific area is available. Conversion factors for HC, SOx, NOx, PM2,5 and PM10 are given for the Atlantic, Baltic, Black Sea, Mediterranean and North Sea, in the handbook [3]. The SIMPACT tool uses the average for these areas as default values. There is also a check box Inland waterways above the "External cost conversion factors" heading. If this is checked, the two input parameters *Cost of accidents per tonkm* and *Cost of habitat damage in tonkm* appears. This is because these two external cost categories are only relevant for inland waterways transportation.

Truck capacity

Both the external cost impact estimation and the truck transportation cost estimation depends on the truck cargo capacity. The user must therefore enter the truck capacity in the *Truck capacity in cargo units* input cell.

Truck trip configuration

Both the external cost impact estimation and the truck transportation cost estimation also depends on parameters related to the trip that the trucks would drive to move the cargo between the producers and consumers. The tool assumes that for truck transportation, the cargo is loaded to trucks at producers and delivered directly to consumers without any intermediate transfer between vehicles. The tool estimates the number of trips that the trucks must drive for each producer – consumer pair, based on the LA tool estimated amount of cargo moved between the producer and consumer, and the user input truck cargo capacity. The tool does not estimate the distance between each producer – consumer pair, nor the driving speed or cost parameters. These must therefore bet entered by the user.

For each producer – consumer pair identified by the LA tool, the tool will add a column in the table under the heading "Truck trip configuration", see Figure 28. The first row of each column shows the producer, and the second row the consumer. These cells are read only and generated by the LA tool. For each such column, the user must enter the *Distance* that the truck must drive between the producer and consumer, the average driving *Speed*, the *Cost per hour*, the *Cost per km*, and any road *Toll or ferry costs*.

Figure 28: Truck comparison input parameter configuration

2.4.8.2 LA tool generated MA tool simulations

The LA tool generation of MA tool simulations are configured on the simulations page under the heading "Cost and emission analysis" to the right in Figure 3. LA tool generated MA tool simulations allows the user to investigate cost, emission, and external cost impact of the logistic system concept.

This configuration page allows the user to choose which parts of the logistic system (ships and their route) to include, however, to analyse the full logistic system concept, all lines in the list in Figure 29 must be chosen. Each line contains the *Ship*, the *Route*, the number of *Computed simulations* for that route and ship, the *Simulation coverage,* an input cell for the non-operational time for the ship *Downtime*, and a *status*. These will be discussed in the following.

Figure 29: LA tool generated MA tool simulation configuration

The configurations and results from the LA tool that is used to generate a MA tool simulation are:

- The ship model (where additional configuration must be completed in the MA tool)

- The locations (where some minor additional configuration must be completed in the MA tool)

- The route for each ship

- The typical shipment that each ship load and deliver, including the location where it is loaded and where it is delivered.

The MA tool requires cargo to be organised in shipments to be able to run its simulation, for details, see subsection 0. The typical shipments are generated by the LA tool by tracking how each cargo unit is moved through the logistic system, and by running a clustering algorithm on the resulting cargo flow. The shipments generated by the LA tool can be inspected by pressing *Computed simulations* in Figure 29, the popup is given Figure 30.

There are three generated shipments in the example in Figure 30, which is for ship "Test 1" (see Figure 29). The *Weight* found to the left of each shipment entry in Figure 30, corresponds to the percentage of time that the ship "Test 1" transports this shipment on route "Test route A-B-A". The sum of the *Weight* should be 1 to capture all typical shipments on the route, and this sum is the *Simulation coverage* indicated in Figure 29. Each shipment contains information of the location where the shipment is loaded (the *Producer),* the location where the shipment is delivered (the *Consumer)*, the cargo *Type*, and the *Cargo weight* (this is the weight in ton of the cargo), see Figure 30. It is possible to override the *Cargo weight* manually if the user would like to test a different shipment size.
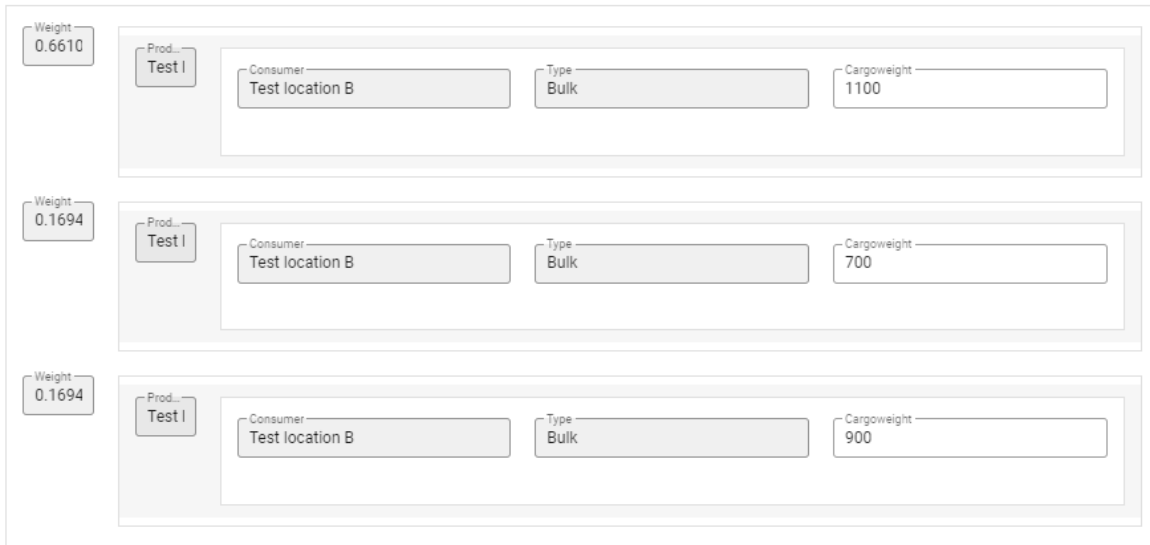
Figure 30: Generated shipments for ship "Test 1"

The *Operational* configuration in Figure 29 lets the user adjust the MA tool estimates for non-operational time. This is discussed in more detail in subsection 2.5.10. However, here, the default value will be the % time that the ship is operational in the LA tool simulations. This value can be overridden by the user if one would like to adjust to account for unscheduled downtime in addition to the scheduled non-operational time from the LA tool simulations. The *status* cell in Figure 29 gives the user information about any incomplete configurations which are required by the MA tool. When the displayed message in this cell is *Ready*, the generated MA tool simulations can be run by pressing the ▶ icon.

Generated simulations are presented in a list, an abstract of the list is given in Figure 31. Each row is a generated simulation, and to the left of each row a status is indicated for the simulation, details are given in Table 1 in subsection 2.5.9. There is also a report that can be viewed by pressing the 📄 icon. This report shows the KPI results for each individual MA tool simulation. Results are further discussed in subsection 2.4.8.3.

Figure 31: Abstract of list of generated MA tool simulations

2.4.8.3 Results

The results of running LA tool generated MA tool simulations are estimated yearly and per cargo unit KPIs. The KPIs are for the waterborne logistic system concept, for truck transport and for the total external cost impact of replacing truck transport by the logistic system concept. The latter two are only estimated if truck comparison was enabled and configured.

The external cost KPI is an estimate of the yearly reduction in external costs if the logistic system concept replaces the configured truck transportation, see Figure 32. This means that the KPI is the sum of all generated external costs from transportation in the waterborne logistic system minus all the generated external costs from truck transportation, where the trucks transport the same amount of cargo between the same producers and consumers as the ships do in the waterborne logistic system. For details on the KPI definition, see [1].

Figure 32: Example external cost KPI

Estimated truck transportation cost per cargo unit is given in Figure 33. The estimate is given for each producer – consumer pair, and the user can select among the producers from the *From* dropdown list, and the consumers receiving cargo from the selected producer from the *To* dropdown list, to investigate the transportation cost between each producer – consumer pair.
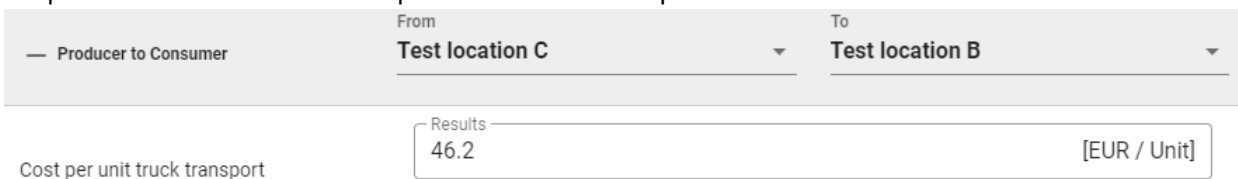

Figure 33: Truck transport cost per transported unit between producer x and consumer y

The KPIs for the waterborne logistic system concept are cost and emission estimates per transported unit, EEOI, cost per tonkm, and the yearly amount of transported cargo. The KPIs are estimates for transportation between the locations in the logistic system, and the user can select which parts of the logistic system they want to investigate the performance of, by choosing the *From* and *To* location in Figure 34. Locations where cargo is loaded to a ship in the logistic system are available in the *From* dropdown, and when a *From* location is chosen, only locations where cargo transported from the *From* location is unloaded are available in the *To* dropdown. This includes locations that receives cargo from the *From* location via a terminal. As an example, if cargo is moved from A to B with one ship, loaded to another ship at B and moved to C, it is possible to investigate the KPIs for the A to B transport, for the B to C transport, and for the combination of A to B and B to C by choosing *From* A and *To* C. This enables comparison between the waterborne logistic system to truck transport (recall that truck transport is estimated for producer – consumer only), as well as investigation of the performance on each transportation leg.

