Bundesstelle für Seeunfalluntersuchung
Federal Bureau of Maritime Casualty Investigation

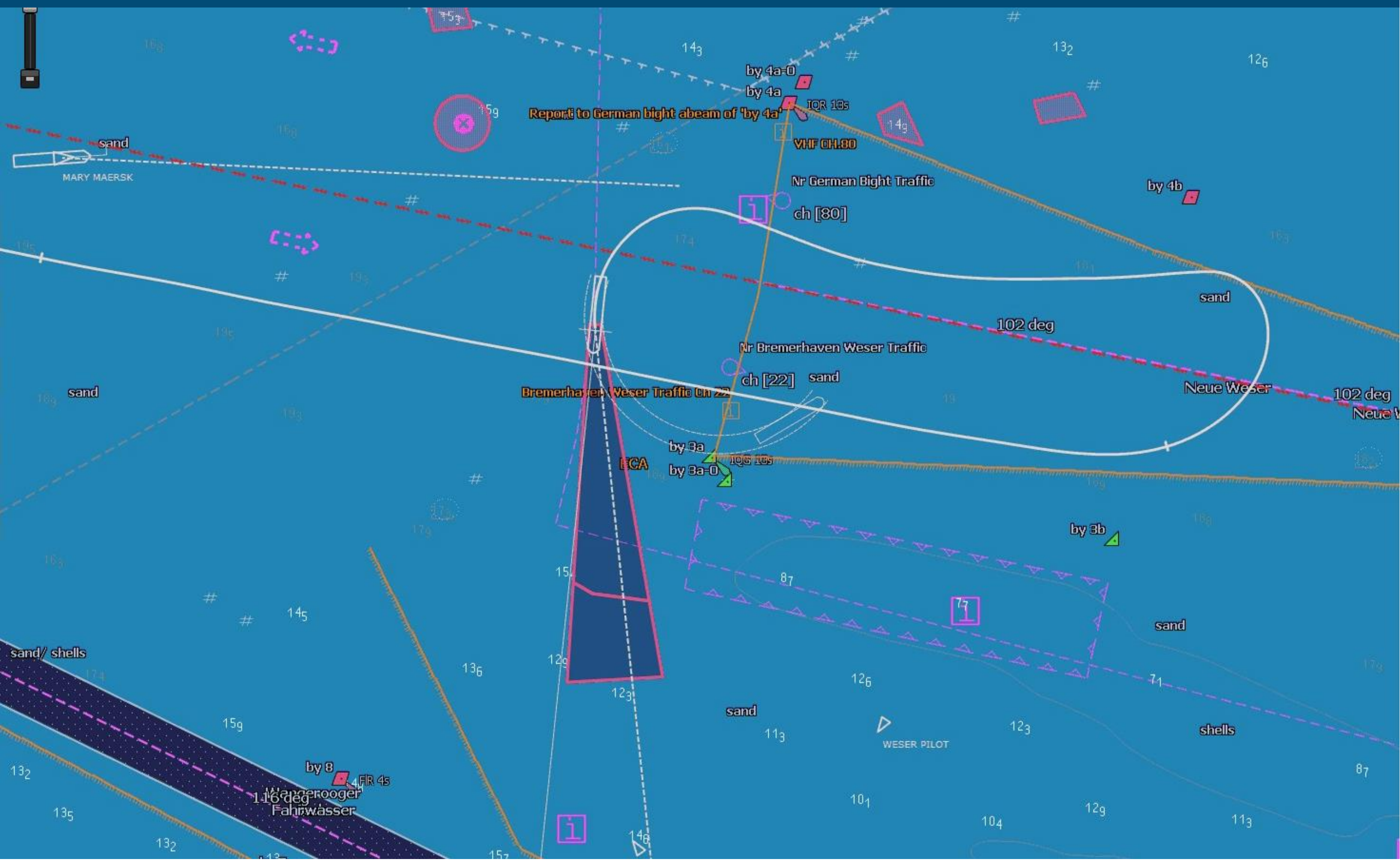
BSU

Serious Marine Casualty

Grounding of the MUMBAI MAERSK while entering the Neue Weser fairway on 2 February 2022

Investigation Report 37/22

26.03.2025



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Cover picture: VDR MUMBAI MAERSK

This investigation was conducted in conformity with the Law on Improving Safety at Sea by Investigating Marine Casualties and Other Incidents (German Maritime Safety Investigation Law – SUG). According to said Law, the sole objective of this investigation is to prevent future accidents. This investigation does not serve to ascertain fault, liability or claims (Article 9(2) SUG).

This report should not be used in court proceedings. Reference is made to Article 34(4) SUG.

The German text shall prevail in the interpretation of this investigation report.

Amendments

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Abbreviations

A/S	Aktieselskab (Danish: public limited company)
ABS	American Bureau of Shipping (classification society)
agF	Exceptionally large vessel
AIS	Automatic Identification System
AWR	Alte Weser Radar / Außenweser Radar
B	Buoy (navigation mark)
BG Verkehr	German Social Accident Insurance Institution for Commercial Transport, Postal Logistics and Telecommunication
BGBl.	Federal Law Gazette
BSH	Federal Maritime and Hydrographic Agency
BSU	Federal Bureau of Maritime Casualty Investigation
BWT	Bremerhaven Weser Traffic
C	Crew member
CA	Course alteration
CCME	German Central Command for Maritime Emergencies
CMA CGM	Merger of two French shipping companies: 'Compagnie Maritime d'Affrètement' and 'Compagnie Générale Maritime'
COG	Course over ground
COLREGs	International Regulations for Preventing Collisions at Sea, 1972
DE	Germany
DGPS	Differential Global Positioning System
DO	Part of the type designation of the aircraft manufacturer Dornier
DSME	Daewoo Shipbuilding & Marine Engineering
E	East; longitude
ECDIS	Electronic Chart Display and Information System
EEE	Also referred to as 'Triple-E'; series of sister ships to which the MUMBAI MAERSK belongs
Engl.	English
ETA	Estimated time of arrival
FLC	Feeder Logistics Centre
GRT	Gross register tonnage
HDG	Heading (i.e., course steered)
HVCC	Hamburg Vessel Coordination Center
ICS	International Chamber of Shipping
IHO	International Hydrographic Organisation
IMO	International Maritime Organization
IMPA	International Maritime Pilots' Association

INT	International navigational chart
ITZ	Inshore traffic zone
kts	Knots (speed, nautical miles per hour; 1 knot ≈ 1.852 km/h)
kW	Kilowatt
M	Master
m	Metre
ME	Main engine
MERAC	Maritime Emergencies Reporting and Assessment Centre
MIRG	Marine Incident Response Group
MPX	Master-pilot information exchange
MRCC	Maritime Rescue and Coordination Centre
N	North; latitude
NL	Netherlands
nm	Nautical mile(s)
N-Reede	Neue Weser Nord-Reede roadstead
NTB	North Sea Terminal Bremerhaven
NTC	Nautical Terminal Coordination
NvD	Nautical supervisor
OOW	Officer of the watch
OSC	On-scene coordinator
P	Pilot
PAB	Port Authority Bremen
para.	Paragraph (legal context)
PNR	Point of no return
POO	Port Operations Office
PPU	Portable pilot unit
ROT	Rate of turn
rpm	Revolutions per minute (here: turning speed of an engine)
SeeSchStrO	German Traffic Regulations for Navigable Maritime Waterways (“Seeschiffahrtstraßen-Ordnung”)
SI	SAKIZAYA INTEGRITY
SMS	Safety Management System
SOG	Speed over ground
SOLAS	International Convention for the Safety of Life at Sea, 1974
STCW Code	Seafarers' Training, Certification and Watchkeeping Code
STW	Speed through the water
TAT	Towing assistance team
tdw	Tonnes deadweight

TEU	Twenty-foot equivalent unit (standard 20-foot container)
TSS	Traffic separation scheme
UKC (UKCmin)	(minimum) Under-keel clearance
ULCS/ULCV	Ultra-large container ship/ultra-large container vessel
UTC	Universal time coordinated
VDR	Voyage data recorder
VPO	Voyage planning officer
VTS	Vessel traffic service
WaStrG	Federal Waterways Act
WSA	Waterways and shipping office
WSV	Federal Waterways and Shipping Administration
λ	Longitude
φ	Latitude

1 SUMMARY

On 02/02/2022, the ultra-large container ship (ULCS) MUMBAI MAERSK was en route from Rotterdam in the Netherlands to Bremerhaven in Germany. The ship had decided to use the further seaward deep-water route for the voyage. In the course of a turning manoeuvre before entering the narrow section of the “Neue Weser” fairway, the ship ran aground on a dumping ground for dredged spoils next to the fairway.

While approaching the narrow fairway section, the MUMBAI MAERSK was advised by radio that her berth would remain occupied for longer than planned, but would soon become vacant. Due to her draught of 12.80 m, the ship was tide-dependent. The vessel initially proceeded to cross the pilotage area border. Due to the continued delay in the departure of the outbound vessels, however, the MUMBAI MAERSK turned back and sailed in the opposite direction before entering the section of the fairway where neither turning nor the safe passing of two large ships is easily possible.

Less than 30 minutes later, the MUMBAI MAERSK was informed that she could now sail for Bremerhaven, after all. Accordingly, another turn was immediately executed to return to the original course. The planned manoeuvre failed for various reasons, and the MUMBAI MAERSK ran aground directly south of the fairway on a dumping ground for dredged spoils.

The German Central Command for Maritime Emergencies (CCME) was notified and assumed overall command of the operation just over an hour later. After extensive planning by a salvage company and one failed salvage attempt, it was reported that the ship had been refloated at 0114 on 04/02/2022.

The diving inspection of the underwater hull for class maintenance, as well as all class surveys were carried out at the next port of call (Århus in Denmark). To this end, an interim permit to continue the voyage was issued in Bremerhaven after the ship had entered the port under its own steam. The inspection revealed that, apart from paint abrasions, the ship had not sustained any damage during the accident.

The BSU's investigating team focused their investigation on voyage planning and execution, sediment management in the German Bight, and arrival planning for Bremerhaven. The manoeuvre leading up to the accident and various other manoeuvre scenarios were simulated and tested in the ship-handling simulator at Bremen University of Applied Sciences as part of the investigation.

The report concludes with safety recommendations on, *inter alia*, radio discipline among traffic participants in the Weser pilotage area, and pilotage requirements for large ships.

2 FACTUAL INFORMAION

2.1 Photograph of the ship

Figure 1: The MUMBAI MAERSK on the River Elbe[1]

2.2 Ship's particulars

Name of ship:	MUMBAI MAERSK
Type of ship:	Fully cellular container ship
Flag:	Denmark
Port of registry:	Copenhagen
IMO number:	9780471
Call sign:	OWNQ2
Owner:	Mærsk Line A/S
Shipping company:	Mærsk Line A/S
Year built:	2018
Shipyard:	Daewoo Shipbuilding & Marine Engineering (DSME)
Classification society:	American Bureau of Shipping (ABS)
Length overall:	399.0 m
Breadth overall:	58.6 m
Draught (max.):	17.0 m
Gross tonnage:	214,286
Deadweight / Carriage Capacity:	123,406 t/19,630 TEU
Engine rating:	2 x 31,000 kW

[1] Source: Hasenpusch Photo-Productions, photograph of the MUMBAI MAERSK, 2018.

