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Maritime Emergency Preparedness – Drifting Ships

T E Berg[1], Ø Selvik[2], R Indergård[3] and E Ringen[4]

[1] Scientific Advisor, SINTEF Ocean, Trondheim, Norway
[2] Senior Advisor, SINTEF Ocean, Trondheim, Norway
[3] Senior Advisor, SINTEF Ocean, Trondheim, Norway
[4] Senior Software Developer, SINTEF Ocean, Trondheim, Norway

E-mail: Tor.berg@sintef.no

Abstract. The Norwegian Coastal Administration registers maritime incidents in Norwegian waters. Drifting ships and drifting objects may cause serious incidents and possible disasters. By analysing ship traffic in Norwegian waters, it is documented that the frequency of drifting ships has been approximately 0.15% of the registered ship transits, or 150–165 drifting cases annually. In addition to a possible grounding when a vessel reaches the coastline, the increased use of the ocean space for wind farms, floating solar installations, and fish farming structures (moving from sheltered coastal sites to exposed locations) increase the risk of collision with different types of ocean structures, including offshore oil and gas installations. The need for adequate emergency preparedness to prevent drifting ships from colliding with different types of ocean structures or a final grounding can be solved through different types of mitigating measures. One measure could be to have dedicated emergency towing vessels for handling vessels drifting towards ocean structures or on a course leading to a possible grounding. A reliable tool for predicting a drifting vessel's path is important for planning an emergency towing operation. Systems to provide a fast and safe setup of an emergency towing connection under different environmental conditions are needed, while the competence of the crew on the emergency towing vessel and the ship to be towed is a critical factor for a successful emergency towing operation under adverse conditions.

1. Introduction

The Norwegian Coastal Administration (NCA) has the national responsibility for pollution preparedness from all ships within the Norwegian Economic Exclusive Zone (EEZ). Vardø Vessel Traffic Centre (NOR VTS) is responsible for monitoring vessel traffic in Northern Norway. One major task is to identify vessels with suspicious tracks and find out the cause of this behaviour. Special care is given to tracks deviating from the vessel's voyage plan. By contacting the vessels, the cause is identified. It may be that a vessel is performing planned maintenance during the voyage, but in some cases, a vessel is drifting due to a blackout or problems with the steering system. If a drifting vessel approaches the 12 nm zone off the Norwegian coast and there is a possibility that the vessel will cause pollution, the NCA may scramble the Norwegian Emergency Towing System (NETS) to assist the disabled drifting vessel using one of the Norwegian Coast Guard vessels allocated for NETS. Some brief descriptions of the organization of NETS and actual emergency towing incidents are prepared by SINTEF Ocean in collaboration with the Norwegian Coastal Administration and Norwegian Coast Guard [1]–[3]

In addition to grounding, the possibility of collision with different ocean structures is increasing as more such structures are placed in more exposed coastal waters (different types of fish farms). Within the Norwegian EEZ, there are a number of oil and gas installations and a growing number of offshore windmills/wind farms that need protection from drifting ships.

Early observation of drifting vessels, good models for calculation of drifting paths in all types of weather, combined with available emergency towing vessels positioned to reduce transit time to a disabled drifting vessel.are all part of the solution to this problem.

2. Drifting ship statistics

The Norwegian Coastal Administration gathers information on all types of incidents for vessels sailing within the Norwegian EEZ. They produce annual reports as shown in Fig. 1. The figure compares incident types for the years 2020–2022. The two largest incident types are drifting vessels and drifting objects. From the analyses of vessel traffic in Norwegian waters, it is documented that the frequency of drifting ships has been approximately 0.15% of the registered ship transits, or 150–165 drifting cases annually. In addition to a possible grounding when a vessel reaches the coastline, the increased use of the ocean space for wind farms, floating solar installations, and fish farming structures (moving from sheltered coastal sites to exposed locations) increases the risk of collision with different types of ocean structures, including offshore oil and gas installations.