The amount of *Transported cargo* is the yearly amount of cargo transported from the *Form* location to the *To* location. It can help the user to understand differences in results such as different KPI results for A to B transport vs B to A transport, which could be caused by differences in the amounts of cargo going from A to B and B to A. It is also intended as an input to cost benefit analyses to calculate the incomes that are generated by the transportation work.

Note: The EEOI is a ship specific KPI and is displayed as NaN if the selected *From* and *To* pair implies transportation by more than one ship.

Figure 34: Example KPI calculation results for location A to D transport performance

2.5 MASS Analysis Tool

2.5.1 MASS analysis tool functionality

The SIMPACT MASS analysis tool estimates costs, emissions and societal costs of a configured ship, or autonomous ship system concept. It does this by estimating capital costs, operating costs, and voyage related costs, as well as energy consumption, emissions, and transported cargo (weight and distance), which is converted to external costs.

Energy estimation is an important part of the tool and is based on the SINTEF Ocean tool Gymir [4]. The energy estimation is based on simple hydrodynamic models of the ship concept hulls. The models take momentary sailing speed, wind and waves as input and gives required power as output. Energy estimation is done by simulating the ship sailing along the configured route, exposed to the configured weather, and at the configured sailing speed. Energy is converted to fuel, fuel cost, and emissions, by using recognised conversion factors. Since the sailing speed is the main determining factor for the ship concepts energy

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consumption, the tool allows the user to configure a speed range for the simulation such that e.g., emission and costs can be plotted as a function of speed.

The tool includes various cost models which are configured by the user. These models convert capital costs and operational costs to periodic costs, such that the cost of an activity can be determined from the duration of the activity. In addition, activity-based costs (voyage costs), such as port fees and cargo handling costs, are modelled as per activity costs and tracked by tracking each conducted activity. Details on cost models are found in D8.1, and in the discussions related to each module in the following sections.

The tool allows for configuration of multiple ship concepts, and it is possible to run the same scenario for each ship, and view KPI plots for convenient comparison of the ship concepts.

The following sub-section will discuss each module of the MA tool, how it is configured, and key functionality.

2.5.2 Ship configuration

Depending on the screen size and the view zoom, the configuration page may have one or two columns. In either case, the sequential order of each configuration remains the same. The following will assume that the view has two columns.

Creating a ship model instance is done in the same way as discussed in subsection 2.3.2, note that multiple ship model instances can be created and configured.

The left column of the ship configuration starts with a dropdown for choosing the ship concept model, see Figure 35. Upon choosing a ship concept model from the database, the main dimension of the chosen ship concept model is displayed, and an estimated new build cost is calculated and displayed. The estimated new build cost can be overridden by the user, but it should be noted that choosing another ship concept model will automatically overwrite any user input for the new build cost. The new build cost estimate is calculated based on a regression formula developed in the SATS project [5]. The estimate includes conventional machinery and propulsion, but not other equipment such as for cargo handling or auto-mooring. A method for adjusting the new build cost due to non-conventional machinery is given in *"Autonomous ship concept evaluation - Quantification of competitiveness and societal impact,"* [1]. It should be noted that though it is possible to overwrite the automatically estimated new build cost, there is a dedicated capital cost input which can be used to adjust the total capital cost estimate for installed equipment. We will get back to this in the discussion related to Figure 39.

Ship concept model

Property	Value	Unit
Length	61.14	[m]
Design draft	3	[m]
Breadth	12.4	[m]
Cargo capacity	1074	[ton]

Reference ship *: AEGIS Daughtercraft

Cost of new build *: 8292103 [EUR]

Figure 35: Choose ship concept model

The next configuration menu that can be found in the left column is the machinery, see Figure 36. The configuration is done by choosing machinery and engine type from the dropdowns in Figure 36. This configuration defines which conversion factors are used for converting energy to fuel consumption and emissions. One should make sure that the chosen machinery is consistent with the new build cost estimate by adjusting it as described in "Autonomous ship concept evaluation - Quantification of competitiveness and societal impact," [1], if it is non-conventional.

Figure 36: Choose machinery and energy source

The next configuration menu in the left column is the Cargo holds, see Figure 37. The configuration is intended to capture cases where different orders must be separated in different cargo holds.

Note there is currently no logic in the MA tool using the cargo hold configuration, this is currently only used in the LA tool, and can also be configured from the LA tool. It is therefore not mandatory to configure cargo holds for running MA tool simulations. However, to have consistency between the simulation in the LA tool and the MA tool, it is important to verify that the combined cargo hold capacity equals the *Cargo capacity* of the ship concept model, which is given upon choosing ship concept model (see Figure 35).

Note the cargo hold instance created in the MA tool is shared with the LA tool. This means that configuration for cargo holds done in the MA tool will be identical in the LA tool and vice versa.

Figure 37: Cargo hold configuration

The Cargo hold is configured by entering the *Weight capacity*, and the optional fields *Volume capacity, Container capacity,* and *Pallet capacity*, see Figure 38. These are used in the LA tool, as elaborated in section 2.4.2, however notice that *Weight capacity* is the only mandatory field. It is, however, possible to store the cargo hold without configuring *Weight capacity.*

Figure 38: Cargo hold configuration user input

The next configuration menu in the left column is the cargo handling and equipment cost configuration, see Figure 39. For each cargo handling equipment that is to be included in the ship concept model; the *Add Equipment* button is pushed. Doing so opens a configuration wizard.
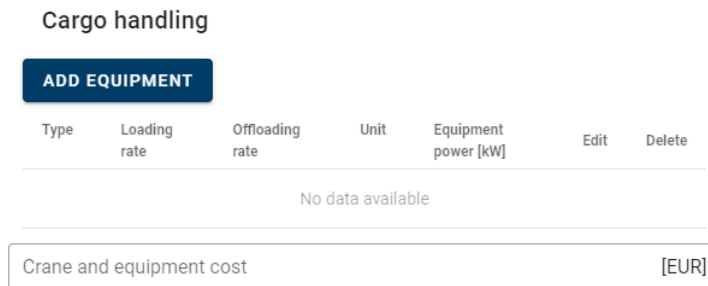
Figure 39: Cargo handling and equipment cost configuration

The first step is given in Figure 40. It is possible to save at this stage by pressing *SAVE*, doing so will save an incomplete configuration, but a cargo handling equipment instance will be saved. To use the ship model which this cargo handling equipment model belongs to in a simulation, it will be necessary to complete the configuration first. It is also possible to abort the configuration at this stage by pressing *CANCEL.* To move on with configuration, select the *Loan handling capabilities* drop down in Figure 40.
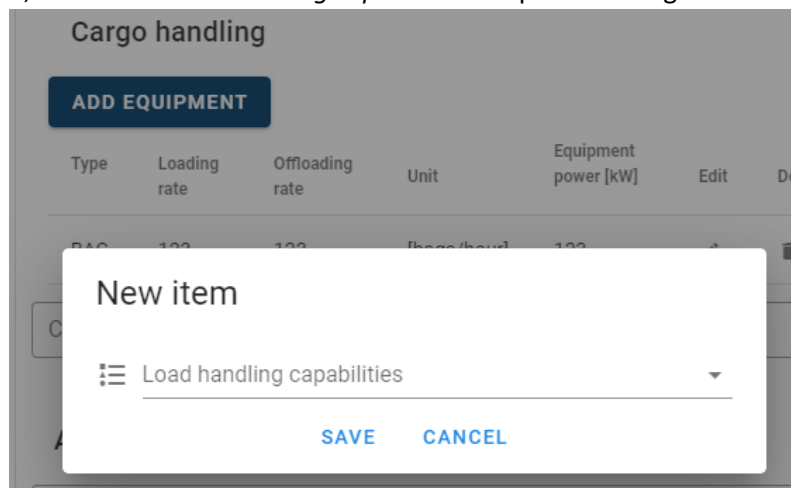
Figure 40: Add cargo handling equipment wizard - first step

This opens the next window, given in Figure 41. In this step the user can choose between a set of predefined cargo types. Choosing cargo type defines the type of cargo that the cargo handling equipment can handle.
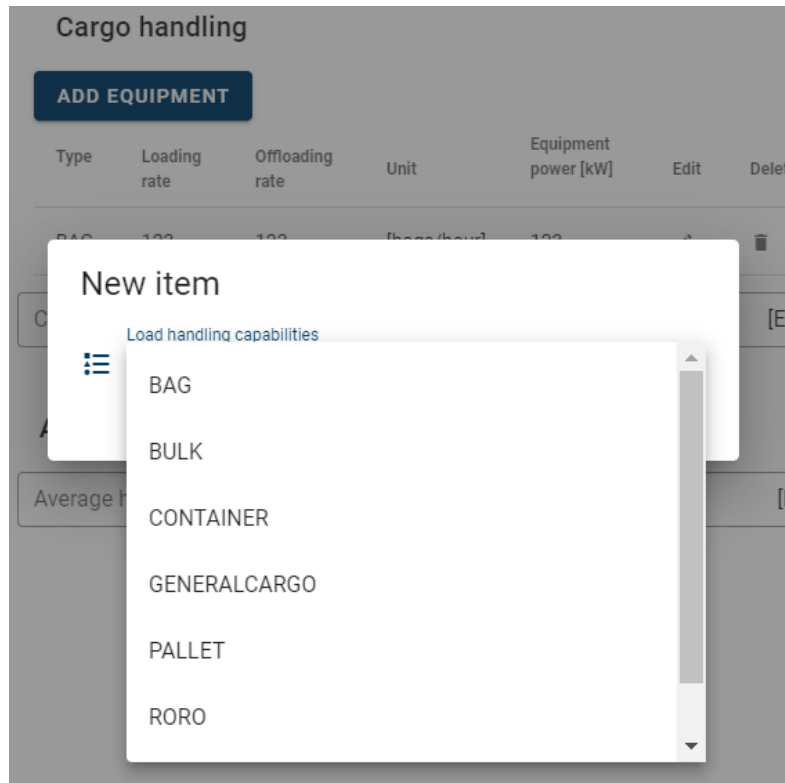
Figure 41: Choose load handling capability

When the cargo type is chosen, the wizard moves to the next step which is given in Figure 42. In this step the *Loading rate* and the *Offloading rate*, as well as the *Power consumption* of the cargo handling equipment is configured. It is still possible to change the cargo type by using the dropdown at the top of the wizard menu in Figure 42. Doing so will change the unit of the *Loading rate* and *Offloading rate* input boxes. To complete the configuration the user needs to press *SAVE*, while the configuration is aborted by pressing *CANCEL*.