Main engine:	2 x Doosan/MAN 7G80ME-C95T2
Service speed:	23 kts (max.), 16 kts (cruising)
Hull material:	Steel
Hull design:	Conventional (closed hatches, cell guides, double bottom, etc.)
Minimum safe manning:	12

2.3 Voyage particulars

Port of departure:	Rotterdam (NL)
Port of destination:	Bremerhaven (DE)
Type of voyage:	Merchant shipping / international
Cargo information:	Containers
Crew:	29
Draught at time of accident:	Df = 12.80 m, Da = 12.80 m
Pilot on board:	Yes

2.4 Marine casualty information

Type of marine casualty:	Serious marine casualty / grounding
Date, time:	02/02/2022, 2306 (local time = UTC + 1)
Location:	A dumping ground for dredged spoils in the North Sea (in the approach to the River Weser, about 3.5 nm north of the island of Wangerooge, south-east of the Weser 3a and a-O buoys)
Latitude/Longitude:	φ = 53° 51.1' N, λ = 007° 53.6' E
Voyage segment:	Pilotage waters
Consequences:	– the ship remained at the scene of the accident for 26 hours; – extensive salvage operations coordinated by the German Central Command for Maritime Emergencies.

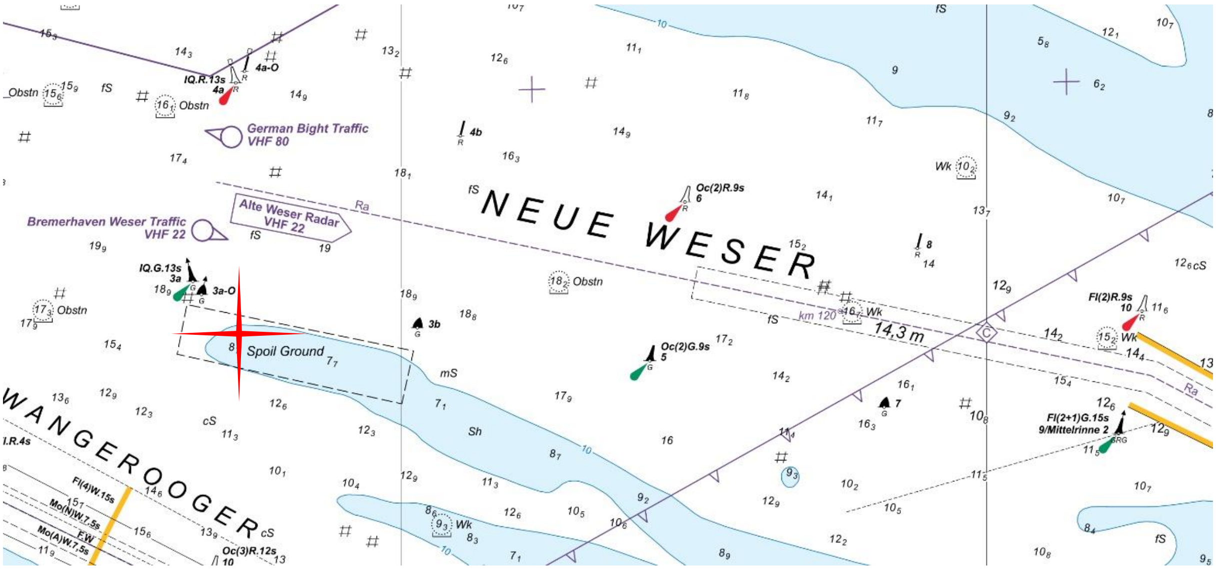


Figure 2: Scene of the accident, entrance to the Neue Weser [2]

2.5 Shore authority involvement and emergency response

Agencies involved:

- Vessel Traffic Service Bremerhaven;
- ship operator Mærsk Line;
- salvage company SMIT Salvage;
- German Central Command for Maritime Emergencies (CCME);
- BG Verkehr;
- Waterway Police Bremerhaven;
- emergency medical care teams and shipboard emergency response teams (for fire, explosion, etc.);
- classification society ABS (for calculations).

Actions taken:

- periodic soundings of all double-bottom components, such as tanks, cofferdams, etc. by the crew;
- assumption of overall operational command by the CCME (0130 on 03/02/2022);
- first unsuccessful attempt to refloat the ship at the next high tide (0158 on 03/02/2022, aborted at 0328);
- preparation of a refloating plan by SMIT Salvage (the salvage company commissioned by Maersk), in coordination with the CCME;
- next salvage attempt (this time successful) two high tides later from 0052 on 04/02/2022, vessel reported as refloated at 0114;
- main engine tests in the German Bight;

[2] Source: German Federal Maritime and Hydrographic Agency (BSH), Navigational Chart DE2 (INT 1456) (detail), 2020.

- inspection of all double-bottom elements by the classification society, the Ship Safety Division (BG Verkehr), and the insurers;
- diving inspection in Århus: apart from paint abrasion, no damage found on the bottom, stern section, screws, sea chests, transverse thrusters, etc.

Resources used:

- Towing vessels involved:
  - first salvage attempt:

    BUGSIER 9, BUGSIER 30, multipurpose and water pollution control vessel MELLUM, multipurpose vessel NEUWERK, RT EMOTION, RT EVOLUTION, RT PIONEER, VB EMOE (all units were made fast by the end of the salvage attempt);
  - second salvage attempt:

    BUGSIER 3, BUGSIER 7, BUGSIER 30, FAIRPLAY 25, NEUWERK, RT EVOLUTION, RT PIONEER, salvage tug SOVEREIGN, VB EMOE (all units were made fast except BUGSIER 3, BUGSIER 7 and RT PIONEER, which were pushing as per instructions, as well as the MANTA and VB EMOE, which remained on standby and later acted as escort tugs);
- sounding vessel ZENIT to determine the exact water depths;
- oil surveillance aircraft (DO-228);
- response equipment used by the standby emergency teams (ambulances, helicopters, etc.).

3 COURSE OF THE ACCIDENT AND INVESTIGATION

3.1 Course of the accident

The course of the accident was reconstructed using VDR[3] recordings, in particular from the bridge microphones, radar equipment and ECDIS[4], as well as radio traffic recordings, AIS[5] track data of the ship, the MRCC's[6] operational plan, and statements of the people involved.

On 02/02/2022, the ultra-large container ship (ULCS[7]) MUMBAI MAERSK is en route from Rotterdam in the Netherlands to Bremerhaven in Germany. The ship decides to use the further seaward deep-water route (Western Approach traffic separation scheme).

Figure 3: Traffic separation schemes in the Jade-Weser-Ems section of the North Sea[8]

[3] VDR: Voyage data recorder (black box). Computerised system on board seagoing vessels that continuously records various data relating to the navigational and technical operation of a ship (particularly for analysis in a marine casualty investigation).

[4] ECDIS: Electronic Chart Display and Information System.

[5] AIS: Automatic Identification System (standardised system for exchanging ship particulars both among vessels and for shore-based traffic monitoring). Receiving stations (such as other traffic participants or vessel traffic services) can display them on a screen or overlay them on an electronic chart system or a radar image, for example.

[6] MRCC: Maritime Rescue and Coordination Centre – operated in Germany by the German Maritime Search and Rescue Service.

[7] ULCS (also ULCV, ultra-large container vessel): Very large container ships with a carrying capacity of more than 12,000 TEU (twenty-foot equivalent units, twenty-foot standard container).

[8] Source: Federal Waterways and Shipping Administration, German Bight traffic separation schemes in the Ems-Jade-Weser section, 2017. Additional entries by the BSU.

Her destination is the Stromkaje quay (several riverside berths belonging to two container terminals, NTB and Eurogate), North Sea Terminal Bremerhaven (NTB).

Figure 4: Seaports with Stromkaje quay, Bremerhaven[9]

2018[10]:

The pilot boards by helicopter.

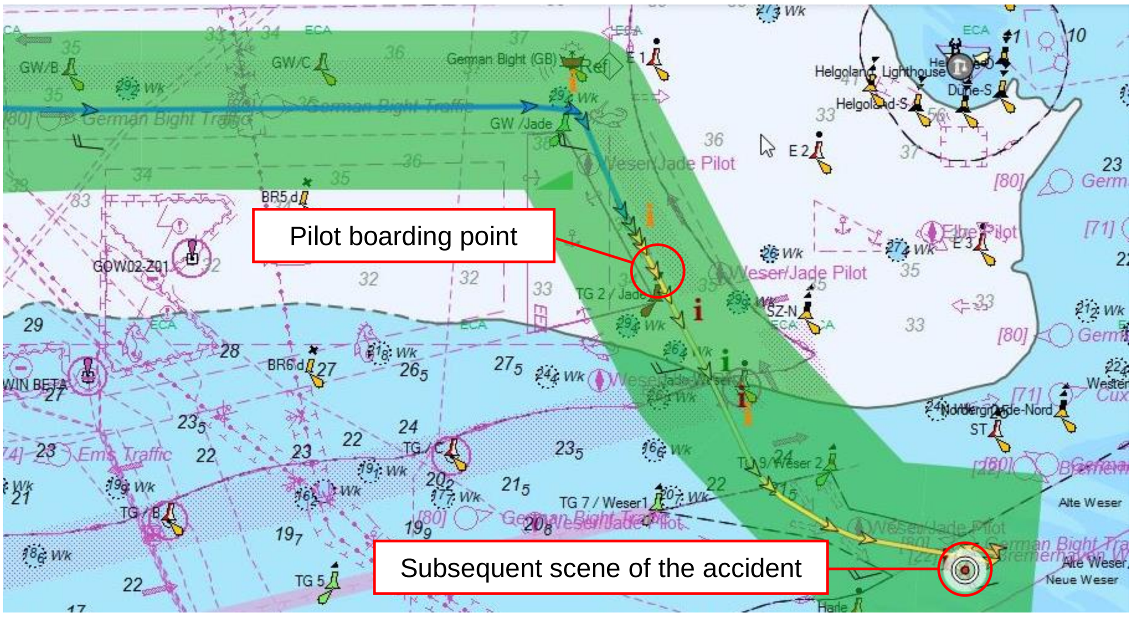


Figure 5: Course of the MUMBAI MAERSK's voyage before the accident [11]

[9] Source: Wikipedia. Ports in Bremerhaven, image of the Stromkaje quay in Bremerhaven, last retrieved on 04/09/2023.

[10] Unless otherwise stated, all times shown are local (CET = UTC + 1).

[11] Source: MarineTraffic, screenshot of details of the MUMBAI MAERSK's track on the day of the accident, 02/02/2022.

The MUMBAI MAERSK's sister ship, the MARY MAERSK, is sailing ahead of her and the bulk carrier SAKIZAYA INTEGRITY (referred to simply as 'INTEGRITY' hereafter) behind her. These two vessels intend to use the same tidal window[12] as the MUMBAI MAERSK to enter the Neue Weser[13]. The bulk cargo on the INTEGRITY is destined for Nordenham, a port further upstream on the River Weser.[14]

Throughout the evening, the pilot asks the Danish master several times whether he understands the radio traffic. He apparently understands German well enough to follow most of it without a translation. However, various pieces of information are repeatedly not translated for the Indian third officer, neither by the pilot nor by the master. Communication between pilot and captain is conducted entirely in English.

Approximately 2135:

Bremerhaven Weser Traffic[15] informs the MUMBAI MAERSK that one of the two berths that are possibly intended for her in Bremerhaven will remain unavailable for an indefinite time.

The CMA CGM LAMARTINE (referred to simply as 'LAMARTINE' hereafter) lost one of her anchors in the German Bight before entering Bremerhaven, which was not replaced during her call. This means that the ship needs an escort tug when departing and must adapt to the tug's lower speed. Neither the harbour pilot nor the sea pilot, who both boarded the ship before her departure, had been informed of this fact beforehand. The Bremen Port Operations Office[16], which coordinates the deployment of harbour pilots, and the Pilot Association Weser II / Jade were evidently unaware of this fact.