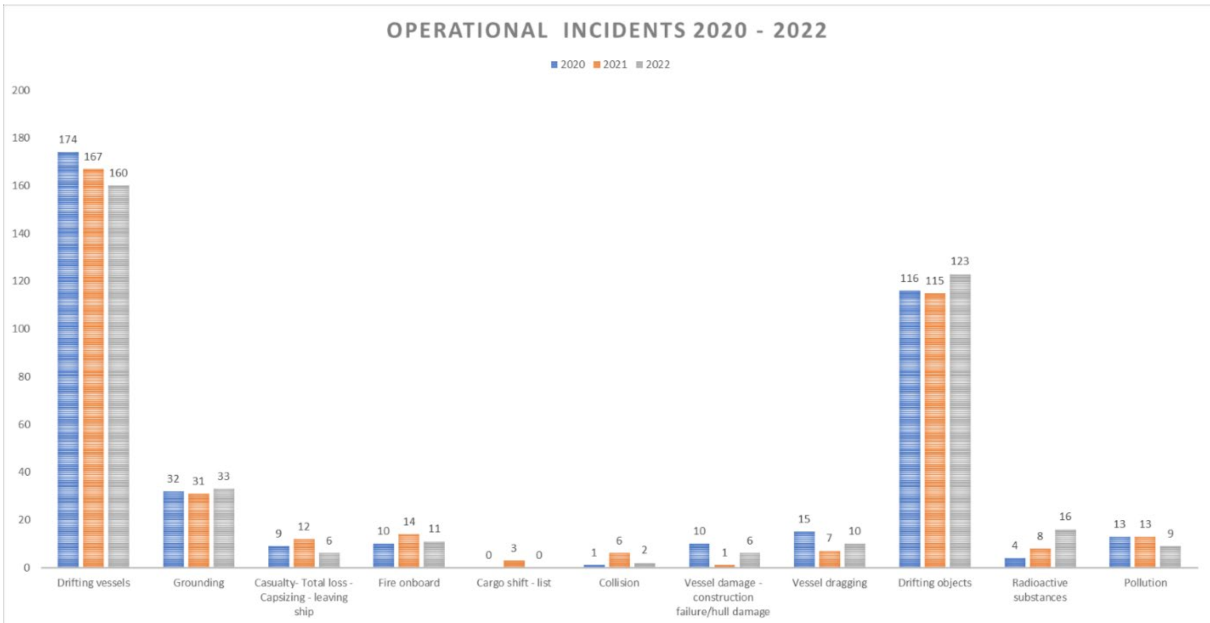

Fig. 1. Incident statistics collected by the Norwegian Coastal Administration's Ocean and Coastal Vessel Monitoring Vardø division [4].

3. Drifting ships – emergency towing cases

3.1. Cases in Norwegian waters – 2021–2023

3.1.1. MV Melinda. The bulk vessel MV Melinda (LOA 190m, GT 32 839) was in transit from Riga to Murmansk. As the ship sailed through the Norwegian EEZ, it had reported to and was in the Barents Ship Reporting System [5]. On January 17, 2022, at 14.45 hours, the ship called NOR VTS using VHF, stating that the ship had some problems with the rudder and steering system. The master informed NOR VTS that they needed some time to test the system. Two hours later, he called for assistance. At that time, the vessel was in the TSS 37 nm off Andøya (see Fig. 2). The weather was deteriorating and the risk of drifting into the coastline was increasing. Using the BarentsWatch system, the VTS got information on other vessels close to MV Melinda. From the system, it was found that Norwegian Coast

Guard Vessel KV Harstad was the closest vessel. This Coast Guard vessel happens to be one of the vessels in the Norwegian Emergency Towing Services [6].

Based on available information, the Norwegian Coastal Administration declared the MV Melinda drifting as a possible case for a major pollution incident. Resources from the Joint Rescue Coordination Centre (JRCC in Bodoe), Norwegian Coast Guard, Norwegian Coastal Administration, and Norwegian Navy were called to set up an emergency response group. To give the response group background information for decision-making about a possible rescue and pollution prevention, NOR VTS performed a drifting path estimation using a tool found in the restricted part of BarentsWatch. More information on this tool is presented in Section 4.2. The results are shown in Fig. 3. Based on the outcomes from the drifting path study, it was seen that the vessel could drift into the Norwegian Coast and result in a need for a SAR operation and finally a major pollution accident.

The ship owner, after discussions with the master, asked a UK salvage company to assist the drifting vessel. A local tug company in Tromsoe (with a small ocean-going tug), got a contract to take control of the drifting ship. However, this tug had an expected ETA of 10 hours, which was estimated to be too long before an attempt to establish an emergency towing line could start. The governmental emergency response team then decided that a government-led operation had to be initiated. NCG KV Harstad was given the responsibility to be the On-Scene Commander. During the first contact between the two masters, the MV Melinda master rejected a towing line from the Coast Guard vessel. NOR VTS then contacted the UK Salvage company with the information that NCG KV Harstad was representing NETS. In the following contact between the two masters, the one on MV Melinda agreed to set up an emergency towing line to the Coast Guard vessel.

Fig. 2. Starting position, drifting track and towed track (red line) for MV Melinda [7].