If the ship concept includes a cargo handling equipment that can handle more than one type of cargo, this can be configured by adding one cargo handling equipment for each cargo type by completing the steps in Figure 39 to Figure 42. In the same way, multiple different cargo handling equipment can be added by completing the same steps.
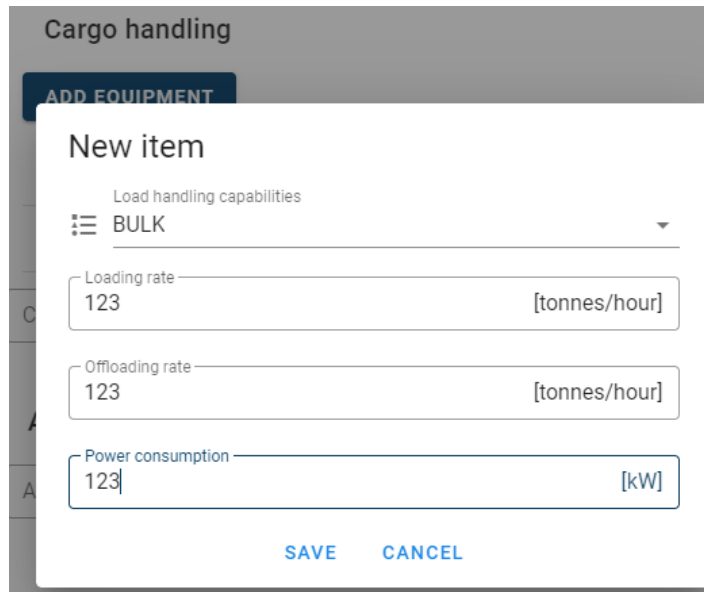
Figure 42: Configure cargo handling equipment loading and unloading rate, and power consumption

The *Crane and equipment cost* input box in Figure 39 is a manual input and is not affected by the cargo handling configurations. This means that the user can add any numerical value one would like to, and that this input can be used to include the investment cost of any additional equipment such as, e.g., auto-mooring, not only cargo handling equipment. It is up to the user if this input is used, or if only the *Cost of new build* input in Figure 35 is used.

NOTE the cargo handling equipment instance created in the MA tool will be available in the LA tool and vice versa. This means that configuration changes done in either tool will impact both. However, the *Power consumption* configuration is not used by the LA tool.

NOTE cargo handling equipment is not mandatory for the ship configuration, however, if there is no cargo handling equipment configured for the ship, then it is required to configure cargo handling at each location that the ship loads or offloads to. This will also be discussed in the location module.

The final configuration menu in the left column is the auxiliary power input box, see Figure 43. This input should capture all loads that consumes power, except for propulsion and cargo handling. Examples are auxiliaries, hotel loads, various equipment, etc.

Figure 43: Auxiliary power configuration box

The right column of the ship configuration starts with the configuration of the Key enabling technologies (KET)for MASS, see Figure 44. The configurable KETs in the ship configuration are: Situational awareness, Autonomous navigation, Intelligent machinery, Connectivity, Autonomous cargo handling. The key enabling technology Remote Control Centre (RCC) configuration is not included on the ship configuration page and is discussed separately later. Pressing *ADD KET* opens a wizard.

Figure 44: KET configuration

The first step of the wizard is given in Figure 45. The user can choose the KET one wants to add from the dropdown at the top of Figure 45. The user can also save by pressing *SAVE*, which will add an empty configuration which must be completed before a simulation can be run. The configuration can be aborted by pressing *CANCEL*.
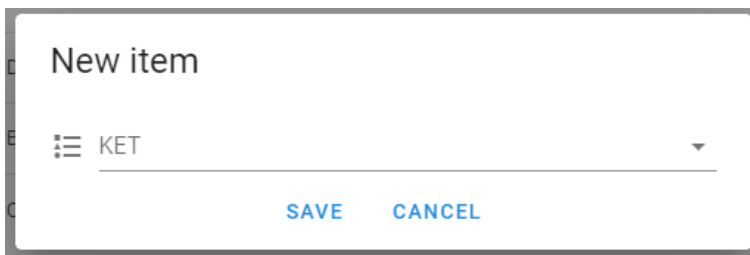
Figure 45: KET configuration wizard step one - choose KET

Pressing the *KET* dropdown gives access to a list of predefined KETs as given in Figure 46.
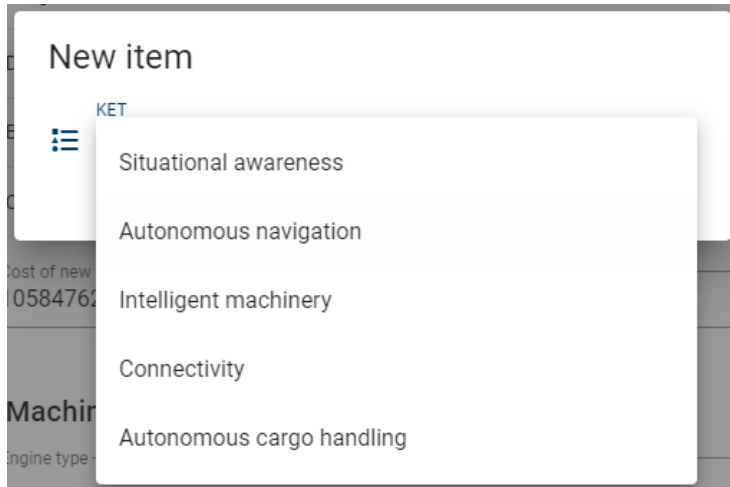
Figure 46: KET configuration wizard step one - Predefined KETs

When the user chooses a KET the wizard moves to the next step, given in Figure 47, where the yearly operational cost related to the KET is entered, and the investment cost (CAPEX) of the KET is entered. There are no other effects of choosing a KET. Ship models without superstructure must be chosen by choosing the correct ship model in Figure 35.
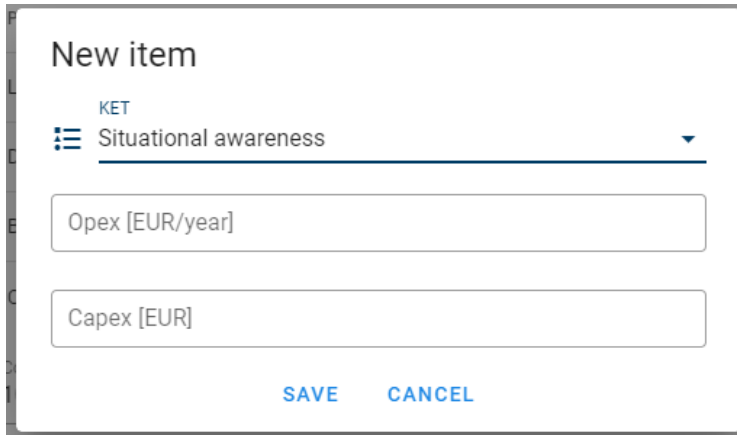
Figure 47: KET configuration wizard step two - configure OPEX and CAPEX for the KET

The next configuration menu in the right column is the Crew roster configuration, see Figure 48. This is intended for estimating the crew related yearly cost. As seen the roster has some pre-made suggestions for crew members and associated estimated yearly salary. Note that this salary represents all the yearly costs for the specific crew member. It is possible to delete, add, or modify the crew member roster configurations. A crew member is deleted by pressing the 🗑 icon and is edited by pressing the ✏ icon.

Figure 48: Crew roster configuration part 1

A crew member is added by pressing *Add Crew member, upon which the popup in* Figure 49 appears. The user must enter *Name* and *Salary*. If the users prefer, the roster can be one line with a lump sum estimation for the yearly crew cost.

Figure 49: Crew roster configuration part 2

The final part of the ship configuration is found at the bottom of the right column. This is where the final cost configuration is done, and where the summary of operational (OPEX) and investment (CAPEX) costs are found, see Figure 50. The cost per kg fuel is entered in the *Fuel price* input box. Operational expenses, in addition to the operational expenses discussed above, can either be configured as a lump sum in the *OPEX costs* input box, or as a more detailed configuration by ticking off *Detailed OPEX.*

Figure 50: Cost configuration and cost summary view

Ticking off *Detailed OPEX* extends the cost configuration with the fields given in Figure 51. The purpose of the detailed OPEX configuration is to give a more detailed breakdown, as a guide for estimating the operational expenses.

The *CAPEX interest rate* and *CAPEX years of depreciation* in Figure 50 are mandatory fields, used to estimate the yearly capital cost, based on these inputs and the total CAPEX. It is also possible to add investments costs not covered by the previously discussed configuration steps by using the *Additional CAPEX* input box. This is also where required investments outside the ship, such as, e.g., land-based infrastructure, must be included. The total CAPEX and OPEX is displayed at the very end of the ship configuration page, see Figure 50.