For this reason, the LAMARTINE now has to wait for the arrival of the tug, which was only requested by the harbour pilot. Moreover, the ship's departure speed is now

[12] Tidal window: Ship-specific period of time (about equally long on either side of high tide) during which a ship with a deep draught has enough water under her keel to navigate a fairway.

[13] The so-called 'Neue Weser', a section of the fairway in which only a narrow dredged channel is available, begins after buoys Weser 9/Weser 10. With only a few exceptions, deep-draught and/or wide-beam ships cannot pass one another there. Refer to the announcements of German Federal Waterways and Shipping Agency North-West regarding para. 23 (3) No. 43 (overtaking restrictions) and para. 24 (2) (meeting restrictions) of the SeeSchStrO (German Maritime Traffic Regulations, “Seeschiffahrtsstraßen-Ordnung”).

[14] Vessels that continue past the container terminal in Bremerhaven are referred to in radio traffic as 'Geeste-Schiffe' [Geeste ships], after the River Geeste, a tributary that flows into the River Weser at Bremerhaven.

[15] Name of the Vessel Traffic Service Bremerhaven radio station (VHF channel 22).

[16] The Port Operations Office (“Hafenbetriebsbüro”) is a subdivision of the Bremerhaven Port Authority and operates under the Hanseatic City of Bremen Port Office. It coordinates inbound traffic planning for the Bremen ports and assigns harbour pilots to their duties.

reduced, meaning the MUMBAI MAERSK will be unable to enter the Neue Weser for longer than originally planned.

At this time, the MUMBAI MAERSK has reached at the inner Jade/Weser pilot boarding point.

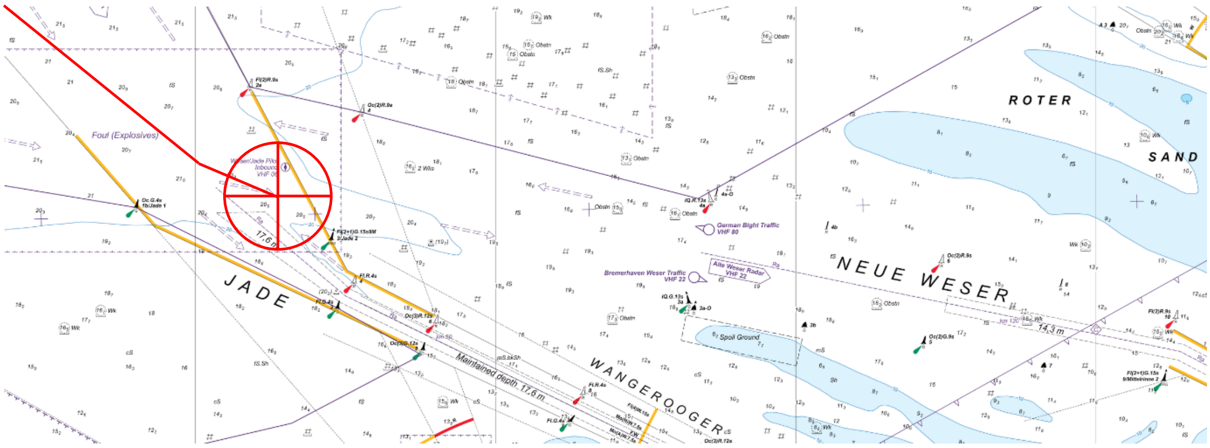


Figure 6: Past track[17] and approximate position at about 2135[18]

Accordingly, the MUMBAI MAERSK reduces her speed to about 5 kts to delay her entry into the Neue Weser.

A short time later, contact is made with the MARY MAERSK. The entry sequence of the vessels and how to best adhere to it is discussed. This sequence was previously communicated and requested by Maersk Operations. Subsequently, the MARY allows the MUMBAI MAERSK to overtake her, then leaves the fairway in a southerly direction to drift there.

[17] The past track is a linear representation of the route already navigated by a ship. Approximated here and below.

[18] Source: Federal Maritime and Hydrographic Agency (BSH), Navigational Chart DE2 (INT 1456) (detail), 2020.

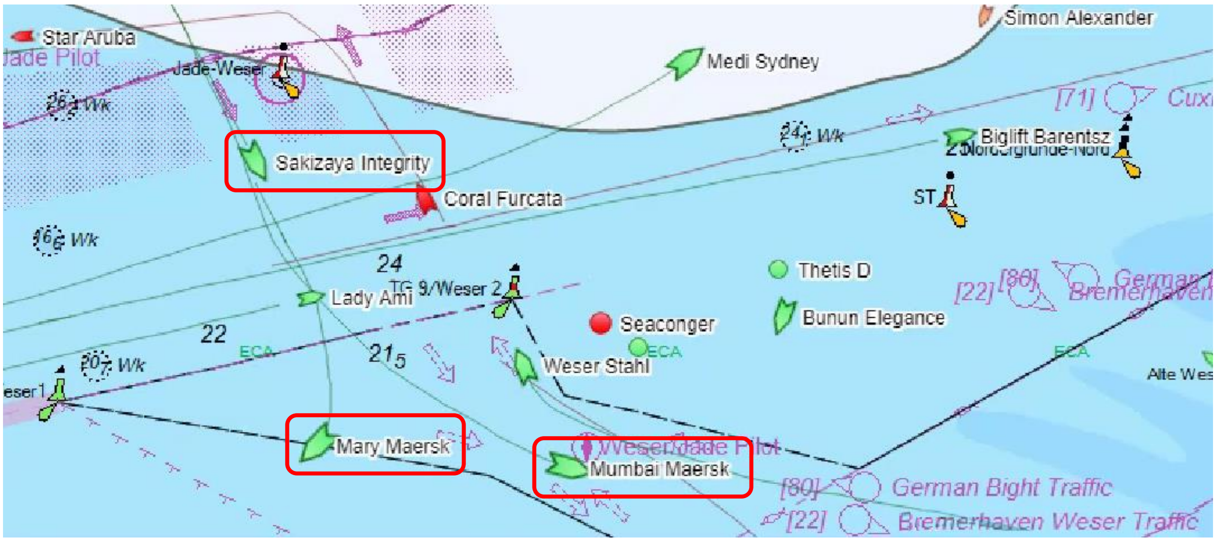


Figure 7: Traffic situation at about 2145[19]

Approximately 2145:

The LAMARTINE reports to Bremerhaven Weser Traffic that two tugs have been made fast and she is now casting off.

Alte Weser Radar (AWR)[20] relays the same information to the two Maersk ships. They also report that the MAERSK KANSAS, occupying the other of the two berths for the two large container vessels, has not yet made any contact at all.

Shortly afterwards, the LAMARTINE reports to Bremerhaven Weser Traffic again, informing them that the casting-off manoeuvre will be delayed due to problems with an aft mooring winch.

Following this, the Duty Nautical Officer, who serves as the watch supervisor of the Vessel Traffic Service Centre, establishes a provisional schedule. This schedule is then relayed via VHF by the radar advisor to the sea pilot. According to the plan, the MUMBAI is expected to arrive in Bremerhaven at 00:15 and then turn[21]. MUMBAI, INTEGRITY, and MARY MAERSK are each to maintain a 45-minute interval between their respective entries.

[19] Source: MarineTraffic, screenshot of an animation of the traffic situation on the evening of the accident, 02/02/2022.

[20] Name of the radio station of the radar assistance provided by pilots belonging to the Weser II/Jade Pilots' Association.

[21] Generally, incoming ships turn before berthing with their starboard side at the Stromkaje quay in Bremerhaven. The departure manoeuvre can then be carried out quickly and without any additional turning.

On the MUMBAI MAERSK, an ECDIS is centred on the container terminal in Bremerhaven, enabling the Stromkaje quay to remain in view. The ship symbols generated from the vessels’ AIS data would indicate when they move.

Approximately 2200:

Alte Weser Radar informs the two incoming Maersk ships that the required berths remain occupied.

The pilot on the MUMBAI MAERSK then contacts Bremerhaven Weser Traffic by radio to obtain further information. However, they too have no information other than that what is already visible on the ship's ECDIS – i.e., the LAMARTINE's bow is already slightly clear of the pier, but her stern is not moving, evidently due to the problems with the winch.

The pilot urgently requests conclusive information as to whether the MUMBAI can enter the Neue Weser or not, because before entering, he will have to decide whether to turn around and sail back in the direction of the North Sea, which would destroy the previously agreed schedule. The nautical supervisor at the vessel traffic service promises to enquire.

The pilot and master of the MUMBAI MAERSK discuss the situation.

At 2203, the vessel traffic service supervisor tells the LAMARTINE that she is to be completely clear of the pier within ten minutes. Otherwise, she will have to remain at her berth. At this time, the MUMBAI MAERSK is approaching the last possible location in the fairway where turning around is still safely possible.

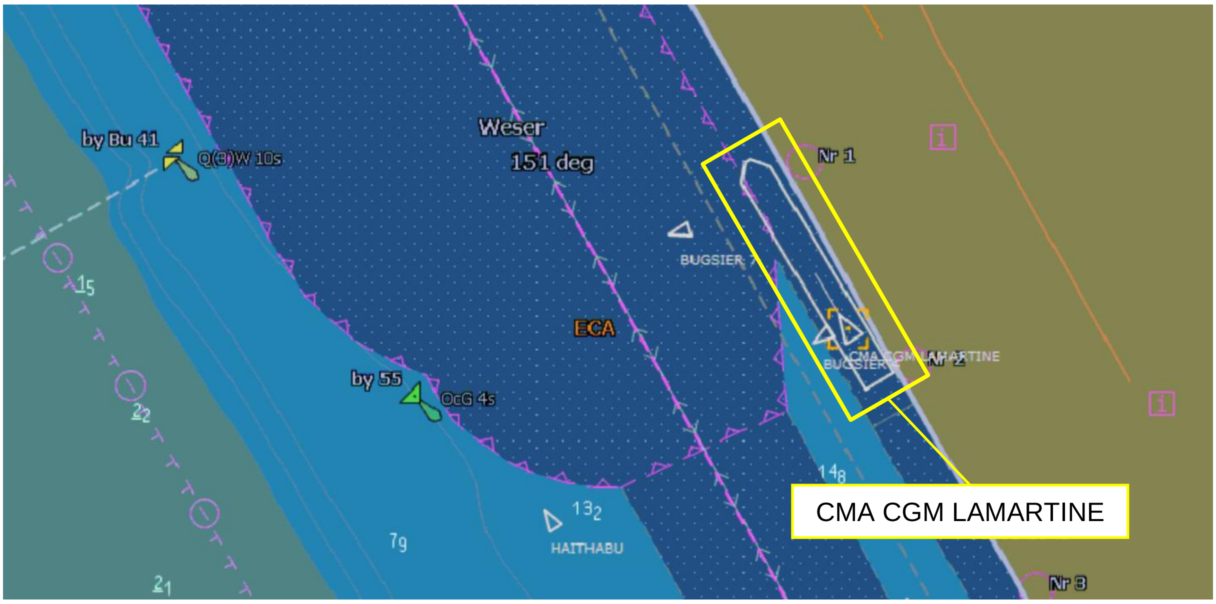


Figure 8: CMA CGM LAMARTINE with her bow clear of the pier[22]

Approximately 2205:

To establish what is happening on the MAERSK KANSAS, which is also still at the pier in Bremerhaven and failing to report to the vessel traffic service, the pilot on the MUMBAI MAERSK calls his colleague on the ship by mobile phone. He learns that the casting off manoeuvre has already started and a tug is being made fast.