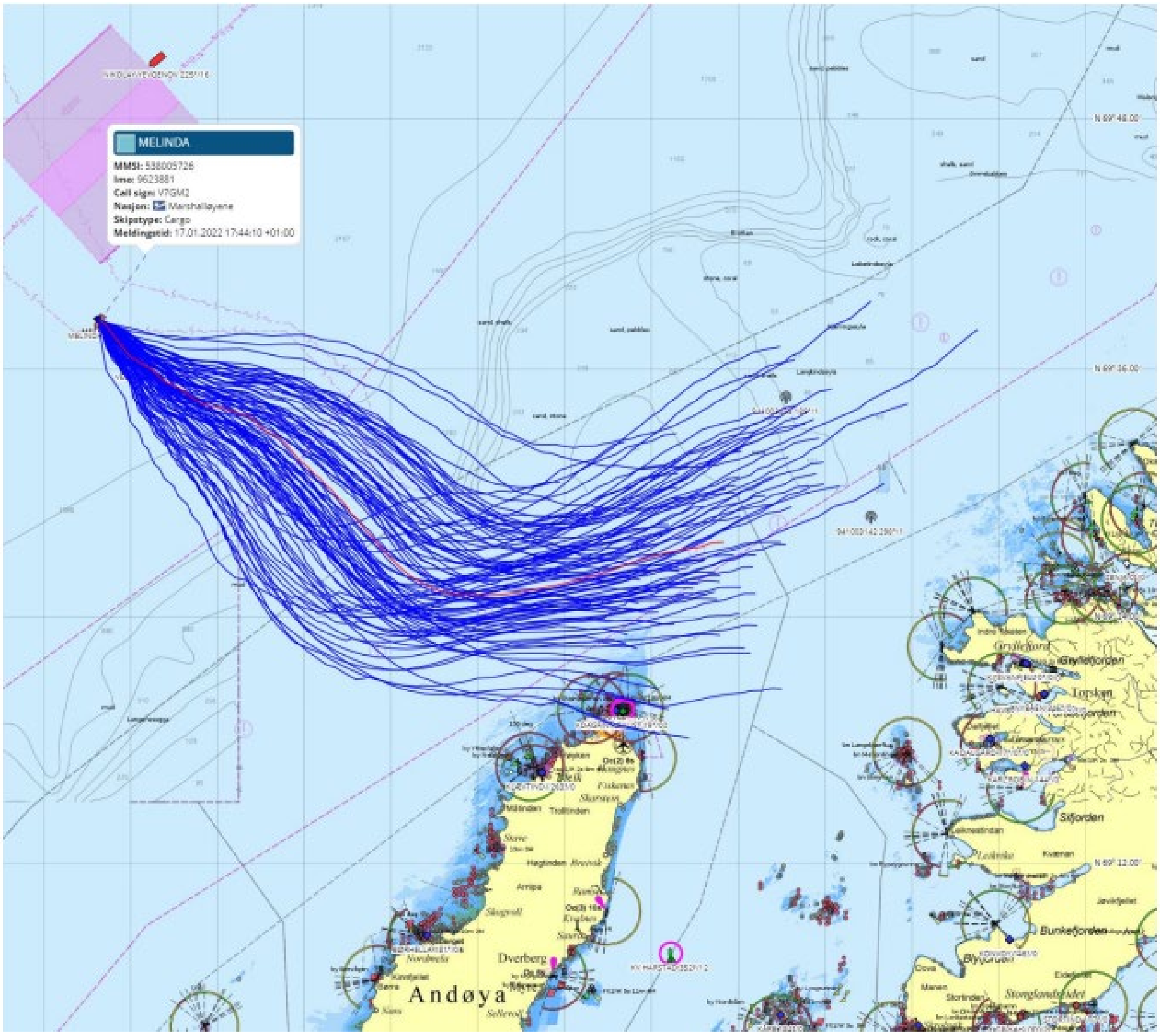

Fig. 3. Drifting path ensemble – varying initial conditions and weather parameters (courtesy BarentsWatch/Norwegian Coastal Administration) [7].

The weather conditions when the emergency towing line was set up:

- Wind: NNW 12–17 m/s
- Sea: 4.5–5 m waves.
- Snow showers

while MV Melinda was drifting SSE at a speed of 3–3.5 knots. Fig. 4 illustrates the preparation of the emergency towing gear on KV Harstad prior to the transfer of the emergency towing connection.

A detailed description of the MV Melinda incident was presented in a meeting arranged by SINTEF Ocean on behalf of a national competence network (Kompetanseforum for krevende fartøysoperasjoner) in June 2022 [7]. The first attempt to transfer an emergency towing line from KV Harstad failed. The gun line was shot to MV Melinda, but the line broke when the transfer of the messenger line started. The second attempt was successful, the uncontrolled drifting stopped, and the disabled vessel was towed into sheltered waters. During this part of the operation, it was reported that the rudder on the towed vessel was locked 15 degrees starboard, leading to a shearing motion with rather high tension in the towing line. The towing speed was reduced; then, the towed vessel lined up with the towing vessel. More information, including pictures and video clips, has been published by the Norwegian Coastal Administration [8] and Norwegian Broadcasting Corporation [9].

Fig. 4. Preparing the emergency towing gear on KV Harstad (Photo: Bjørn Amundsen, Norwegian Coast Guard).

3.1.2. MT Bergstraum. In November 2022, the coastal tanker MV Bergstraum (LOA 123 m) was sailing along the western coast of Norway, heading for the port at Elnesvågen. Early in the morning, the vessel had a technical failure leading to an engine blackout. The vessel had a position approximately 0.6 nm off the coast (see Fig. 5). Luckily, the weather was calm (including a low current speed) when the blackout happened. A Coast Guard vessel (KV Njord) was close by and able to swiftly establish an emergency towing line, assisted by the crew on the tanker. Towing into the port met no problems.