NOTE the Total OPEX in Figure 50 do not include RCC costs. These are configured in the RCC module, and the total yearly OPEX for each ship is given in the results view, which will be discussed later in the document.

Figure 51: Detailed OPEX configuration

Note remember to save the configuration, the tool has no autosave functionality!

2.5.3 RCC configuration

Creating an RCC model instance is done in the same way as discussed in subsection 2.3.2, note that multiple RCC model instances can be created and configured.

The RCC configuration page is given in Figure 52. The user can either directly enter a yearly RCC cost estimate per ship or tick the *Advanced* check box for a more detailed view.

Figure 52: RCC configuration

The more detailed RCC configuration is given in Figure 53. The user can enter an estimated yearly cost for the *Building costs* (any cost related to the RCC building/office/location. This could simply be a rental cost, or

it could be the cost of owning and maintaining the building/offices, it also includes the office supplies and equipment, other supplies or material for the employees, and all other costs related to a building such as electricity, fees for waste and water, insurance, etc.), an estimated yearly *Equipment cost* (the yearly cost for the RCC equipment and technology, such as the operator stations, servers, communication equipment, etc., including the yearly capital cost, maintenance costs, and operational costs of these), an estimated *Average yearly operator cost* (all the cost items related to employing one person for a year), *Number of ships operated by the RCC*, the *Ships per operator* (the number of ships that each operator is in charge of), the *Working hours per year per operator* (the number of hours per year that each operator works), the *Opening hours* (how many hours a day is the RCC open for operating ships), and the *Days open per year* (the number of days per year that the RCC is open for operating ships). The estimation based on these inputs is described in more detail in *"AUTOSHIP deliverable D8.1: Generic business case model and KPIs,"* [4].

When all configurations have been entered, the *Yearly cost per ship* for the RCC is calculated by pressing the ⟳ icon next to the *Yearly cost per ship* box.

Note that unchecking the advanced option clears the estimated *Yearly cost per ship.*

Figure 53: Advanced RCC cost estimation

Note remember to save the configuration, the tool has no autosave functionality!

2.5.4 Port cost configuration

Creating a Port cost model instance is done in the same way as discussed in subsection 2.3.2, note that multiple Port cost model instances can be created and configured.

The port cost module is intended for configuring the costs and fees that needs to be paid when a ship enters and stays at a harbour, and for cargo handling at the harbour. The module will be tied to locations defined in the Location module (subsection 2.5.5).

The port cost module is based on terminology for Norwegian ports, and it is possible to load average costs for Norwegian ports given in [6]. This is done by clicking the 📁 icon in Figure 54.
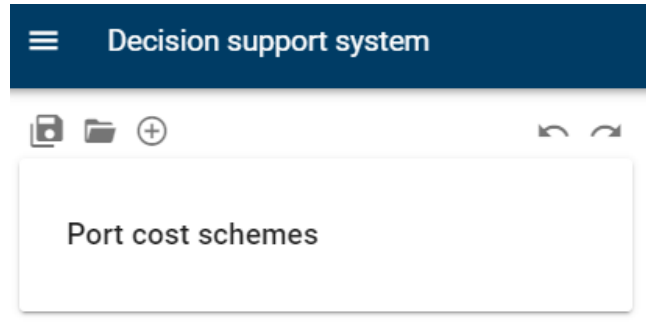

Figure 54: Port cost schemes

Doing so opens the popup in Figure 55 (note that it can take some time before the popup opens). Tick of the check box next to *Default* and press *Load*.
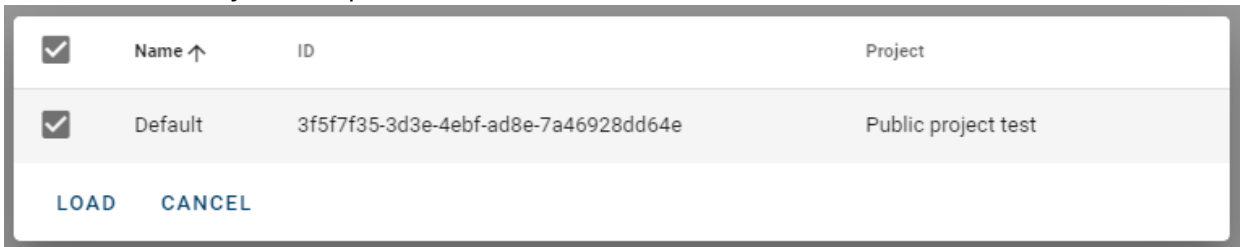

Figure 55: Load default port cost scheme

Pressing load opens another popup as seen in Figure 56. Pres *Yes* to create a copy of the default port cost scheme in your project. Pressing *Cancel* aborts the loading.
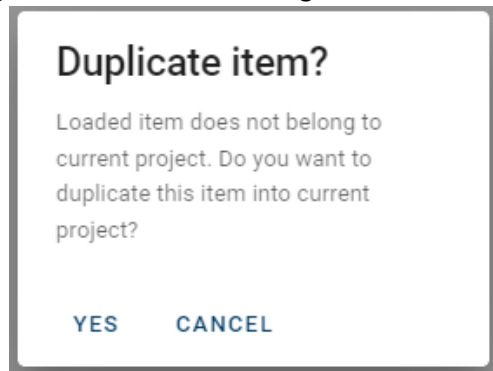

Figure 56: Confirm loading and duplicating item

Note that since it is hard to capture all possible port fees for any port in any country, it is currently unknown if there are port fees or costs that are not captured. The following will discuss the various fees and cost items that can be configured.

Terminal costs are costs paid for using the terminal and the terminal cargo handling equipment, see Figure 57 (the figure shows the default terminal costs, these can be changed by the user). The terminal costs are given per cargo type but note that they do not include cargo dues paid to the port. Cargo dues are discussed later in this subsection. All costs are estimated per visit and is based on the transferred cargo to and from the ship.

For bulk, the configuration input is for *Cost using own crane* and for *Cost using port crane* (see Figure 57). The *Cost using own crane* is the cost per ton bulk, loaded or offloaded using the ship crane, paid to the terminal operator. The *Cost using port crane* is the cost per ton bulk, loaded or offloaded using the port (or terminal) crane, paid to the terminal operator.

For ro-ro, the configuration input is for *Cost per unit* loaded or offloaded via the terminal, paid to the terminal operator (see Figure 57).

For general cargo, the configuration input is a table (see Figure 57). Each entry in the table is the total loaded or offloaded weight and the corresponding cost per ton cargo. If more than one entry is made, the tool will interpolate between the entries to calculate the cost per ton cargo for the total loaded or offloaded weight. If the total loaded or offloaded weight is outside the configured range, the maximum weight entry cost per ton will be used in case the loaded or offloaded weight is above the range, and the minimum weight entry cost per ton will be used in case the loaded or offloaded weight is below the range.

For containers, the configuration input is a table (see Figure 57). Each entry in the table is the container length in foot, and the cost per loaded or offloaded container. If a non-standard container is handled, interpolation is done between the entries. If the non-standard container length is outside the configured container lengths, either the maximum or minimum container length is used, in the same way as for the general cargo table.

Figure 57: Terminal cost configuration (the figure shows the default terminal costs, these can be changed by the user)

Cargo dues can be configured for cargo types: general cargo, dry bulk, wet bulk, ro-ro, and container. The configuration for general cargo, dry bulk and wet bulk is done by filling out weight/cost tables exemplified by general cargo in Figure 58. Interpolation between the entries, and handling of total weights outside the configured range, is done in the same way as for terminal costs – general cargo.

Cargo dues
General cargo

Weight [ton]	Cost (€)	Actions
275	1.44	✏ 🗑
700	1.44	✏ 🗑

Figure 58: Port dues configuration by weight/cost tables, general cargo example

Cargo dues for ro-ro and containers are estimated as a cost per unit. This is different than for the rest of the cargo types, and is exemplified in Figure 59 by port dues for ro-ro.

Roro

Category	Cost (€)	Actions
Cars	13.9	✏ 🗑

Figure 59: Port dues for ro-ro

Ship weight-based costs and dues are the final cost configurations for the port cost scheme. These are all based on the same type of weight/cost tables, where weight is the ship tonnage. These are the Mooring and cast-off costs, the Port dues, and the Fairway dues. Exemplified by port dues in Figure 60. The table has entries for each cost per ship weight break point. E.g., for the configuration in Figure 60, if a ship is below 2000 ton, the 2000 ton entry cost per ton is used, if a ship is between 2000 and 3000 ton the 3000 ton cost per ton entry is used, and so on.

Port dues

Weight [ton]	Cost (€)	Actions
2000	128.09	✏ 🗑
3000	180.06	✏ 🗑
4000	232.03	✏ 🗑
5000	282.02	✏ 🗑

Figure 60: Port dues based on ship tonnage

Note there are some known cost items which are not currently captured, these are costs related to pilotage and fee to VTS. These could be included by estimating the yearly amount manually and adding them to the

General costs in the advanced yearly operational cost configuration in Figure 51. The LA tool can support this calculation by giving the estimated number of visits per year to locations in areas where such costs apply.

Note unsupported weight-based costs could be accounted for by adding them to supported costs. E.g., if there is an unsupported cost based on ship weight, this could possibly be handled by adding it to the ship weight-based port dues. If the unsupported ship weight-based cost is e.g., 50 Euro per ton, this could be added to each entry in the port dues table. Also note that as the tool is applied to more case studies, such shortcomings will be revealed, and the tool will be updated to handle these.

Note remember to save the configuration, the tool has no autosave functionality!