In the ensuing radio call between the pilot of the MUMBAI MAERSK and Bremerhaven Weser Traffic, information from either side is exchanged, in particular the ten-minute time limit that had been issued to the LAMARTINE. The pilot once more points out that he will definitely miss the tidal window, i.e., the opportunity to enter the Neue Weser in time, if he turns around now. The ship is therefore advised to continue at the currently reduced speed of 5 kts. for the time being.

Approximately 2215:

The LAMARTINE reports by radio that all lines except a spring line are cast off and she is now ready to sail.

In a radio call with the INTEGRITY behind them, the pilot of the MUMBAI MAERSK learns that the vessel will now enter the Neue Weser and therefore overtake the MUMBAI (as she neither needs a berth in Bremerhaven nor has a problem meeting other vessels, due to her dimensions).

[22] Source: VDR of the MUMBAI MAERSK, ECDIS screenshot at various times, 02/02/2022.

On the MUMBAI, the pilot's mobile phone rings almost simultaneously. His colleague on board the LAMARTINE also informs him that they have reduced the lines to one spring line.

Almost at the same time, the MUMBAI receives the same information from Alte Weser Radar via radio as well. Both state that the MAERSK KANSAS is not communicating.

Approximately 2220:

The MUMBAI MAERSK passes the buoys Weser 3a/4a and thus enters the Weser fairway. Due to the agreements made beforehand, VTS does not object to this entry. The mandatory radar assistance for a ship of this size begins.

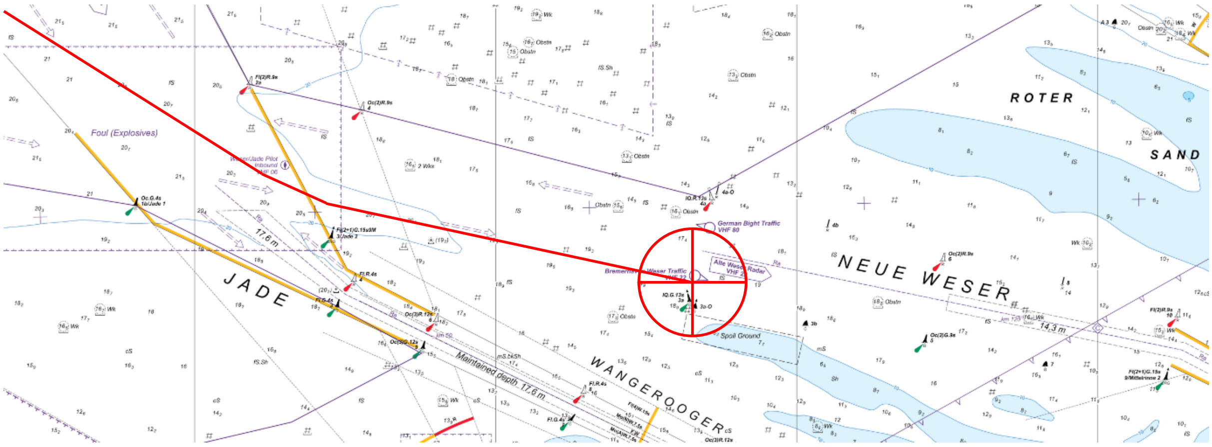


Figure 9: Past track and position at about 2220[23]

The MARY MAERSK attempts to find out via Alte Weser Radar what her entry time will be. The answer cannot be given.

A moment later (2223 – ten minutes after expiry of the ten-minute deadline), Alte Weser Radar gives the information that the LAMARTINE is 'afloat', i.e., has cast off all her lines.

Bremerhaven Weser Traffic then relays the same information, as well as the fact that the MAERSK KANSAS is still failing to communicate in any way. The MUMBAI MAERSK is intended for that berth. When vessel traffic service enquires after the vessel’s latest possible turning point, the MUMBAI's pilot replies that this would still be possible at the Bremer Kreuz junction or Hoheweg Reede roads, if absolutely necessary (two wider areas in the otherwise narrow section of the Neue Weser, i.e., after entering the channel of the same).

[23] Source: Federal Maritime and Hydrographic Agency (BSH), Navigational Chart DE2 (INT 1456) (detail), 2020.

Approximately 2225:

The MUMBAI MAERSK's master and pilot decide to turn around and wait further 'outside' for berths and fairway to become available. At this point, the MUMBAI MAERSK is already in the Neue Weser, but has not yet entered the dredged fairway section, which begins at buoy pair 5 and 6.The master issues the helm order 'hard to port'. The pilot reports the manoeuvre to the VTS centre.

Only two minutes later, Alte Weser Radar reports that the MAERSK KANSAS, which is still moored in the berth earmarked for the MUMBAI MAERSK, is now making the tug fast and reducing her number of lines. Before sailing, the ship would first have to wait for the also departing LAMARTINE, however.

Approximately 2230:

The MUMBAI MAERSK executes a turn over port with a constant rudder angle. The manoeuvre is supported by the incoming tidal current and the prevailing north-westerly wind. A relatively strong current exerts greater force on a ship's stern than on her bow, particularly in cases like this one, where the MUMBAI MAERSK is positioned broadside to the current. Additionally, a vessel naturally tends to turn its bow into the wind when moving forward.

To the radar advisor, it initially appears that this turn may lead the vessel over buoy 4b if speed and rate of turn remain unchanged. The 'prediction' feature of the MUMBAI MAERSK's ECDIS[24] also indicates this. Upon inquiry, the pilot informs the radar advisor of his intentions, stating that he has no concerns about the turning manoeuvre. In the event that the turn should not succeed as planned, the vessel could pass the buoy on the outside (beyond the marked fairway, to the north) as a contingency measure.

[24] The 'prediction' refers to a future track predicted over a fixed period of time, e.g. six minutes, during a course alteration, provided that rate of turn and speed over ground remain constant during this time.

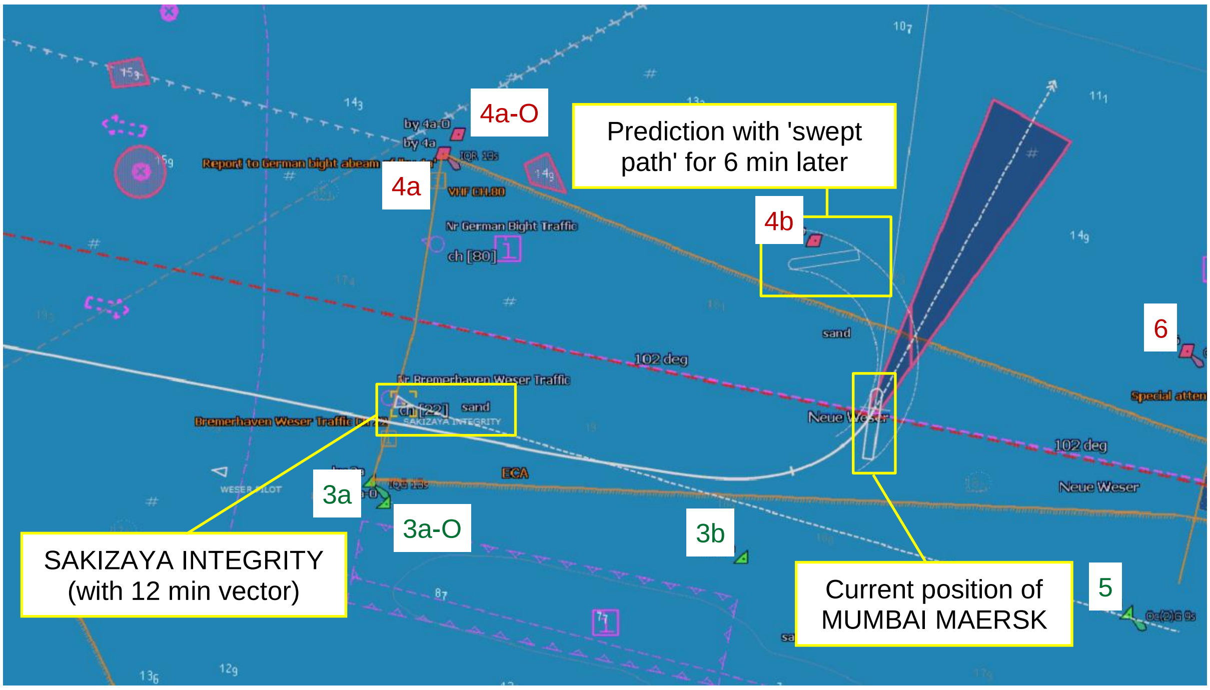


Figure 10: Track with prediction in the first turn (incl. swept path[25])[26]

Accordingly, the rate of turn increases due to the tidal current, and the MUMBAI's radius of turn decreases early enough, because her stern is increasingly 'pushed around'. Thus, the manoeuvre succeeds between the buoys, as was planned.

[25] The 'swept path' refers to the surface area that the hull actually sweeps over while moving (not simply a linear route). This is particularly relevant for lateral components of movement (transverse thrust), as the swept path then becomes wider. The effect is clearly visible in the figure. The prediction also depends on the rate of turn and speed over ground remaining constant for the indicated period (in this case, six minutes).

[26] Source: VDR of the MUMBAI MAERSK, ECDIS screenshot at various times, 02/02/2022.

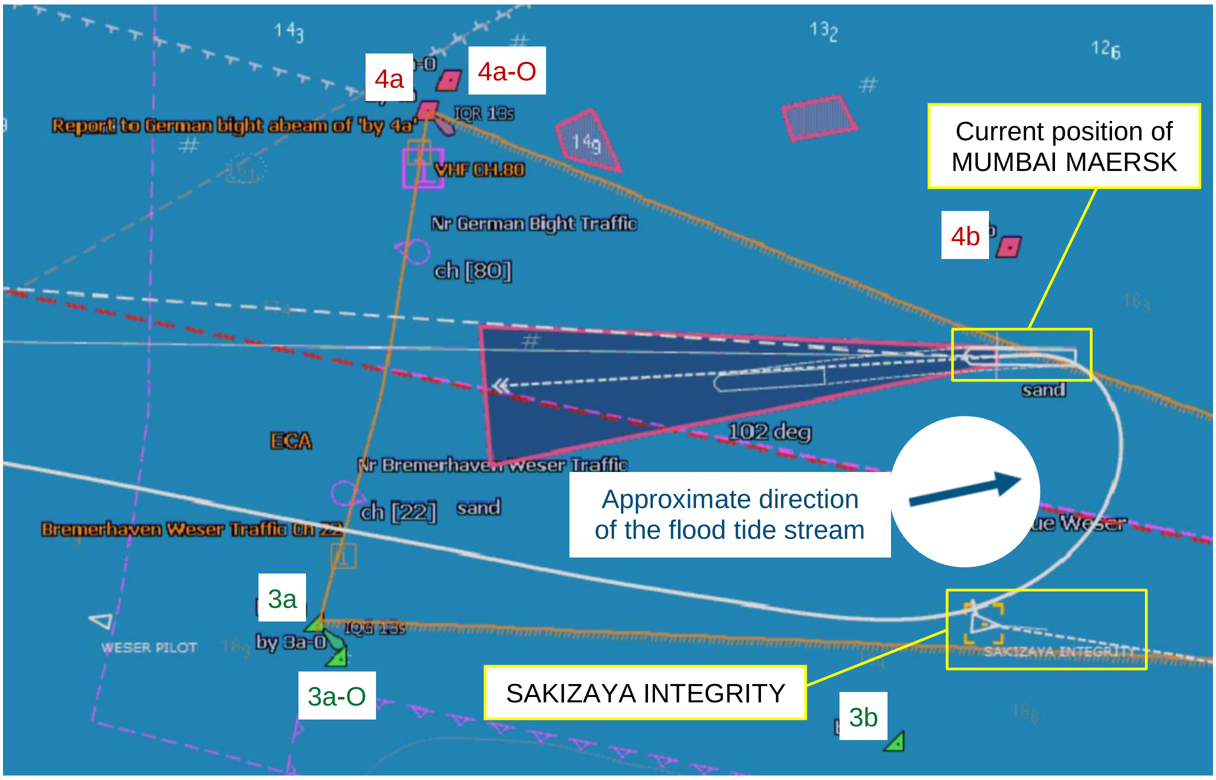


Figure 11: Past track of the first turn[27]

(Aided by the flood tide stream, the rate of turn increases and radius of turn decreases significantly in the final third of the turn, which is why the vessel remains well clear of buoy 4b.)