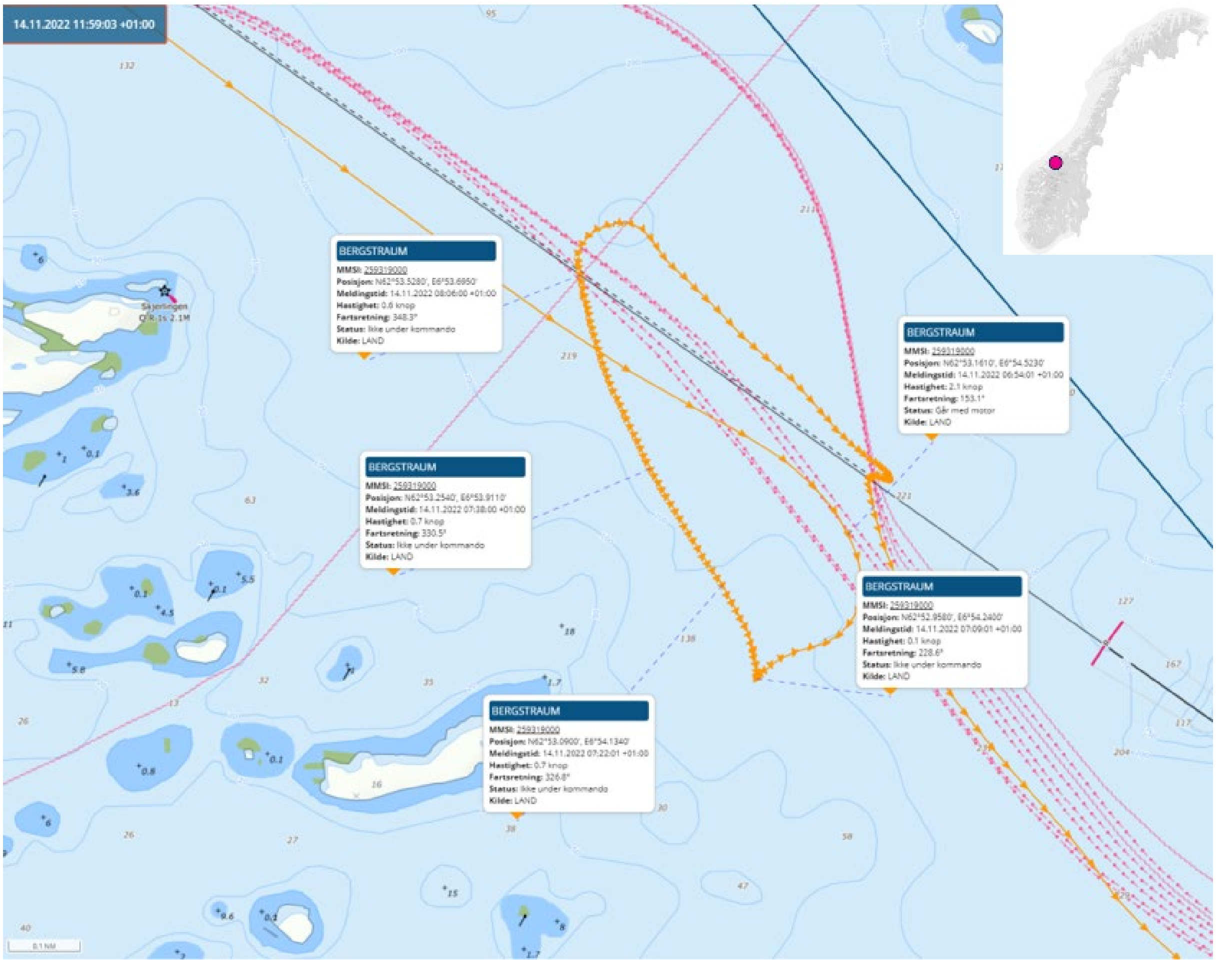

Fig. 5. Sailing route and drifting path for MT Bergstraum during the approach to Elnesvågen. The vessel goes from the north-west along the orange path with triangles. At 7.09 am the vessel was freely drifting until 8.06 am, when the daughter craft from KV Njord arrived.

3.2. An international case

Early in the morning on January 31, 2022, the tanker PECHORA STAR collided with bulk carrier JULIETTA D at Ijmuiden outer anchorage, North Sea. The bulk carrier was damaged, resulting in water ingress in the engine room. The vessel started drifting in harsh weather conditions. To prevent a possible emergency rescue operation, JULIETTA D's crew were lifted off by helicopters. The vessel drifted and made contact with a wind farm grid transformer platform, and her hull was damaged for the second time. In the morning the following day, the OSV SOVEREIGN was able to establish an emergency towline on the unmanned bulk carrier. It was safely towed to Rotterdam, for more information see [10].

A result of this and other incidents was that the Netherlands decided to allocate two Emergency Towing Vessels, primarily to prevent drifting ships from entering sea areas with offshore wind farms.

4. Numerical models for calculation of drifting paths for ships

4.1. Review of existing models

Important parameters for vessel drift calculation:

Hydrodynamic vessel model – draught/trim, bow/stern shape, wave and current forces.

Aerodynamic vessel model – Superstructure volume and distribution, longitudinal/transverse projected area, heel angle, drift angle, wind forces.

Quality of forecasted environmental parameters – current, waves, and wind.

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4.2. SINTEF Ocean models

4.2.1. Quasistatic model. The ShipDrift code is a 3 DOF static solver where environmental forces (wind, wave drift, and current) are balanced against the hull forces caused by moving the vessel through the water. The solver calculates the steady-state scenario and returns the ship's heading, steady-state drift velocity, and direction. Environmental directions/magnitude (wind speed, wave height, etc.) can be changed whenever the user likes, and the program will recalculate the new steady state and continue drifting. The program solves the equilibrium calculations quickly, making it very well suited for a large number of drifting scenarios to generate data for the user to take a statistical approach to where the ship will end up after drifting for a given time in a changing environment.

Environmental forces are calculated based on pre-calculated force coefficients scaled to forces using the actual main dimensions of the vessel. The program contains a predefined set of force coefficients for a typical vessel and can be extended with other force coefficients from different sources.

The quasistatic model can also tune the drifting paths based on actual drift if the user has real-time or historical drifting data from the ship. This functionality is useful for emergency preparedness to best use available data to predict the drifting path of a disabled vessel.