2.5.5 Location configuration

Creating a Location model is done in a slightly different way compared to the module interface discussed in subsection 2.3.2, note that multiple Location models can be created and configured.

The same controls for saving, loading, duplicating and deleting a configured model instance as in subsection 2.3.2 are also available for the Location module, however the controls are placed a bit differently, and creating a location model instance is different. The placement of controls is given in Figure 61.

Figure 61: Location configuration - placement of controls

To add a new Location instance, click on the ⦿ icon in the upper left corner of Figure 61, next click on the location placement in the map. Notice that drag-and-drop does not work for placing locations, one must click on ⦿ icon and on the map to place the location. If the user wants to fine tune the coordinates of the locations, this is possible in the detailed locations configuration page with is opened by clicking on the location pin placed in the map, see Figure 62.
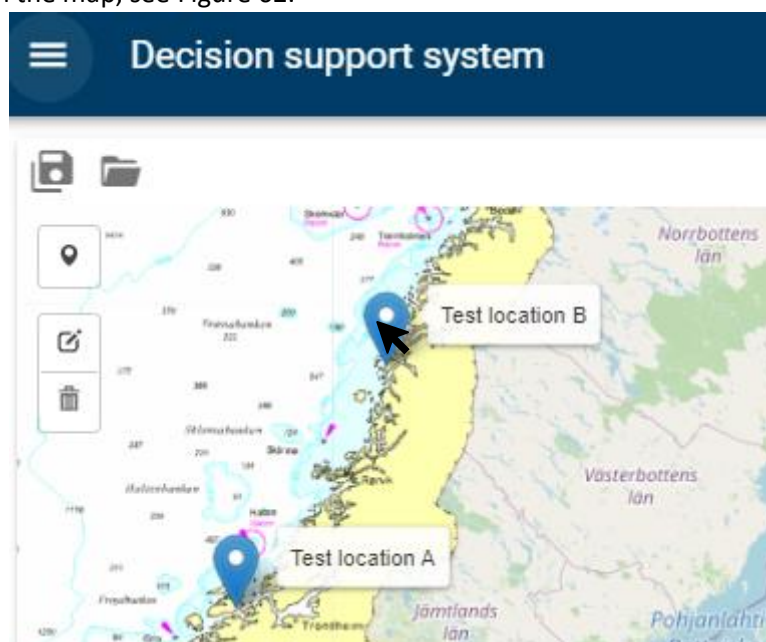

Figure 62: Entering detailed location configuration

The detailed location configuration consists of three main sections, the Location configuration, The Cargo handling, and the Charging. The Location configuration section is given in Figure 63. The location *Name* is a required field, and this name will be displayed in the map next to the location pin as soon as the Location configuration is saved, as seen in Figure 62. When a location instance is created, the *Name* field is blank, and there will be no location name displayed next to the location pin in the map in Figure 62. The next two fields are the location position given as *Latitude* and *Longitude*. These are automatically filled in, based on the location pin placement when the location instance was created. It is however possible to fine tune the placement by manually entering the *Latitude* and *Longitude*. The next configuration input in the Location configuration section is the location *Type*. The location *Type* field is mandatory and is chosen from a dropdown list. The user can choose between consumer, producer, and terminal. These location categories are not used by the MA tool with one exception (however the locations are shared with the LA tool and this configuration is important for the LA tool and are discussed in more detail in subsection 2.4). The only thing the MA tool uses the location *Type* configuration for is to force the user to choose the *Consumer Type* when *Type* consumer has been chosen. This is because in contrast to other location types, some consumers may be aquaculture facilities (such as fish farms in the AUTOSHIP project), and aquaculture facilities are a bit special in terms of Norwegian port cost regulations. Upon entering an aquaculture facility, the fairway due must be paid, but no other port fees or dues are applicable. The *Consumer Type* is a mandatory field for location of *Type* consumer and is chosen from a dropdown list. The user can choose between Harbour or Fish farm. The configuration impacts the way port costs are calculated. The final configuration input for the Location configuration section is the *Port cost scheme*. This configuration input links the location to one of the predefined *Port cost schemes* which are available from a dropdown list.

Figure 63: Location configuration - location data

The next configuration section for locations is the Cargo handling, see Figure 64. This configuration is used to model cargo handling equipment placed on locations. A new cargo handling equipment for the location can be added by clicking *New Equipment*. This opens a wizard.

Cargo handling

Cargo handling equipment

NEW EQUIPMENT

Type *	Loading rate *	Offloading rate *	Unit	Equipment power [kW] *	Override	Actions

No data available

Figure 64: Location cargo handling configuration

The first step of the cargo handling at location configuration wizard is given in Figure 65. The user must choose which cargo type the cargo handling equipment can load and unload, by choosing cargo type from a dropdown list. It is possible to save incomplete configurations, however, the configuration must be completed before a simulation can be run.

Figure 65: Cargo handling at location configuration wizard - first step: Choose type

When the cargo type is chosen, the next step is (see Figure 66) to fill in the *Loading rate*, the *Offloading rate*, the *Power consumption*, and finally to choose if the location cargo handling equipment shall be used even if the ship has its own cargo handling equipment. The latter is configured by ticking off *Override ship cargo handling* and is intended to enable simulations where the harbour (or location) requires that the location cargo handling equipment is used, or simulations where the effect of using ship cargo handling equipment versus location cargo handling equipment, is compared. The configuration can be aborted by clicking cancel. Completing the configuration is done by clicking save.
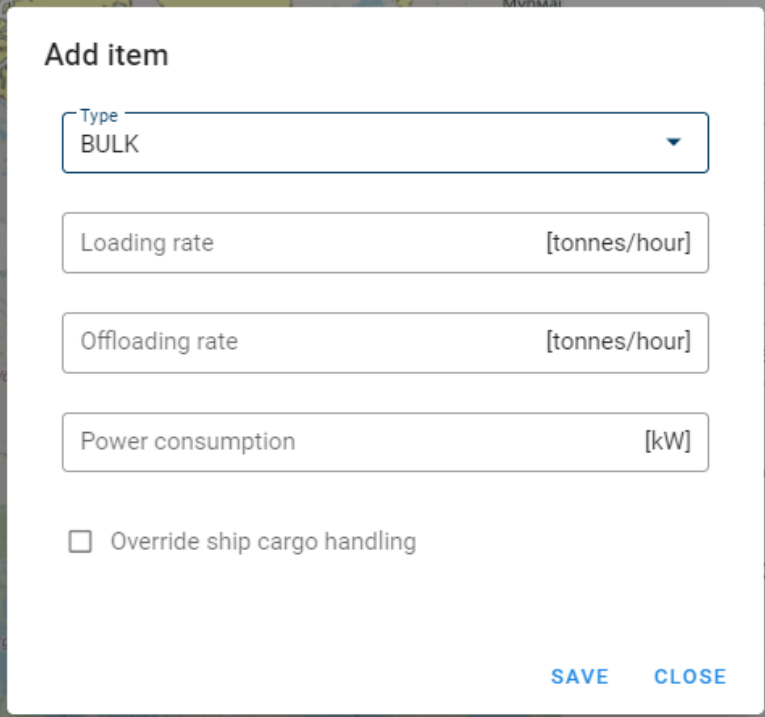
Figure 66: Cargo handling configuration wizard - step two: fill in loading rate, offloading rate, power consumption, and choose if location cargo handling equipment shall be used even if the ship has its own cargo handling equipment

The final configuration section for locations is the Charging, see Figure 67. This section is intended for cases where the ship is configured with *Engine type* "Battery – electric drive". It is used to estimate the time required for charging, and the cost of the energy. Current charging policy in the MA tool is simply to replenish the battery charge at any location that offers charging. The configuration is done by entering the *Charging price* (the cost of each KWh delivered from the charging equipment) and the *Charging power* (the capacity of the charging solution at the location).

Note loss during charging is accounted for in the battery charging model.

Figure 67: Charging for battery configuration

Note It is possible to configure multiple cargo handling equipment at the location, however, currently the simulation of only one cargo type for the project is supported.

Note remember to save the configuration, the tool has no autosave functionality!

2.5.6 Shipment configuration

Creating a Shipment model instance is done in the same way as discussed in subsection 2.3.2, note that multiple Shipment model instances can be created and configured.

A shipment is the collection of cargo that is picked up at a location. It can consist of a set of orders, and one order is a collection of cargo that is to be delivered to one location. The shipment configuration can get its input from the LA tool, which generates typical shipments based on analysing the cargo flow. This is elaborated in subsection 2.4.8.2.