The pilot on the MARY MAERSK informs vessel traffic service that the ship is now scheduled to arrive at the pier at 0100. To this end, they intend to enter the Neue Weser at 2300. After briefly drifting south of the approach to the Neue Weser and sailing a slow loop, the ship is now returning into the fairway, on a head-on course toward the MUMBAI MAERSK, which has now completed her turn.

Figure 12: Traffic situation at about 2235[28]

[27] Source: VDR of the MUMBAI MAERSK, ECDIS screenshot at various times, 02/02/2022.

[28] Source: MarineTraffic screenshot of an animation of the traffic situation on the evening of the accident, 02/02/2022.

The MAERSK KANSAS's pilot reports to Bremerhaven Weser Traffic that they are ready for departure. He is told once again that they must first let the LAMARTINE pass before turning and sailing. (The ship is not facing in the departure direction. This additionally delays her departure.)

Approximately 2235:

The INTEGRITY passes the MUMBAI MAERSK and enters the Neue Weser.

The MUMBAI MAERSK's pilot has a long conversation with the Port Operations Office by radio. He demands a definite statement as to when and in what order the ships are to enter. He is told that the MUMBAI is still scheduled before the MARY. The pilot discusses this information with Alte Weser Radar and the master. They decide to wait until the berth occupied by the KANSAS is actually free before making the reverse turn, back to the original course.

Since, according to the pilot, the reverse turn is not expected in the near future, the MUMBAI MAERSK does not sail close to the northern buoy line but rather slightly further south, leaving ample space to the buoys on each side.

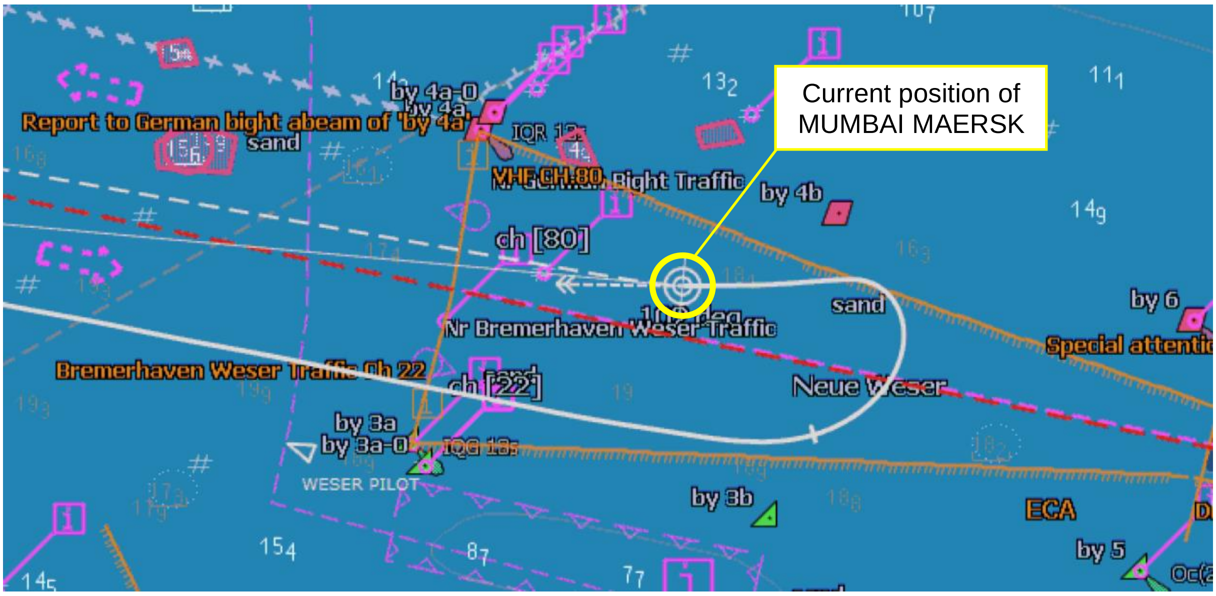


Figure 13: MUMBAI MAERSK on a reciprocal course[29]

Approximately 2240:

The pilots on the MUMBAI and on the MARY MAERSK discuss the situation and arrival order by telephone.

[29] Source: VDR of the MUMBAI MAERSK, ECDIS screenshot at various times, 02/02/2022.

The master of the MUMBAI, who is keeping an eye on the ECDIS centred on the Stromkaje quay, reports that the KANSAS is now clear of the pier, but has not yet turned around. The LAMARTINE is now underway in the direction of the North Sea.

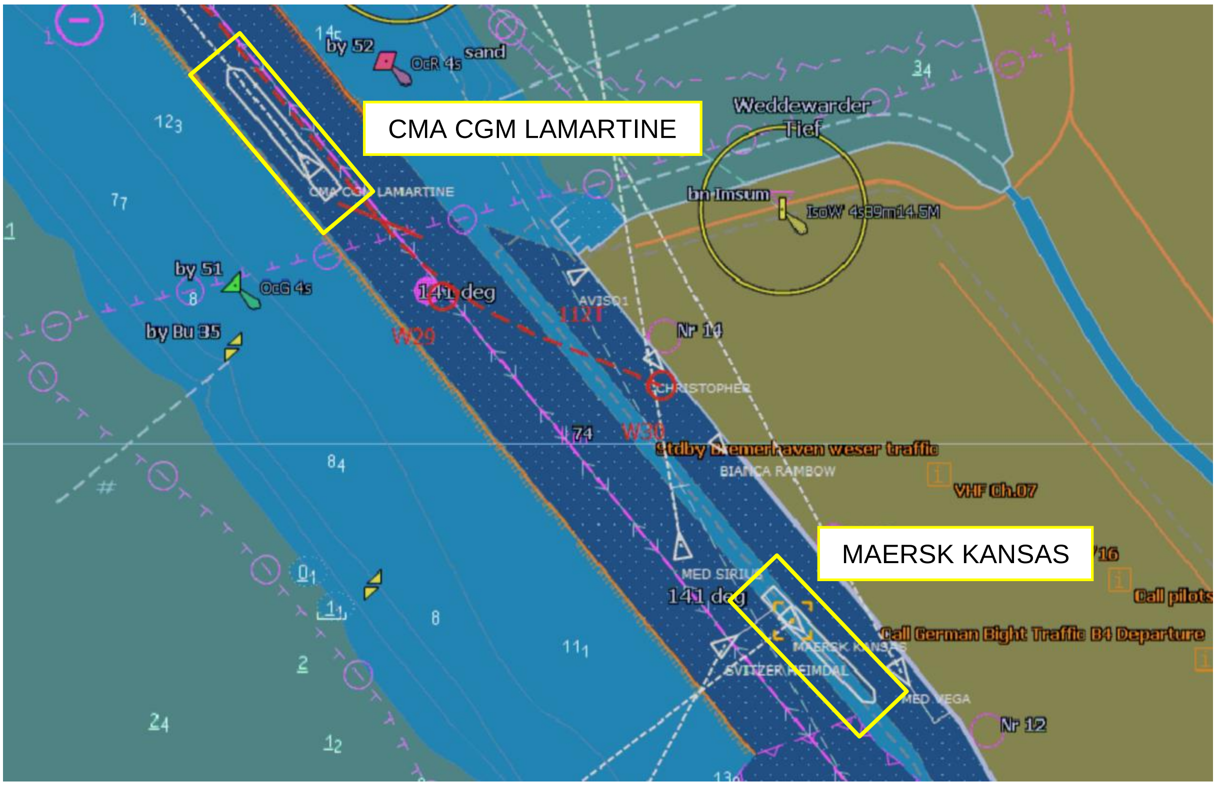


Figure 14: CMA CGM LAMARTINE and MAERSK KANSAS at the Stromkaje quay[30]

Approximately 2245:

The MUMBAI MAERSK's pilot calls Bremerhaven Weser Traffic. He reports that the Port Operations Office has told him to definitely enter Bremerhaven first. Meanwhile, the MARY was told from by same source that they are to be 'at the top'[31] at 0100, which would also require a prompt entry. At the same time, it is not yet possible to say when the MUMBAI will be able to turn back, as this depends on the departing ships.

The MUMBAI's pilot is beginning to get annoyed, expressing the suspicion that the POO may not even know the actual positions of the ships that they are providing with entry times. He insists on a binding and definitive entry sequence that takes the entire traffic situation into account, including the ships leaving the port and their speeds.

In a subsequent radio call between the MUMBAI and MARY MAERSK, the two pilots agree that the MARY should sail toward the Neue Weser extremely slowly. The

[30] Source: VDR of the MUMBAI MAERSK, ECDIS screenshot at various times, 02/02/2022.

[31] The 'top' refers to the exit from the channel of the Neue Weser into the widened, dredged section of the river directly adjacent to the Stromkaje quay in Bremerhaven.

departing LAMARTINE is already underway at 11-12 kts and the KANSAS has turned halfway.

The MSC GEORGIA II (simply referred to as 'GEORGIA' hereafter) becomes part of the traffic situation a little later. She is coming from the River Jade in the south and is planning to turn westward into the fairway on her way to the North Sea. During the MUMBAI MAERSK's planned reciprocal turn, back in the direction of Bremerhaven, the GEORGIA could meet her on a collision course. Accordingly, the GEORGIA's pilot, who has followed the situation on the radio, calls the MUMBAI to ensure they are aware of the potential close-encounter situation.

Approximately 2250:

Bremerhaven Weser Traffic confirms that the MUMBAI MAERSK is to enter before the MARY. Since the INTEGRITY, which has now entered the Neue Weser, is sailing slower than the MUMBAI MAERSK due to the time of arrival she has been given, the MUMBAI's entry time would be delayed even further. The INTEGRITY is therefore asked to cover the distance to the Stromkaje quay (the MUMBAI's destination) more quickly, and then to wait there until her required arrival at the Geeste estuary. Her pilot agrees to this proposal, even though the INTEGRITYs will then have an aft current to contend with, making stopping and slowing difficult.

The pilot of the MUMBAI MAERSK explains the situation to the master, who has apparently already understood.

2253:

Alte Weser Radar informs the MUMBAI MAERSK that the berth occupied by the MAERSK KANSAS is now available. Less than 30 minutes have passed since the start of the MUMBAI’s first turning manoeuvre.

The MUMBAI MAERSK bridge team initially assumed that vacating the berth would take more time. They did not anticipate that a second turn would need to follow so quickly.

The pilot of the MUMBAI MAERSK explains the situation to Alte Weser Radar: In his view, another turn will only be possible once the vessel has cleared the next buoys (3a/3a-O and 4a/4a-O). At the same time, he stresses the need to complete the turn as quickly as possible to keep the MUMBAI MAERSK clear of other vessels. He also points out that the approaching MARY MAERSK must remain behind them in the designated sequence, and that a safe distance between the two ships must be maintained at all times.

The MARY informs Alte Weser Radar that she will move a little further north so as to give the MUMBAI room for her reverse turning manoeuvre.

2254:

The MUMBAI MAERSK's pilot issues the order "hard to port" to turn the ship back in the direction of the port.