4.3. Wind forces

The static wind forces and moments are calculated as follows:

Surge: $$F_x = C_x(\alpha) \cdot \frac{1}{2} \cdot \rho_{air} \cdot U^2 \cdot A_{transverse}$$

Sway: $$F_y = C_y(\alpha) \cdot \frac{1}{2} \cdot \rho_{air} \cdot U^2 \cdot A_{lateral}$$

Yaw: $$M_n = C_n(\alpha) \cdot \frac{1}{2} \cdot \rho_{air} \cdot U^2 \cdot A_{lateral} \cdot L_{OA}$$

The symbols are defined in the following table.

Symbol	Description	Unit
F_x	Wind force in surge for the relative wind heading.	N
F_y	Wind force in sway for the relative wind heading.	N
M_n	Wind moment in yaw for the relative wind heading.	Nm
C_x	Wind coefficient in surge for the relative wind heading.	-
C_y	Wind coefficient in sway for the relative wind heading.	-
C_n	Wind coefficient in yaw for the relative wind heading.	-
α	Wind direction relative to the ship's heading.	deg
U	Wind velocity.	m/s
ρ_{air}	Density of air. Defined to be 1.225.	kg/m^3
$A_{transverse}$	Transverse area of ship superstructure.	m^2
$A_{lateral}$	Lateral area of ship superstructure.	m^2
L_{OA}	Length overall.	m

4.4. Current forces

The static current forces and moments are calculated as follows:

Surge: $$F_x = C_x(\alpha) \cdot \frac{1}{2} \cdot \rho \cdot U^2 \cdot B \cdot T$$

Sway: $$F_y = C_y(\alpha) \cdot \frac{1}{2} \cdot \rho \cdot U^2 \cdot L_{PP} \cdot T$$

Yaw: $$M_n = C_n(\alpha) \cdot \frac{1}{2} \cdot \rho \cdot U^2 \cdot L_{PP}^2 \cdot T$$

The symbols are defined in the following table.

Symbol	Description	Unit
F_x	Current force in surge for the relative current heading.	N
F_y	Current force in sway for the relative current heading.	N
M_n	Current moment in yaw for the relative current heading.	Nm
C_x	Current coefficient in surge for the relative current heading.	-
C_y	Current coefficient in sway for the relative current heading.	-
C_n	Current coefficient in yaw for the relative current heading.	-
α	Current direction relative to the ship's heading.	deg
U	Current velocity.	m/s
ρ	Density of water.	kg/m^3
B	Beam at midships.	m
T	Draught at midships.	m
L_{PP}	Length between ship perpendiculars.	m

The wind-generated current velocity vector and the tidally generated current velocity vector are added, and the resultant velocity vector is used when calculating current forces.

4.5. Wave forces

The static wave drift forces and moments are calculated as follows:

Surge: $$F_x = 2 \cdot \frac{\rho \cdot g \cdot B^2}{L_{PP}} \cdot \int_0^\infty S(\omega) \cdot C_x(\omega,\alpha) \cdot d\omega$$

Sway: $$F_y = 2 \cdot \frac{\rho \cdot g \cdot B^2}{L_{PP}} \cdot \int_0^\infty S(\omega) \cdot C_y(\omega,\alpha) \cdot d\omega$$

Yaw: $$M_n = 2 \cdot \rho \cdot g \cdot B^2 \cdot \int_0^\infty S(\omega) \cdot C_n(\omega,\alpha) \cdot d\omega$$

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Where

$$C_x(\omega,\alpha) = \frac{\overline{F}_x(\omega,\alpha)}{\frac{\rho \cdot g \cdot B^2 \cdot \zeta^2}{L_{PP}}}$$

$$C_y(\omega,\alpha) = \frac{\overline{F}_y(\omega,\alpha)}{\frac{\rho \cdot g \cdot B^2 \cdot \zeta^2}{L_{PP}}}$$

$$C_n(\omega,\alpha) = \frac{\overline{M}_n(\omega,\alpha)}{\rho \cdot g \cdot B^2 \cdot \zeta^2}$$

The symbols are defined in the following table.

Symbol	Description	Unit
F_x	Wave drift force in surge for the relative wave heading.	N
F_y	Wave drift force in sway for the relative wave heading.	N
M_n	Wave drift moment in yaw for the relative wave heading.	Nm
C_x	Wave drift coefficient in surge for the relative wave heading.	-
C_y	Wave drift coefficient in sway for the relative wave heading.	-
C_n	Wave drift coefficient in yaw for the relative wave heading.	-
α	Wave direction relative to the ship's heading.	deg
S	Wave spectrum.	-
ρ	Density of water.	kg/m^3
g	Gravity.	m/s^2
ζ	Wave amplitude.	m
B	Beam at midships.	m
L_{PP}	Length between ship perpendiculars.	m

4.5.1. Use of model on a drifting ship – general cargo ship. The quasistatic model described above is implemented and in use by the Norwegian Coastal Administration to plan emergency response and as a tool during incidents to predict the drifting path of the vessel. When used to predict the drifting path of a vessel, the model is tuned based on the automatic identification system (AIS) of the initial phase of drifting. The use of this model when Eemslift Hendrica started drifting on April 5, 2021, 60 nm west of Ålesund, Norway, is described by Berg et al. [3].