The shipment configuration page is given in Figure 68. First the *Pick up location* must be selected from a dropdown list that holds all the configured locations in the project. Next, at least one Order must be created by pressing the ⊕ icon. Each order must be configured by setting the *Delivery location*, which is chosen from a dropdown list that holds all the configured locations in the project. The cargo within each order must also be configured.
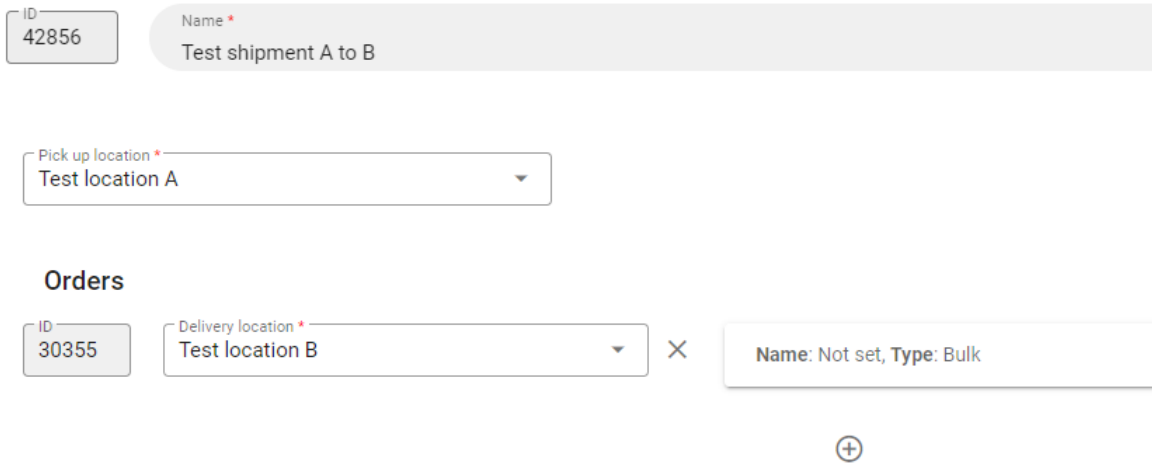

Figure 68: Shipment configuration page

Configuring the cargo within each order is done by pressing the box right of *Delivery location* in Figure 68. This expands the box and reveals all the order cargo configuration fields, see Figure 69. The cargo *Type* is not configurable as it is fetched from the Project cargo type configuration. The order *Name* field must be set, the order total *Weight* in ton must be set, and the order total *Volume* in cubic meter must be set.
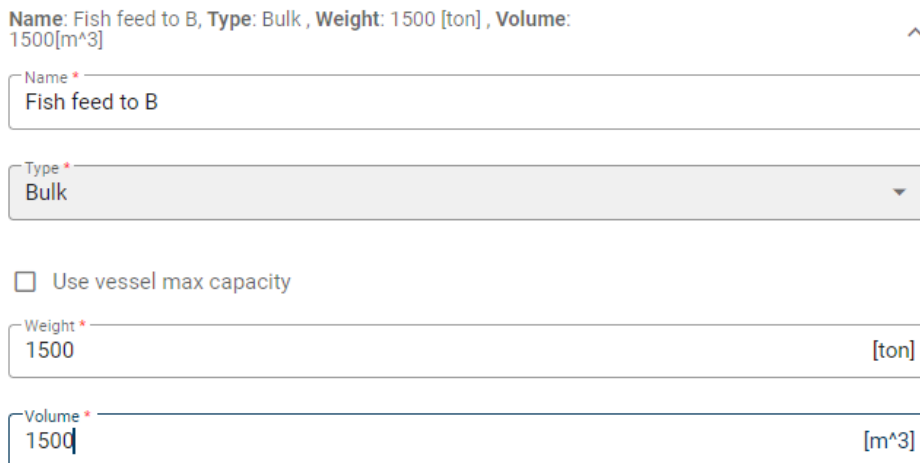

Figure 69: Order cargo configuration

An alternative to explicitly setting the order *Weight* and *Volume* is to tick the *Use vessel max capacity* tick box. Doing so changes the order cargo configuration fields as seen in Figure 70. This option is currently only supported for cargo in bulk. The functionality is that the user can specify the percentage of the ship capacity that the order shall correspond to, by configuring the *Weight in precent of vessel capacity* box. This is useful for studies comparing ships of different sizes where a certain percentage cargo utilisation is assumed.

Figure 70: Order cargo specified as percent of the ship cargo capacity

2.5.7 Voyage plan configuration

Creating a Voyage plan model instance is done in the same way as discussed in subsection 2.3.2, note that multiple Voyage plan model instances can be created and configured.

The Voyage plan configuration is given in Figure 71. The Voyage plan is the basis for the simulation and is an instruction for the sequence of tasks that the ship shall do, and which shall be simulated. The configuration is done by specifying the pick-up of shipments, and delivery of orders. And by specifying the start and stop location for the simulation (which will be elaborated shortly). Based on this, the MA tool infers a task sequence consisting of loading tasks, sailing tasks, offloading tasks, etc.

The task configuration is done by adding tasks by pressing the ⊕ icon. For each added task, the user must first choose the task type by pressing *Task* and selecting task type from the dropdown. The available task types are "Pick up shipment" and "Deliver order". The "Pick up shipment" tasks are configured by choosing which configured order shall be picked up from the *Shipment* dropdown. All configured shipments are available from the dropdown. The deliver order tasks are configured by first choosing the shipment from the *Shipment* dropdown, and then the order from the *Order* dropdown. The *Shipment* dropdown holds all the configured shipments, while the *Order* dropdown only holds the orders within the chosen shipment.

The sequence of the configured tasks is important as it determines the Voyage plan. In Figure 71 the ship will start by picking up shipment "42856 – Test shipment A to B" at location A, sail to location B and deliver order "30355 Fish feed to B" within shipment "42856 – Test shipment A to B". Next it will load shipment "78926 – Test Shipment B to A", sail to location A and deliver order "39560 – Fish to A" within shipment "78926 – Test Shipment B to A".

Figure 71: Voyage plan configuration task sequence, pick up shipment and deliver order configuration

As already mentioned, the start and stop location must be configured by the user. This is because the simulation needs to know where the ship is located when the simulation starts, and where it shall be located when the simulation ends. In the case discussed above, start location could be set to location B, which means that a sailing task for sailing from B to A would be inserted prior to loading at A. In this case, we set the start at location A, see Figure 72. Another reason for why the stop location must be specified is to be able to distinguish between cases where there is only one shipment that is transported from A to B, and where in one case the ship returns to A while in the other case it stops at location B.

Figure 72: Configure start and stop location

When the task sequence and the location start and stop have been configured, the map at the bottom of the Voyage plan configuration page will look as in Figure 73. The green circle at location A indicates that this is where the ship will start, while the inner red circle at location A indicates that this is where the simulation will end. The blue circle at location B indicates that the ship will visit this location during the simulation.
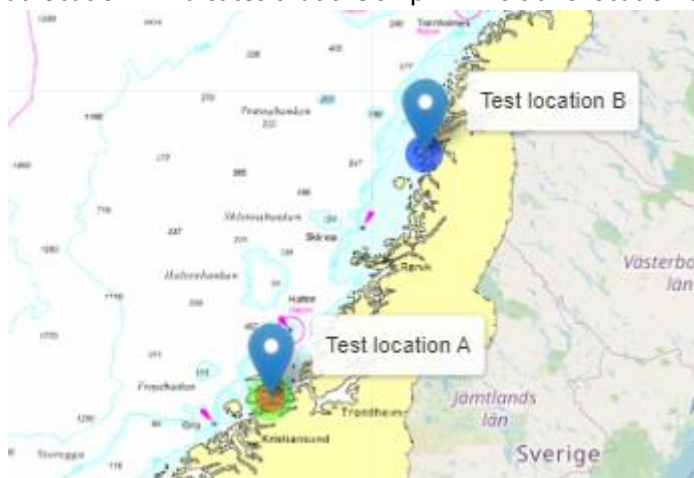

Figure 73: Voyage plan map - prior to generating route

The next step is to press the generate route button to the left in Figure 72. Doing so generates a route, consisting of a set of waypoints between location A and B, see Figure 74. The route generation is based on a dataset for typical routes between the main ports in Norway. Any location not located on these routes will cause a straight line from the location to the nearest point on the routes in the data set. For locations outside of Norway, the route generation will result in straight lines between the locations. However, the routes can manually be adapted pressing the ✏ icon in Figure 74.

Figure 74: Generated route between location A and B

The manual configuration of waypoints is done by dragging the white boxes representing waypoints, see Figure 75, to the new location. Additional waypoints can also be added between the configured waypoints. This is done by clicking on an existing waypoint, while in edit mode, at which point a transparent waypoint will appear, see Figure 76. The transparent waypoint is a suggested new waypoint, clicking on it will make it a new waypoint and it will become solid white. The newly made waypoint can be moved to the desired position.
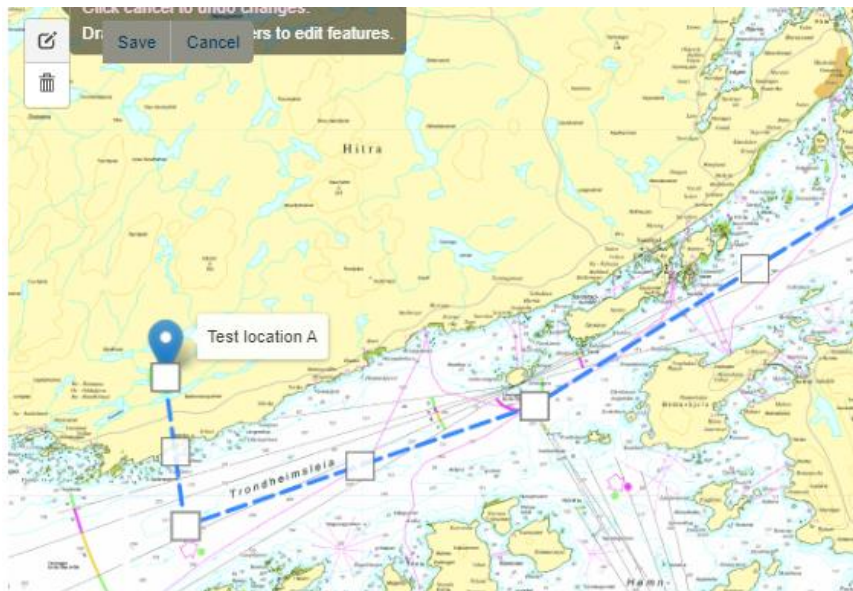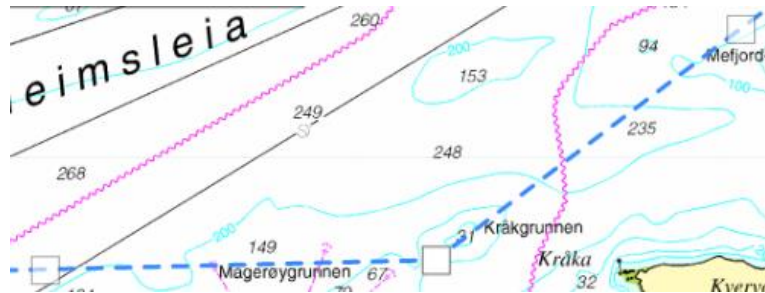

Figure 75: Manual waypoint configuration

Figure 76: Manual configuration of waypoints - add waypoint by clicking the transparent suggested waypoint

2.5.8 Weather configuration

Creating a Weather model instance is done in the same way as discussed in subsection 2.3.2, note that multiple Weather model instances can be created and configured.