He and his colleague on the MARY agree that the MUMBAI will endeavour to reach buoy no. 49 at around 2345. This will still leave enough time for the MARY to make use of the same tidal window. MARY replies that they are still waiting for the POO to provide them with an exact entry time. The INTEGRITY confirms that she will sail ahead of the MUMBAI quickly enough to allow her to enter as soon as possible without risking an overly close approach.

2258:

The MUMBAI MAERSK's third officer reports that the ECDIS prediction indicates a dangerous close-quarters situation with buoy 3a. The pilot points out that it is important to remember that this is merely a prediction. The captain expresses concerns about the tight passage, as well. The pilot reassures him that he has no doubts about the manoeuvre's success, but acknowledges that the passage will indeed be a close one.

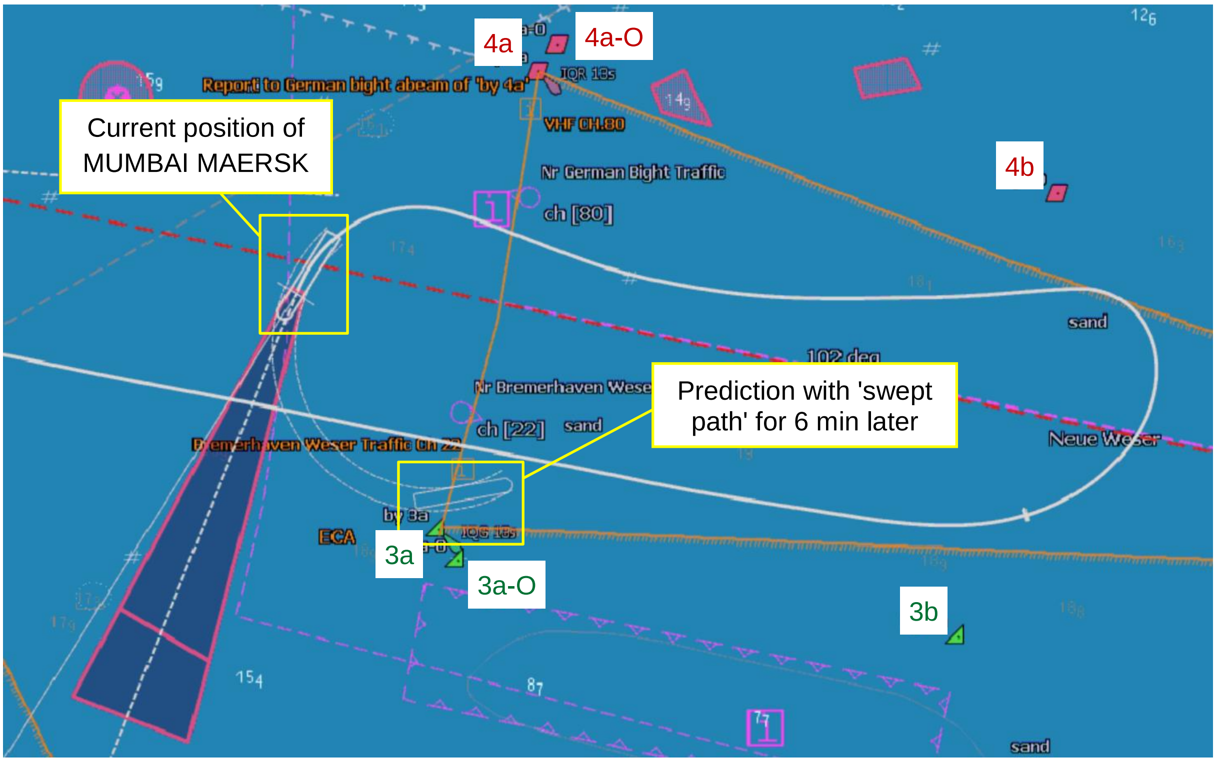


Figure 15: Track with prediction in the second turn, 2258[32]

[32] Quelle: VDR der MUMBAI MAERSK, Screenshots der ECDIS zu diversen Zeiten, 02.02.2022. 22:58:22 Uhr.

2300:

Alte Weser Radar also reports that the passage of the buoys appears tight. The master then says that he believes it would be better if the buoys were kept on the port side, which the pilot then confirms. The MUMBAI MAERSK's turning radius is increased with a few short amidships and starboard rudder angles (first hard starboard, then smaller angles).

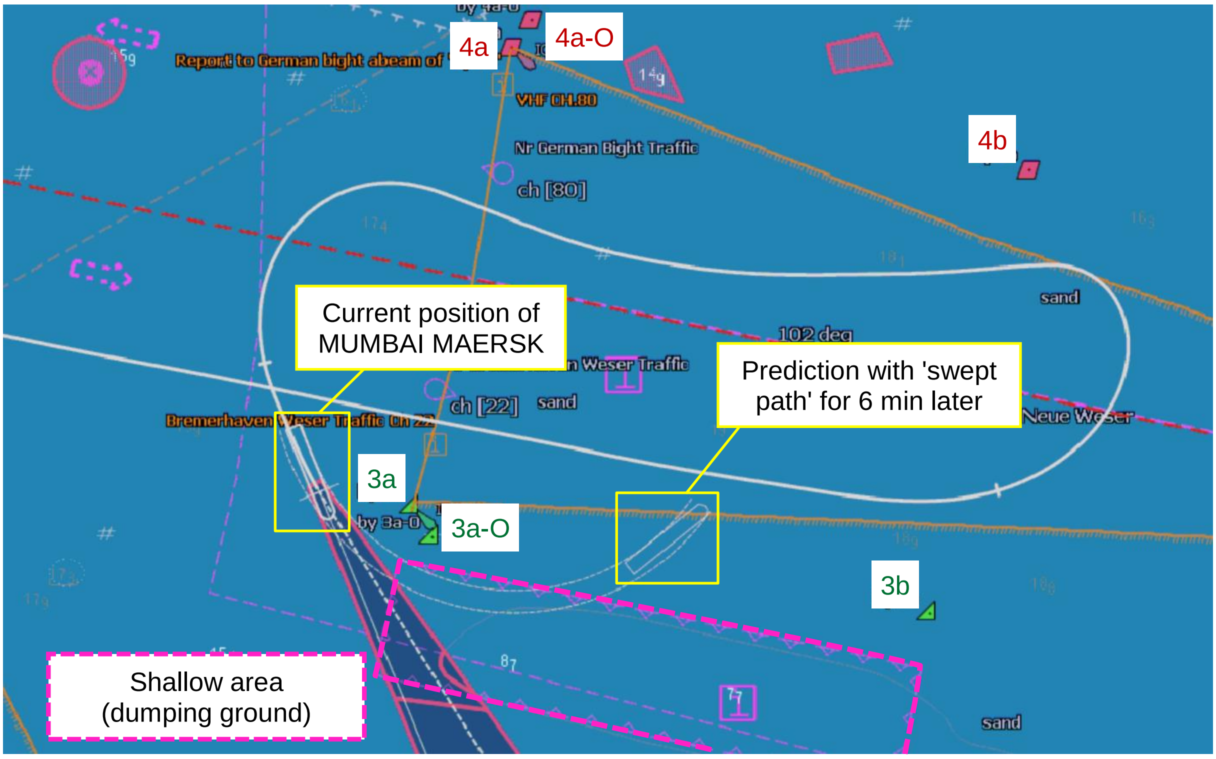


Figure 16: Increased turning radius[33]

Rather than over buoy 3a, the prediction now passes over the dumping ground

The MARY MAERSK reports to Bremerhaven Weser Traffic that her entry time has now been set for 1030 on the following day. She sails out of the fairway to the north, onto the Neue Weser Nord roadstead to anchor there.

The MUMBAI's pilot reports to Alte Weser Radar that buoy 3a will be kept on the port side, before immediately turning back into the fairway. AWR remarks that, in that case, the situation looks better.

They now intend to reduce the MUMBAI MAERSK's turning radius again with “hard to port”. The third officer draws the master's attention to a shallow area with a water depth of 8.9 m just south of the buoy (a dumping ground for dredged spoils). The master asks the pilot about it, who in turn replies that the shallow area will be avoided as long as

[33] Quelle: VDR der MUMBAI MAERSK, Screenshots der ECDIS zu diversen Zeiten, 02.02.2022. 23:02:07 Uhr.

they remain close to the buoy line. He recommends that the engine telegraphs be set to full ahead for a brief period, so as to increase the rudder response and thus further reduce the turning radius. Once the MUMBAI MAERSK clears the buoy, he recommends 10° starboard rudder to gradually bring the vessel onto an easterly course toward Bremerhaven.

The captain disagrees with the pilot's recommendation and instructs the turn to be continued. He overrides the pilot's rudder command, changing it to "hard to port". The vessel, however, hardly responds to this rudder adjustment.

3.1.1 Accident

Approximately 2305:

The pilot enquires about the under-keel clearance, which, according to the master, is 1.2 m. Shortly afterwards, the master declares that the ship has evidently run aground.

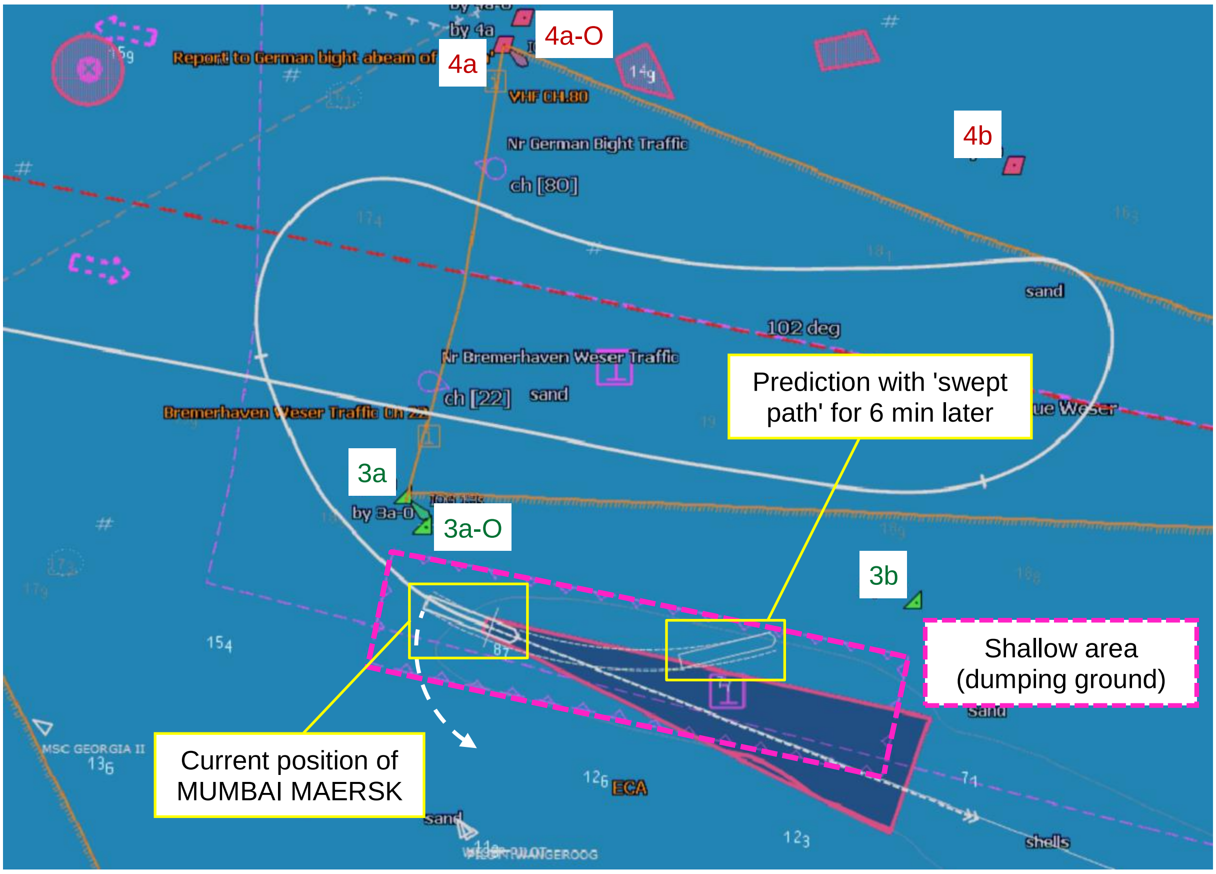


Figure 17: Time of grounding[34]

The prediction already indicates a lower speed.