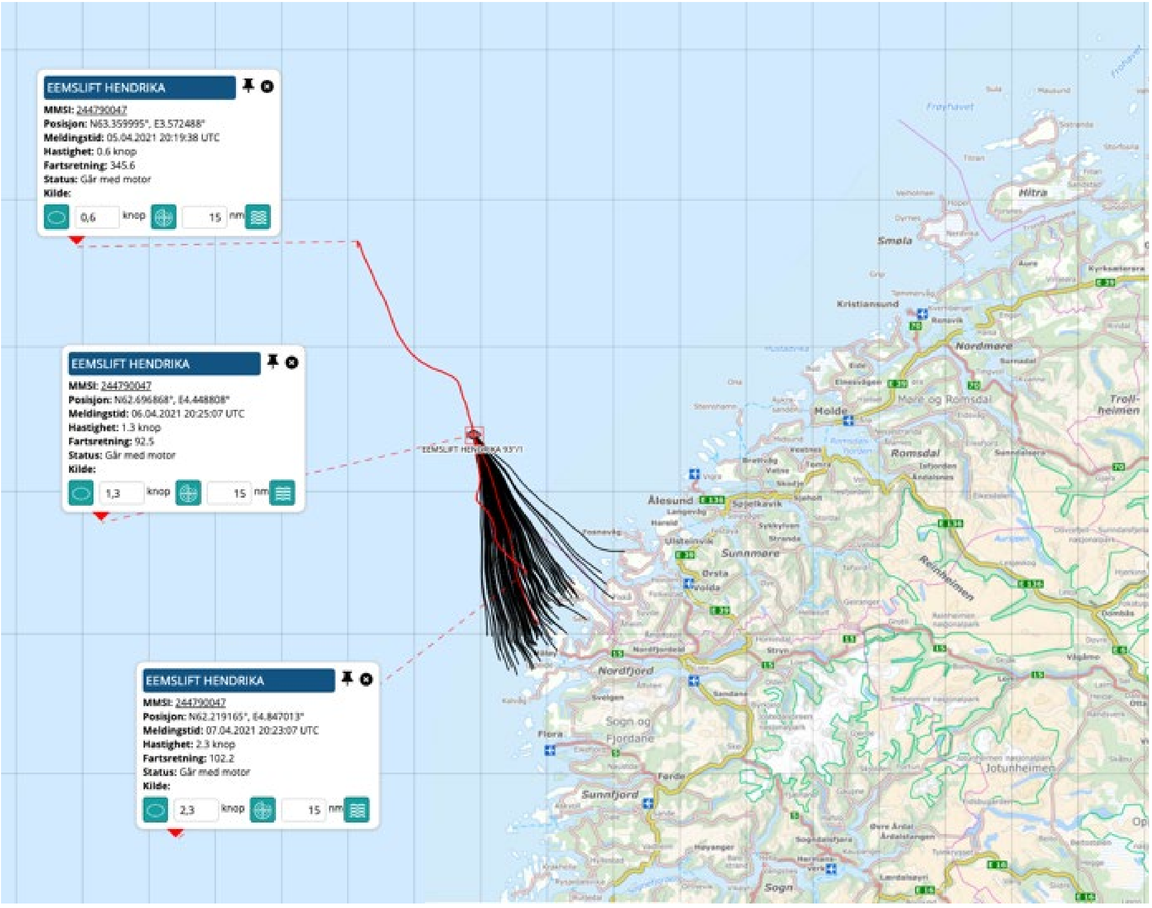

Fig. 6. Sailing actual drift and predicted drift for Eemslift Hendrica (Figure from [3]).

5. Application of drifting path models in the Norwegian governmental maritime emergency preparedness system

NOR VTS is responsible for monitoring ship traffic in the Norwegian Exclusive Economic Zone (EEZ). The incident statistics in Fig. 1 are compiled by their «Ocean and Coastal Vessel Monitoring Vardø» division. Part of their work is to identify drifting vessels and contact them to find out if they need assistance. Often the response is that the situation onboard is under control. However, as shown in figure 1, there is a significant number of vessels needing assistance to prevent them from drifting ashore or into areas with different types of ocean structures. If NOR VTS evaluate that the risk for an incident is high, they may initiate a governmental emergency response action. When there is a need to use state towage service, NOR VTS notifies the Norwegian Coast Guard. The Coast Guard has since 2020 been the operational part of the Norwegian Emergency Response Service (NETS) and will then dedicate vessels to the mission.

A part of the agreement between NCA and the Coast Guard includes a risk-based approach to position and mobilize the state towing capacities. Six vessels have been dedicated to NETS. Two of the vessels are anchor handling tugs (approximately 270 tonnes bollard pull) and four are ordinary Coast Guard vessels (approximately 100 tonnes bollard pull). Based on weather forecasts, NOR VTS and the Coast Guard agree on the position the emergency towing vessels to optimize their position with respect to the traffic pattern and specific vessels that have a large pollution potential in case of an accident.
When a critical vessel drift scenario develops, the emergency response team applies a dedicated tool for the study of possible drifting tracks. SINTEF Ocean has in collaboration with NCA, and the Coast Guard developed a tool for prediction of possible drifting paths using the quasistatic tool described in subsection 4.2. Through variation of the starting condition for the simulation tool, and different

environmental parameters (wind, waves and current), an envelope of predicted paths is produced. The outcome is then used by the master on the emergency towing vessel to optimize the sailing route to the drifting vessel.

6. Emergency towing of disabled drifting vessels

6.1. International requirements – onboard equipment for emergency towing

IMO resolution MSC.35(63) [10], adopted on May 20, 1994, requires an emergency towing arrangement only for oil, chemical, and gas tankers of 20 000 tonnes deadweight and above. The arrangements shall be fitted both forward and aft of the vessel and should always be capable of rapid deployment in the absence of main power on the ship to be towed and easy connection to the towing vessel. Strength calculation for the strongpoint and fairleads is to be based on IMO MSC/Circ. 1175 [11].