The weather model configuration starts with entering a *Name* and then selecting the *Voyage plan* for which weather is to be configured, see Figure 77.
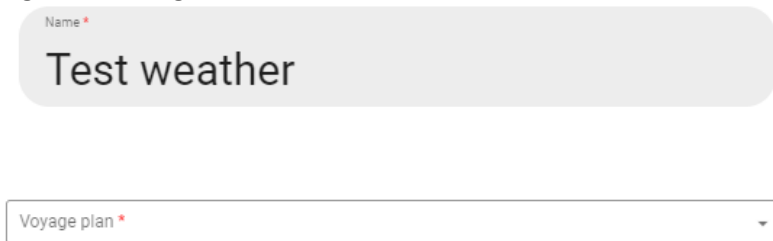

Figure 77: Weather configuration initial step

Selecting the *Voyage plan* populates the map in the weather configuration with the configured route and waypoints, see Figure 78.
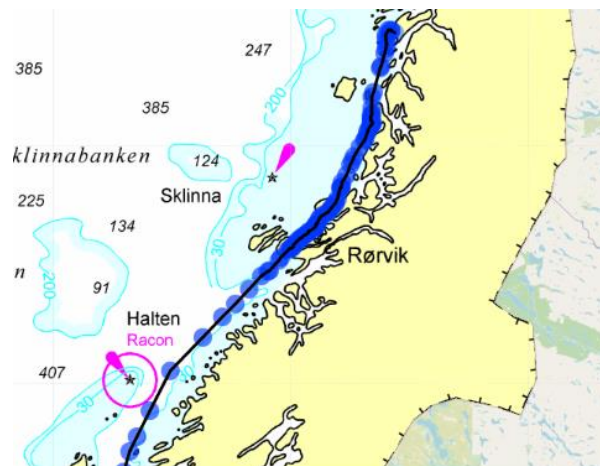
Figure 78: Weather configuration - route and waypoints

Weather can be configured on waypoints, this allows the user to configure weather with the resolution that the user prefers, only limited by the number of waypoints. If only one waypoint is configured with weather, then this weather applies for the entire route. If two or more waypoints are configured with weather, then the waypoints without configured weather will get the weather configuration from the nearest waypoint with configured weather. An example is given in Figure 79 where weather is configured at the lower most waypoint (*Lat* and *Lon* in the table are the light green cells), and at the upper most waypoint (*Lat* and *Lon* in the table are the dark green cells). The light green line shows the part of the route that will be simulated with the weather configured at the waypoint with the light green *Lat* and *Lon*, and the dark green line shows

the part of the route that will be simulated with the weather configured at the waypoint with the dark green cells. The transition between the light green and dark green line is the midpoint between the waypoints with configured weather. Also notice that it is possible to configure multiple weather profiles for the same waypoint such that variation over e.g., a year, can be captured. In the example in Figure 79, the dark green waypoint is configured with two different weather profiles. Each have the configuration parameter *% time spent* set to 50. This means that each of the two configured weather profiles will be used 50 % of the time the ship sails this part of the route in the simulation.

Note when the weather configuration is started the lowest line in the table in Figure 79, the one with 🖫 icon at the end, is the only one shown. This line is the configuration input line, that is the line where the weather configuration is entered for a given waypoint. The configuration input line *Lat* and *Lon* will update when a way point is clicked on. When the line is populated with data, the user presses the 🖫 icon and a new line appears with the configured and stored data, while the configuration input line remains. Clicking on another waypoint will update the *Lat* and *Lon* for the configuration input line*,* and a configuration for that waypoint can be entered.
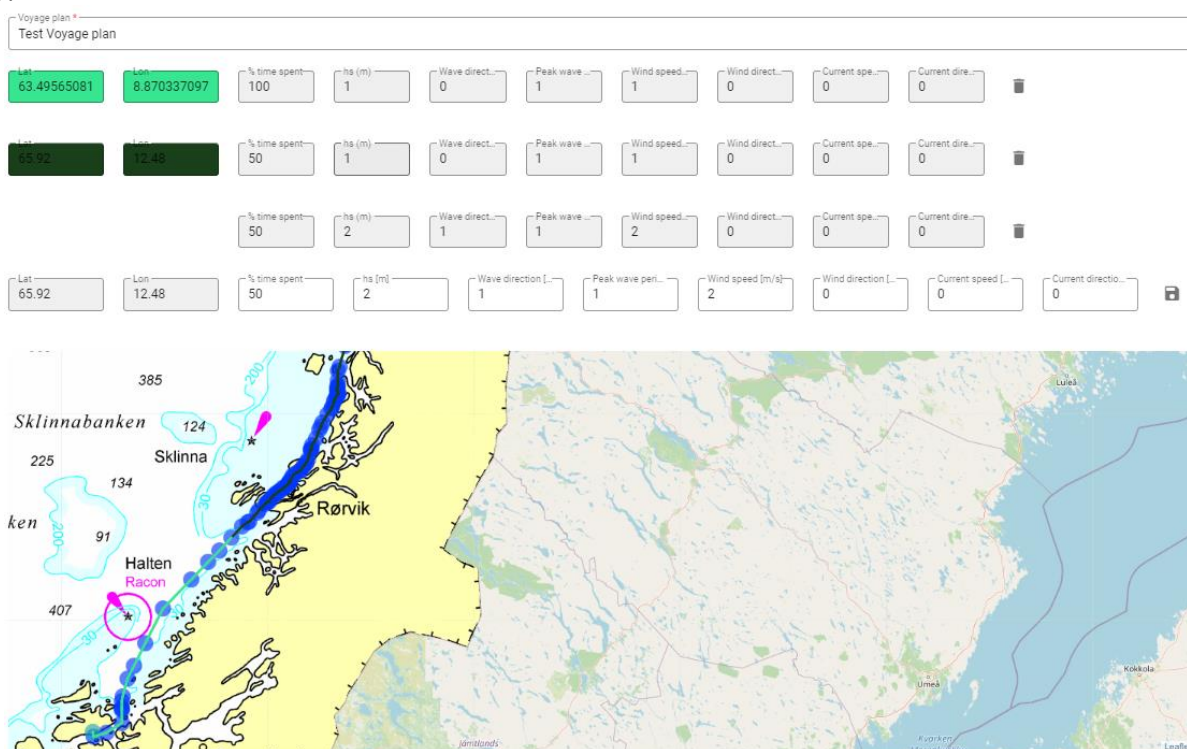

Figure 79: Route with weather configuration on two waypoints, one waypoint has two weather configurations

Note The parameters for weather should be based on weather statistics for the area. SINTEF is currently working on a tool for automatically generating such weather statistics, under another project. This will in time be integrated with the MA tool.

2.5.9 Study configuration

Creating a Study model instance is done in the same way as discussed in subsection 2.3.2, note that multiple Study model instances can be created and configured.

The study module is where all the previously described configurations are combined into one study. A study is a set of simulations which are run to analyse the configured autonomous ship system concept. The study configuration page, before any choices other than setting a name for the study are done, is given in Figure 80. The *Name* of the study must be entered, and then the user must choose the study type from the *Type* dropdown. Two options are available; compare ships and compare Voyages.

Figure 80: Study configuration page – initial page configuration

Choosing compare ships alters the study configuration page as given in Figure 81. The user must choose one of the configured voyage plans from the *Voyage plan* dropdown, and one of the configured weather models from the *Weather dropdown.* The user can set up several simulations for different sailing speeds by configuring the speed range by setting the lowest speed in *Sailing speed start,* the *Sailing speed increment*, and the highest speed in *Sailing speed stop.* Speed is given in knots. Finally, the user must add the ship concept that is to be analysed, or the ship concepts if more than one ships are to be compared, by pressing *Add Ship* for each ship that is to be included in the analysis.

Pressing *Add Ship* adds a line where one of the configured ships must be chosen from the *Ship* dropdown, and one of the configured RCCs must be chosen from the *Remote Control Centre* dropdown. An example where one autonomous ship called "Test 1" is to be compared to a conventional ship called "Test conventional", is given in   Figure 81.

Figure 81: Study configuration - example compare ships

If the user would like to compare the performance of one ship concept on different voyages, e.g., if there are two or more options for routing, then the Compare Voyages option is chosen in the studies *Type* dropdown in Figure 80. This changes the study configuration page as given in Figure 82. The user must choose the ship concept that is to be analysed from the *Ship* dropdown, configure the speed range in the

same way as for compare ships, and add the voyage plans that are to be compare by pressing *Add Voyage Plan* for each voyage plan that is to be compared.