[34] Source: VDR of the MUMBAI MAERSK, ECDIS screenshot at various times, 02/02/2022.

Due to the bow's contact with the seabed, the fore section is abruptly decelerated. This takes place at a speed of almost 10 kts, and in the course of a turn to port. The aft section, which is still afloat and moving, therefore begins to slew anticlockwise around a pivot point at the grounded bow (see dashed arrow in Figure 17). Because this causes a continuing speed of 0.5 kts to be indicated on the log, and because the rising tide still has another 90 minutes before it turns, there is initially hope among the bridge crew.

2306:

The pilot contacts Bremerhaven Weser Traffic and reports the probable grounding. After consulting with the master, they decide to wait before ordering tugs, for the time being, since it is not yet clear whether the ship will refloat with the rising tide.

The master contacts Maersk by telephone and reports that the ship has run aground.

The engines are running at full astern, the bow thrusters full to port.

Approximately 2320:

The idea of dropping an anchor is dismissed in case the ship drifts onto it, potentially resulting in a punctured or otherwise damaged underwater hull.

The master orders the engine telegraph to be set to zero to prevent the propellers from moving in extremely shallow, muddy water, or possibly even sand.[35] The bow thrusters are turned off for the same reason.

The tank levels in the double bottom are checked to identify a possible water ingress, but no changes are observed.

Approximately 2325:

The MUMBAI MAERSK has stopped moving. Due to the described slewing motion after the initial grounding, her heading is now offset by approximately 180° from the direction in which she ran onto the dumping ground.

[35] If engines and propellers are suddenly forced to operate against a fixed resistance, i.e., if an external force causes them to decelerate (in this particular case at maximum rpm), this can, in the worst case, lead to severe damage and total loss of both engines and their propeller shafts, endangering the members of the engine department in the process. The propellers might also be damaged or even destroyed.

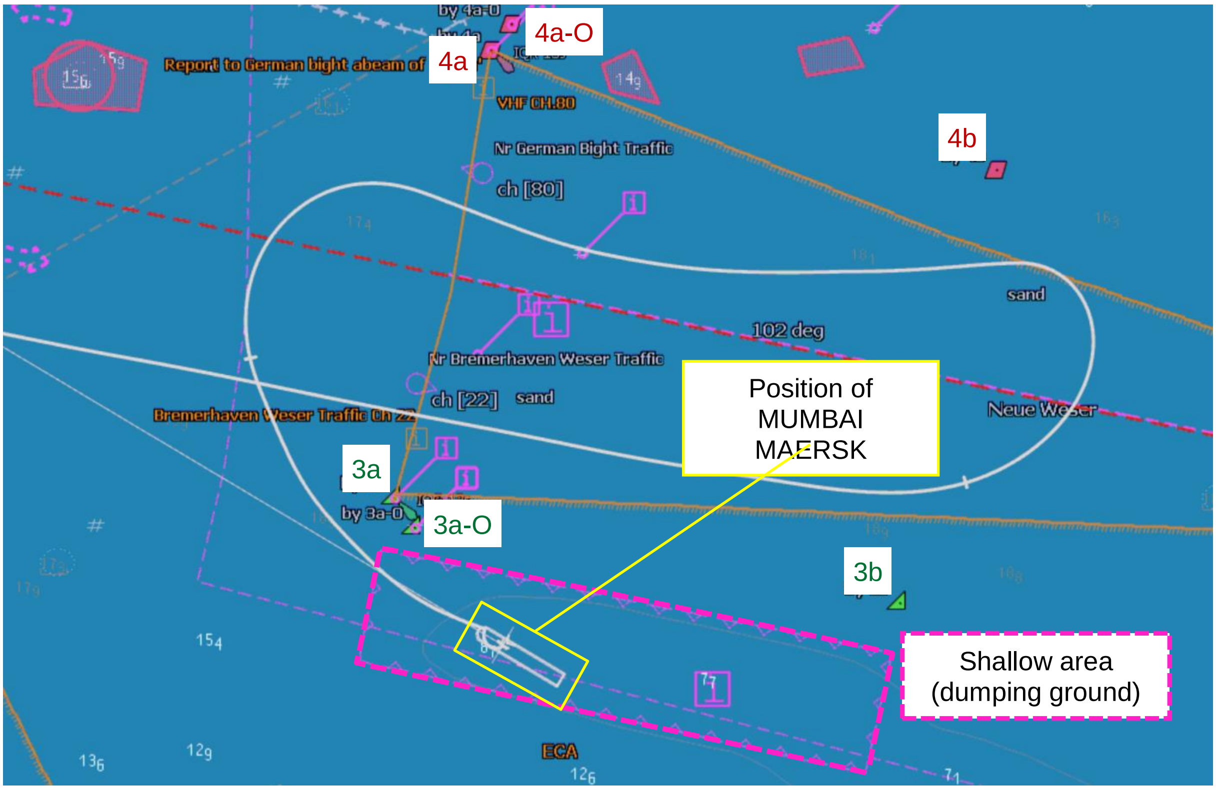
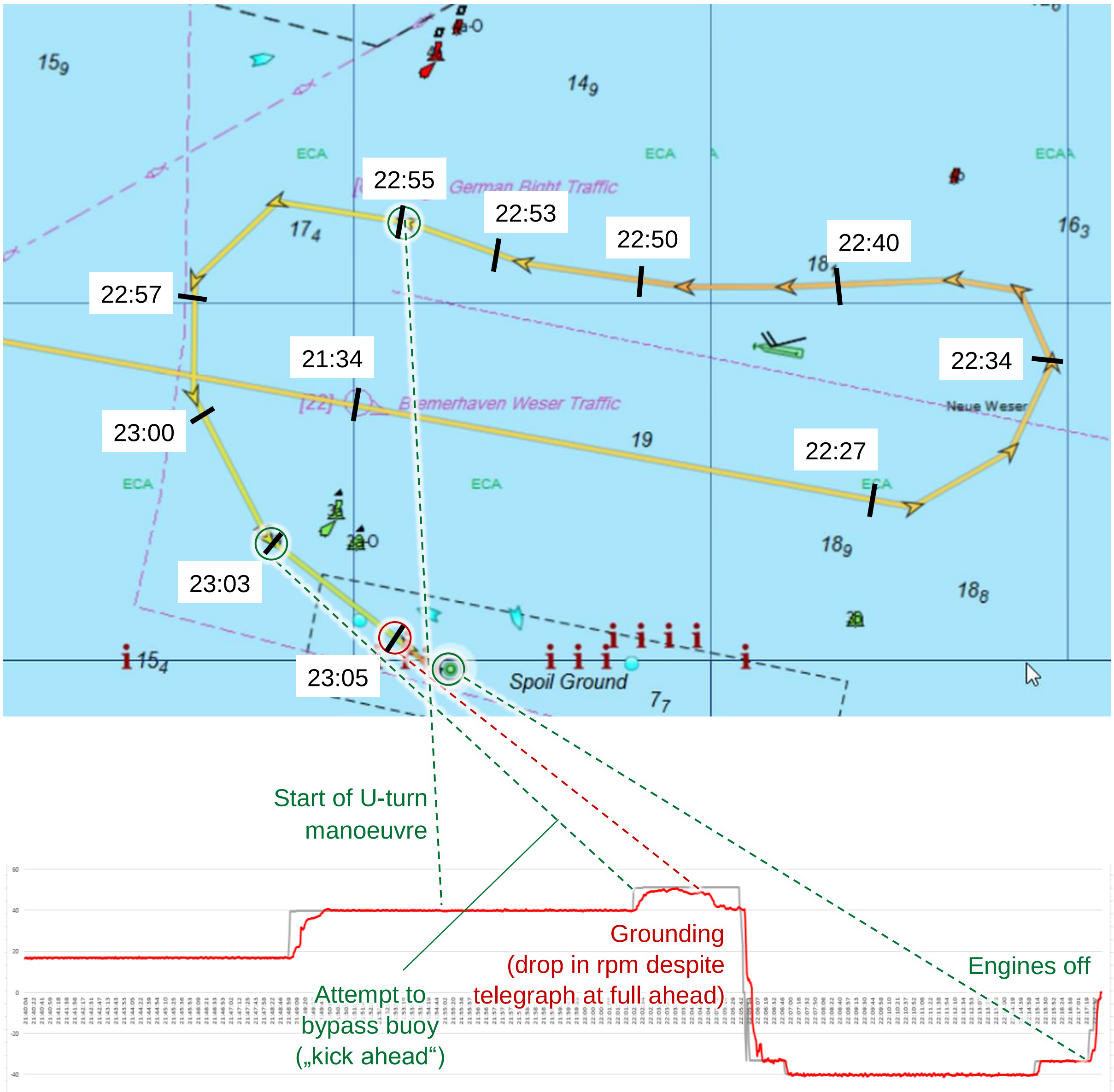


Figure 18: Final position after running aground[36]

[36] Source: VDR of the MUMBAI MAERSK, ECDIS screenshot at various times, 02/02/2022.



Bridge telegraph order & Main Engine 1 rpm (starboard main engine)
(system time = UTC = local time = CET - 1)

Figure 19: Chronological sequence versus engine speed[37]

[37] Sources: MarineTraffic screenshot of details of the MUMBAI MAERSK's track on the day of the accident, as well as VDR sensor data from the MUMBAI MAERSK (prepared by BSU), 02/02/2022.

3.1.2 Salvage operations

Vessel Traffic Service (VTS) Bremerhaven notifies the CCME's Maritime Emergencies Reporting and Assessment Centre (MERAC). Shipping in the vicinity is instructed to pass the distressed vessel at a sufficient distance and low speed. It is not necessary to close the sea area, as the MUMBAI MAERSK does not pose a threat to the safety and efficiency of traffic due to her position outside the fairway.

The multipurpose vessel NEUWERK and the tug BUGSIER 9 are in the vicinity of the distressed vessel and the VTS has requested those two vessels, as well as the BUGSIER 30 from Heligoland, the RT EVOLUTION and the RT EMOTION from Bremerhaven, the multipurpose and water pollution control vessel MELLUM, the VB EMOE and the RT PIONEER from Wilhelmshaven. Additional tugs ordered by the master cannot come to the scene of the accident because they are already scheduled as assistance tugs for the bulk carrier SAKIZAYA INTEGRITY, which is also underway to Bremerhaven.

The ship has a slight “hogging”, i.e., the middle section is lying a little higher than fore and aft.

At 0120 on 03/02/2022, the VTS submits an emergency management takeover request to the CCME, which assumes overall control of the operation at 0130. The CCME's on-scene coordinator (OSC) goes on board the NEUWERK.

It is established that there has neither been recognisable damage to the MUMBAI MAERSK's hull, nor has water pollution occurred.

The CCME begins to issue regular press releases up until the successful salvage of the MUMBAI MAERSK.