For all other cargo ships above 500 GT, new requirements were included in SOLAS based on two IMO documents [12], [13]. For such ships, a ship-specific emergency towing procedure should be developed. It has to be carried aboard the ship, and the procedure is to be based on the ship's existing equipment. The procedure contains a section on onboard training for personnel responsible for deploying the emergency towing gear.

6.2. Calculation of required towing force for a disabled vessel

The required towing force (RTF) is the force necessary to hold or tow the vessel in the environmental conditions of waves, wind, and current. The RTF can be explained by the following equation:

$$RTF = R_{Calm} + R_{Wind} + R_{Wave}$$

where

R_{Calm} = Hull resistance in calm water
R_{Wind} = Wind resistance
R_{Wave} = Hull resistance in waves

Calm water resistance is what a vessel would experience in the event of totally calm weather conditions, i.e., no waves excluding the waves created by the ship. The calm water hull resistance typically consists of frictional resistance due to the viscosity of the water, which creates friction with the hull of the ship and depends, among other things, on the cleanness of the hull. There is also resistance from the waves made by the vessel, depending highly on the hull shape. The resistance from the propeller and eventually the rudder can also be considered as calm water resistance. The resistance depends on whether the propeller or rudder is installed or not, locked, or free to rotate. A factor that tends to influence water resistance is the depth of the water, as in shallow waters, the water has greater difficulty moving aftwards.

The wind resistance during emergency towing of a disabled vessel depends, among other things, on the wind velocity and projected area. The wind resistance may be significant depending on the size of the disabled vessel and the severe wind conditions often experienced by drifting vessels.

The towed vessel is, in addition to the wind resistance and calm water resistance, subject to wave drift forces. The mean wave drift forces can be estimated through either direct pressure integration or conservation of fluid momentum. The wave drift force is often calculated without forward speed; however, forward speed will increase the forces. The mean wave drift force is proportional to the wave amplitude squared and linear with the area subjected to the waves.

The tow force required to tow a containership under emergency conditions was studied by Shigunov and Schellin [14]. Five containerships of different sizes were considered in steady-state wave, wind, and current conditions. Tow forces were obtained for the wind and current aligned with the primary direction of the waves, wind deviating 30 degrees from the wave direction, and current deviating up to 90 degrees from the waves. The direction of the tow force deviated up to 90 degrees from the vessel heading. A formulation estimating the maximum towing force as a function of the significant wave height and the ship length between particulars, Lpp, was proposed. The formulation was based on the equilibrium equations of the towed vessel in the horizontal plane.

6.3. Effective bollard pull towing a disabled vessel

The estimated required towing force can be compared to the tug's bollard pull. A tug's bollard pull is normally measured in a test in calm water and limited current and wind conditions. During the test, the tug's trim may also have been optimized, and sufficient depth and clearance for a free propeller stream are ensured. The calm weather, optimized trim, and sufficient clearance for a free propeller stream cannot be achieved in a real operation and need to be considered when comparing the required towing force with the strength of the tug.

During an emergency tow, the weather may be harsh, i.e., the power required for the tug itself to achieve forward speed in the waves can be considerable. Further, the distance between the towed object and the tug may be short, and the tug's propeller may induce propeller wash at the towed object, increasing the towing resistance.

6.4. Connecting to a disabled vessel

The Norwegian Coast Guard's 2022 Presentation of the MV Melinda incident [7] explained the emergency towing tug's arrival procedure at the location of the disabled vessel MV Melinda. When the tug arrived at the vessel's location, the tug circled around the ship to check its condition, draughts, and trim. Different ships will lay to weather, seas, and current differently and will drift to the lee side at different rates, so the tug laid ahead and astern of the ship to see how the ship and tug drifted and laid relative to each other at each location. The tug decided to lay to the side of MV Melinda's bow to connect the emergency towing equipment to the bow of MV Melinda. If the weather is heavy, the disabled vessel is not in immediate danger of going aground, and it is in the interest of safety, the tug may choose to delay the tow connection until weather and sea conditions improve.

Systems to provide a fast and safe setup of an emergency towing connection under different environmental conditions are required only for oil, chemical, and gas tankers of 20 000 tonnes deadweight and above [15]. The tug's connection to the disabled vessel will depend on the towing arrangement identified in the disabled vessel's Emergency Towing Book (ETB) if existing. Preferably prior to departure, the tug should obtain a copy of the ship's ETB and talk to the vessel master to ensure that the towing gear is ready to be deployed and determine how to transfer the equipment to the tug. Alternatively, the tug may use its own equipment. How and where the disabled vessel's towing equipment is stored, the condition of the equipment, and the time taken by the disabled vessel to assemble the equipment are unknown. For the MV Melinda incident [7], the tug used its own towing equipment to be connected to the disabled vessel.

Since emergency ship towage varies, it is difficult to outline exactly how the tug should connect to a disabled vessel, and this is one of the reasons why the competence of the crew on the emergency towing vessel and the ship to be towed is a critical factor during the transfer of the towing equipment.