Pressing *Add Voyage Plan* adds a line where one of the configured voyage plans must be chosen from the *Voyage plan* dropdown, one of the configured weather models must be chosen from the *Weather* drop down, and one of the configured RCCs must be chosen from the *Remote Control Centre* dropdown. An example where one autonomous ship called "Test 1" is to be analysed by comparing how it performs on the voyage plans "Test Voyage plan" and "Test Voyage plan 2", is given in Figure 82.

Note that weather configurations are tied to the voyage plan route. This means that at least one weather model must be configured per compared voyage plan.

Figure 82: Study configuration – example compare voyages

The next step in the studies configuration is to press *Generate Simulations.* Doing so creates a set of simulations, based on the configurations done so far, presented as a list. See Figure 83.
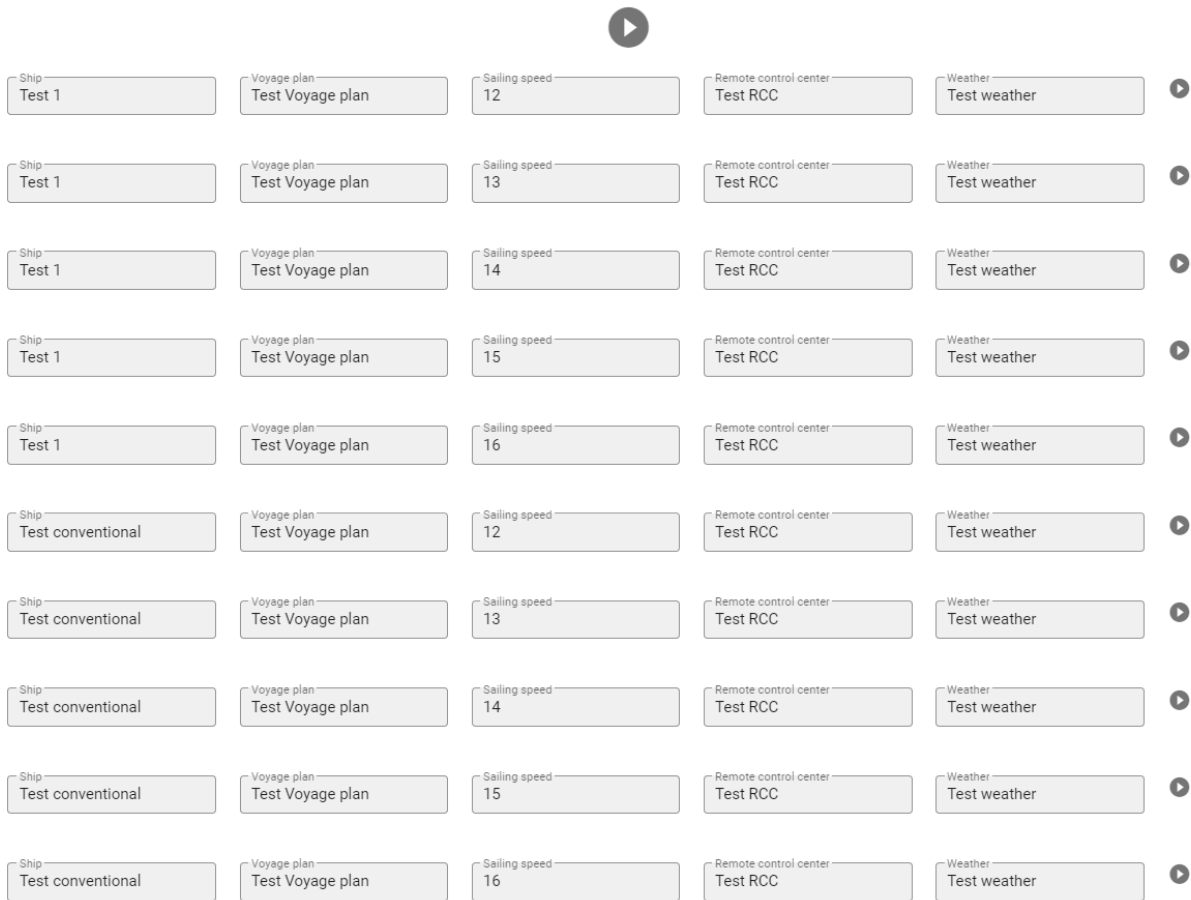
Figure 83: Generated simulations

The final step in the studies configuration is to press the icon to run the simulations. Pressing the at the top of Figure 83 runs all simulations. Pressing the icon next to one simulation instance will run that simulation only. When the simulations are completed, the table will update and look as in Figure 84. Simulation status symbols are summarized in Table 1.
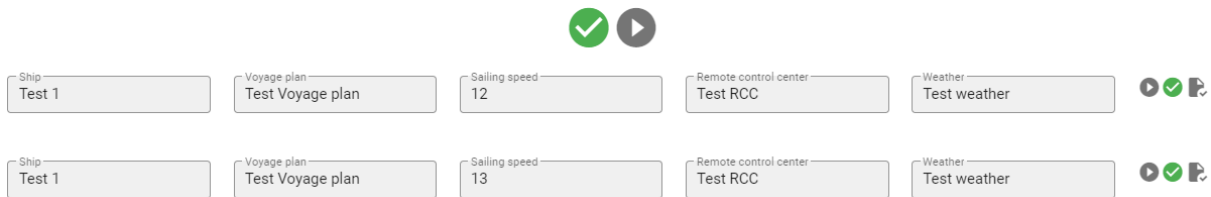

Figure 84: Successfully completed simulations

Table 1: Simulation status symbols

Symbol	Description	Click event
▶	Start simulation	Send simulation start request
○	Simulation request sent, awaiting response from backend	None
↻	Simulation in progress	None

⊙	Simulation failed	Show error message dialogue
✓	Simulation finished successfully	None
🗎	Simulation results dialogue button	Show simulation results report

Note if the simulation configuration is changed, but some of the generated simulations are identical to a previously run simulation, the previously run simulations will be kept and not re-run to save computational load and time.

2.5.10 Results view

The results view will have a list of study results for each configured study which has been run, see Figure 85. To the left of Figure 85 some configuration inputs will appear when a study is selected by clicking on it. These configuration inputs are used to account for non-operational time in the various KPI estimates that are given in the results view. This is done by configuring the percentage of a year where the ship is operational and performing freight work (not waiting for the next job or out of service due to repairs, service, or maintenance). The input is labelled *% operational per year.* After this input is configured, the user must initiate the re-calculation of the KPIs by pressing the ↻ icon in Figure 85.
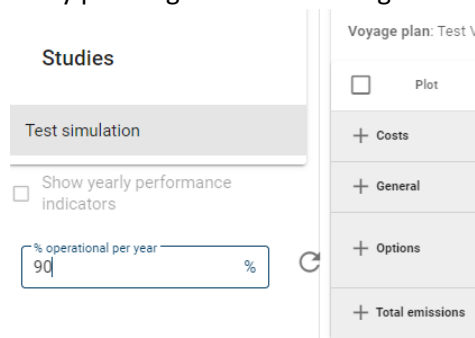

Figure 85: Simulation results overview

After the ↻ icon has been pressed and the re-calculation has completed, the *Show yearly performance indicators* can be set true or false by clicking. This lets the user investigate results for one voyage (*Show yearly performance indicators* = false), or for a voyage where costs and emissions from non-operational time is included (*Show yearly performance indicators* = true). In both cases the results represent typical average performance.

The results are sorted in the categories Costs, General, Location to location results, and Total emissions. The KPIs under Costs, General and Total emissions are estimated for the voyage (see Figure 86), while the KPIs under Location-to-location results are estimates for the part of the voyage that is between the chosen locations, chosen from the From and *To* dropdowns (see Figure 87).

Figure 86: Voyage results

Figure 87: Location-to-location results

More results are shown in similar plots, as a function of speed, where the two configured ships are compared. An example is given in Figure 88 which shows the total power consumption for the Autonomous ship "Test 1" and the conventional ship "Test conventional".
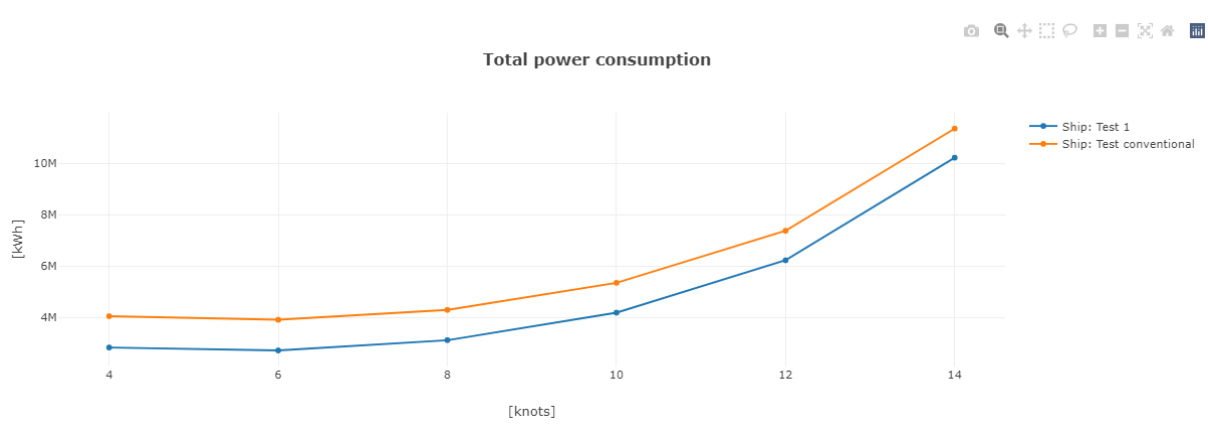
Figure 88: Total power consumption as function of sailing speed of the available parameters (KPIs) for a study

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