The transfer of the towing line normally starts with the tug or the disabled vessel receiving a messenger line. The messenger line can be thrown manually, or by use of a line-throwing gun. The messenger line needs to be passed through the closed chock at the bow or stern of the disabled vessel and not on top of the bulwark. At the end of the messenger line, the towing line or the bridle is connected. The towing line or bridle is connected to the disabled vessel's mooring system or similar on the deck and to the tug's main towing line. The messenger line is removed. Preferably, winch assisting is available to transfer the equipment. If winch assisting is not available on the disabled vessel, the transfer can be performed manually by the crew onboard the disabled vessel; eventually, the messenger line can be passed from the tug back to the disabled vessel via one of the bollards on the disabled vessel so the transfer can be performed by one of the winches onboard the tug. Another alternative if the disabled vessel's towing arrangement is used is to connect a floating buoy at the end of the messenger line to be picked up by the tug. The tug then transfers the towing arrangement on the deck of the tug and connects to its towing wire.

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If there is no crew onboard the disabled vessel, the connection of the towing arrangement is more challenging, especially if the crew members have not deployed the emergency towing arrangement prior to abandoning the vessel.

The connection to the disabled vessel can either be a bridle connection or a single line. From a towing direction stability point of view, a bridle connected to the bow of the vessel is preferred.

Communication between the tug and the disabled vessel is crucial for a successful connection. Often, ships route all external communication through the ship's bridge and then on to the working deck crew. The master onboard the tug for the Melinda incident [7] also pointed out language barriers to communication.

6.5. Forces on the towing line when performing an emergency tow

The total towline tension during towing can be split into static tension and dynamic tension. The static tension can be estimated by parabolic equations for cable slope based on the horizontal towing resistance, the distance between the tug and the towed vessel, and the distributed submerged weight of the towing cable. Estimation of the dynamic tension requires a mathematical model of the complete towing system considering independent motion analysis of the tug and towed object in a given sea state to achieve the resulting towline forces.

The stiffness of the towline controls the dynamic tensions in the towing line in addition to the slow-varying motions between the tug and the towed object. The dynamic forces on the towing line are highly dependent on the towline stiffness. The stiffness can be split into two components, one due to elastic elongation of the line and one due to the change of geometry of the towline catenary. Elastic elongation is defined by the modulus of elasticity, which depends on the material of the towing line. During towing, it is desirable that geometrical stiffness dominates, i.e., the towline characteristics are weight-dominated by ensuring a parabolic shape of the towing line. With an increased distance between the tug and towed object for a towing line with constant length, the dynamic tension increases in the towing line, so the working line's characteristics get more and more dominated by the elastic elongation. A towing line without sag is only dominated by the elastic elongation and may give high peak tensions in the towing line.

For emergency towing, the towing line material is often chosen based on a handling point of view, not the towing line's characteristics. The synthetic ropes used to connect to disabled vessels provide no or little geometrical stiffness. To achieve geometrical stiffness and sufficient distance between the tug and towed vessel, it is recommended to connect a steel towing wire to the synthetic rope if the rope used to connect to the disabled vessel is used during the towing operation.

6.6. Strength loss in the towing equipment during towage

In comparing the strength of the towing equipment with the dynamic towing force, the strength loss of the ropes when loaded around a curved surface, typical towing connection points, Panama chocks, and connection between two towing lines need to be considered. More severe bends, i.e., small surface radii, can result in great strength loss.

The strength of tow assemblies can also be reduced due to heating up when in use due to internal and external friction. Due to their elastic properties, synthetic ropes will heat up more and faster than wire ropes. Internal friction is the force-resisting motion between the fibres in a line while it undergoes deformation due to bending of the line over a curved surface and due to the cycling tension load. External friction is the chafing between a line and a surface when these move against each, e.g., the towing line through a fairlead or at the connection point between components in the towing line assembly. All synthetic fibre towing assembly components under tension can become damaged if exposed to contact surfaces. Damage to steel wire is less likely, but broken strands are still possible. Chain is the preferred material through areas where chafing can occur, e.g., towing connection points, fairleads, and the deck edge. However, chain is often not suitable for emergency towing due to its heavy weight for handling and is replaced with synthetic line for emergency towing. The synthetic lines need to be protected by

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using a protective line cover, sleeve, or similar in chafing areas. The total towline tension during towing can be split into static tension and dynamic tension.

7. Summary and recommendations

The number of drifting ships in the Norwegian EEZ is approximately 0.15% of the vessels sailing in that area. Industrialization of coastal waters through installation of ocean wind farms, solar power plants, and exposed fish farms requires improved maritime emergency preparedness. National and regional capability to handle drifting vessels is important.

As part of the Norwegian maritime emergency preparedness system, SINTEF Ocean has delivered a tool for calculating the path of drifting vessels. The tool is implemented in the closed part of the BarentsWatch portal. In case of an incident with a drifting vessel, the tool generates an ensemble of paths from a variety of start conditions for the drifting vessel, a generic vessel category, and the available weather forecast.

Emergency towing to prevent a disabled vessel from colliding with ocean structures or grounding in coastal waters is a challenging operation in harsh weather. The lack of an international requirement for an onboard emergency towing system for SOLAS ships (except tankers over 20 000 dwt) complicates the work to establish an emergency towing line, especially in harsh weather situations.

The authors recommend the following actions:

- Increased international sharing of knowledge and experience related to emergency towing operations.
- Further development of ship-specific models for prediction of paths for a drifting vessel.
- Follow-up of onboard training according to the vessel's Emergency Towing Procedures/Emergency Towing Book.
- International collaboration work to develop input for guidelines on Emergency Towing Systems on ships not presently covered by IMO requirements.

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