3.1.2.1 First salvage attempt

A towing assistance team[38] (TAT) from the CCME boards the distressed vessel from the NEUWERK and establishes line connections with the tugs. At 0158, the next high tide, a maritime regulatory order is issued to the various vessels to commence the emergency salvage operation of the MUMBAI MAERSK. First, the NEUWERK and the BUGSIER 30 are instructed to begin towing in a controlled manner. Although the other tugs (mentioned above) are brought in one by one over the following hour to tow or push, three concerted attempts at refloating the vessel are unsuccessful. The salvage operation is therefore aborted at 0328, for the time being.

[38] A towing assistance team usually consists of four seafarers who are specially trained to work on vessels that are not under command and/or have been abandoned. (Source: German Central Command for Maritime Emergencies (CCME), CCME incident log / mission log of the incident 'MUMBAI MAERSK runs aground', 02-03/02/2022).

The NEUWERK and two tugs remain on scene, the other vessels stand down.

As a precaution, the CCME requests the oil surveillance aircraft DO-228 to scan the area for possible oil pollution. Although the operation cannot be carried out until the following afternoon due to poor visibility, it is confirmed that there has been no water pollution.

The CCME begins to draw up contingency plans for potential oil spills or the loss of different dangerous cargoes on board the MUMBAI MAERSK (scenarios such as toxic substance spills, explosions, fire, etc.). One MIRG (Marine Incident Response Group) team for emergency medical care (i.e., paramedics with an ambulance and a helicopter) and another for on-scene firefighting, explosion control, or similar incidents (i.e., firefighters with emergency equipment) are kept on standby for various worst-case scenarios, though fortunately none of them play out.

On board the MUMBAI MAERSK, inspections are carried out every 30 minutes to identify any changes in the deflection of the hull due to the changing water level[39]. All fuel levels and the visual condition of the main engines and steering gear (which can also be affected by a possible deflection) are logged at the same frequency. The various tug crews take hourly readings of the MUMBAI MAERSK's draught from their external positions, and the CCME compares these with the tidal water level. An unplanned change in the draught, condition or position of the distressed vessel does not occur at any time.

3.1.2.2 Second salvage attempt

Maersk instructs the Dutch salvage company SMIT Salvage to draw up a refloating plan. This is continuously coordinated with the CCME by email and/or video conferencing. The salvage master travels to the CCME in Cuxhaven, as does a representative of the shipping company.

To allow sufficient time for planning, the salvage is not scheduled for the next high tide (1440 on 03/02/2022), but rather for the one after that (0254 on 04/02/2022). This is the second of three spring tides, after which the high tides would begin to decrease in height again.[40]

[39] If the water level changes due to the tide, the forces acting on the hull of a grounded ship also change. The buoyancy forces of the water push upward and the weight of the ship downward. Cracks, distortions, chipped paint, etc., especially in specific areas such as the hatch coamings, can indicate that the hull is becoming increasingly deformed – especially if these distortions begin or increase in size between one inspection and the next. In the worst case, it is possible for a grounded ship to break apart as the tide recedes. In this case, not even “preliminary symptoms” of such a scenario were observed: The MUMBAI MAERSK remained stable.

[40] Source: SMIT Salvage, MUMBAI MAERSK daily progress reports, 03-04/02/2022.

The salvage company begins by assessing the condition of the vessel.

Firstly, this concerns up-to-date water depths, which are measured around the ship by the sounding vessel ZENIT (Figure 20).

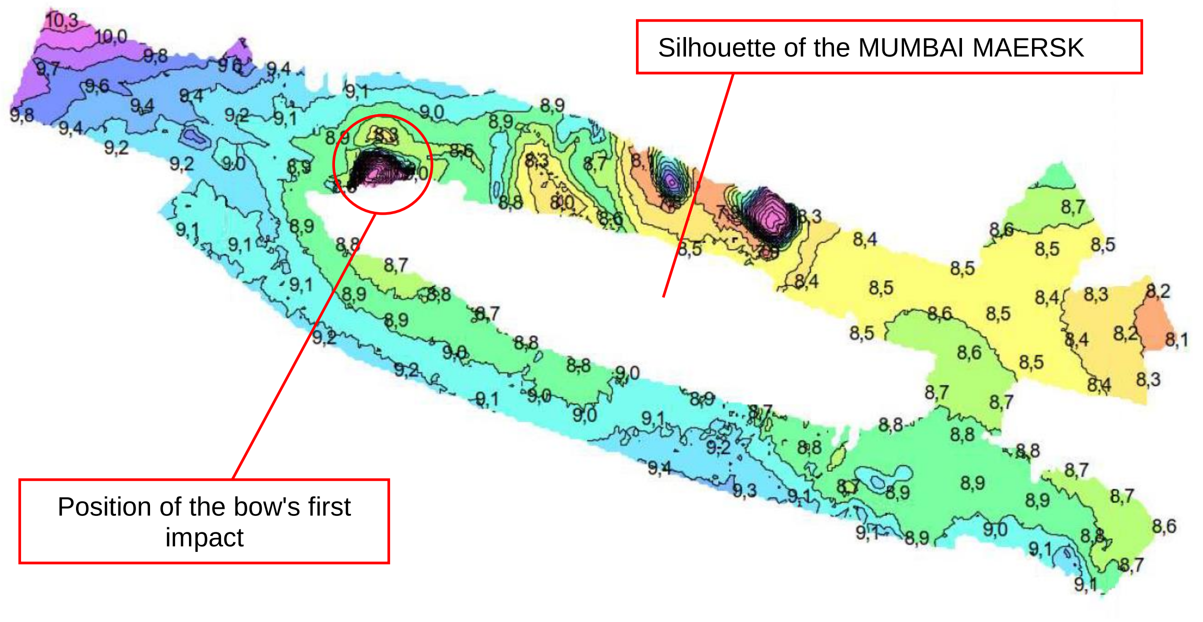


Figure 20: Water depths at the scene of the accident measured immediately afterwards[41]

Secondly, an assessment of the ship and her cargo is made. To this end, various documents are requested from the shipping company, such as

- general arrangement plan;
- emergency towing booklet;
- current stability data;
- dangerous goods manifest;
- current fill level of every tank, and
- current exact draught.

Calculations of the bending moments and shear forces acting on the hull in its grounded condition, as well as the total towing force needed to refloat the vessel are requested from the MUMBAI MAERSK's classification society, ABS (American Bureau of Shipping). A calculation is also made as to how lightering (removing) ballast water, fuel, and operating fluids would affect the ship's stability and the forces acting on her hull – i.e., the maximum weight that can be removed from the lower compartments of

[41] Source: SMIT Salvage, MUMBAI MAERSK daily progress reports, 03-04/02/2022.

the ship without compromising her structural integrity or stability (the so-called 'lightering plan').

The seagoing salvage tugs UNION SOVEREIGN and UNION MANTA from the Netherlands and Belgium, respectively, are requested. The MANTA does not reach the salvage operation on time, the SOVEREIGN is at the scene of the accident that same afternoon.

The VB EMOE is instructed to 'flush' at the MUMBAI MAERSK's port-side fore section (use her propeller to remove silt and mud from beneath the hull of the ship).

Meanwhile, 7,000 t of ballast water, but neither fuel nor operating fluids, are lightered from the MUMBAI MAERSK.

In the event that the next attempt to refloat the ship is unsuccessful, measures are taken to ensure that dredgers in the vicinity can be called in to remove additional silt around the ship, if necessary.

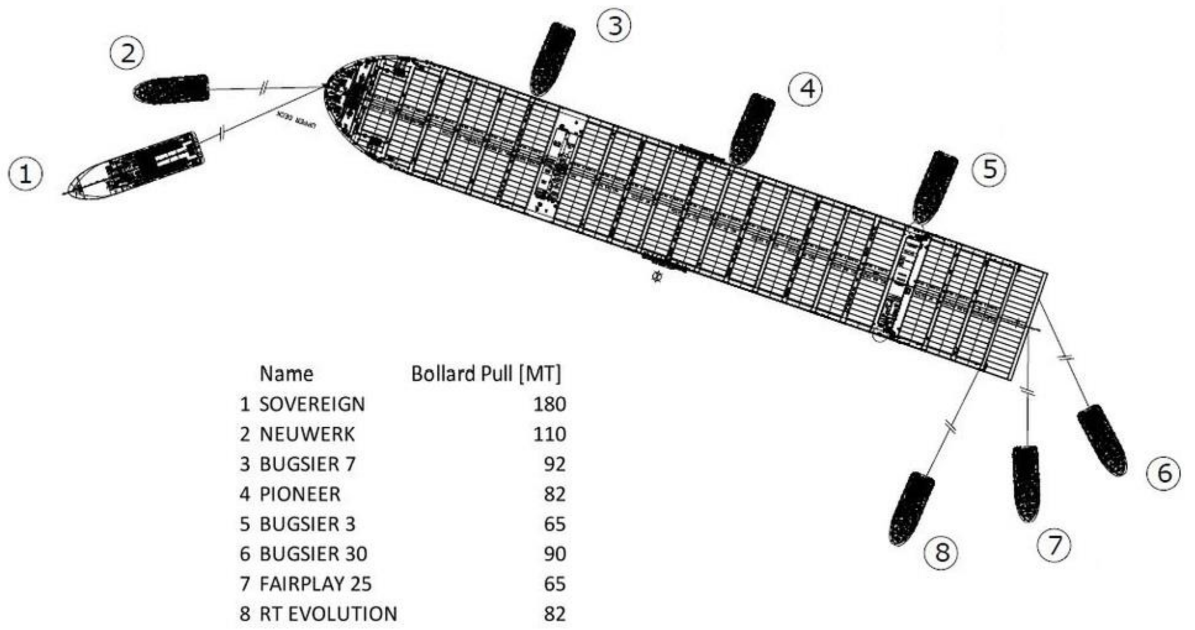
Figure 21: The grounded MUMBAI MAERSK and several tugs[42]

The tugs are positioned according to the refloating plan and made fast late in the afternoon on 03/02/2022 (Figure 22).

The CCME's OSC, a SMIT salvage team, including salvage master and a naval architect (an expert on the structural integrity and stability of ships, among other things), members of the MIRG medical team, a fire consultant, and additional Maersk crew members are brought to the MUMBAI MAERSK by tug. The ship's pilot, master, and chief mate are relieved. The TAT remains on the NEUWERK, the remaining MIRG team members on the MELLUM.

[42] Source: German Central Command for Maritime Emergencies, various photographs submitted, 03-04/02/2022.

The next attempt to refloat the vessel is started at 0050 on the night of 03-04/02/2022, two high tides after she ran aground. The VTS instructs the surrounding maritime traffic to remain well clear of the manoeuvre.



	Name	Bollard Pull [MT]
1	SOVEREIGN	180
2	NEUWERK	110
3	BUGSIER 7	92
4	PIONEER	82
5	BUGSIER 3	65
6	BUGSIER 30	90
7	FAIRPLAY 25	65
8	RT EVOLUTION	82

Figure 22: Tug configuration during the second attempt to refloat the vessel[43]

The greatest towing force (i.e., the SOVEREIGN and the NEUWERK) is positioned at the bow. The BUGSIER 30, the FAIRPLAY 25 and the RT EVOLUTION are to tow at the stern. On MUMBAI MAERSK's starboard side, the BUGSIER 7 is additionally to push at the bow, the RT PIONEER amidships, and the BUGSIER 3 at the stern (see Figure 22).

The UNION MANTA and the VB EMOE are to wait on standby.

This manoeuvre succeeds. At 0114 on 04/02/2022, the MUMBAI MAERSK's successful refloating is reported.

[43] Quelle: SMIT Salvage, Refloating Plan MUMBAI MAERSK (Bergungsplan), 03.02.2022.

Figure 23: View of the MUMBAI MAERSK from the NEUWERK

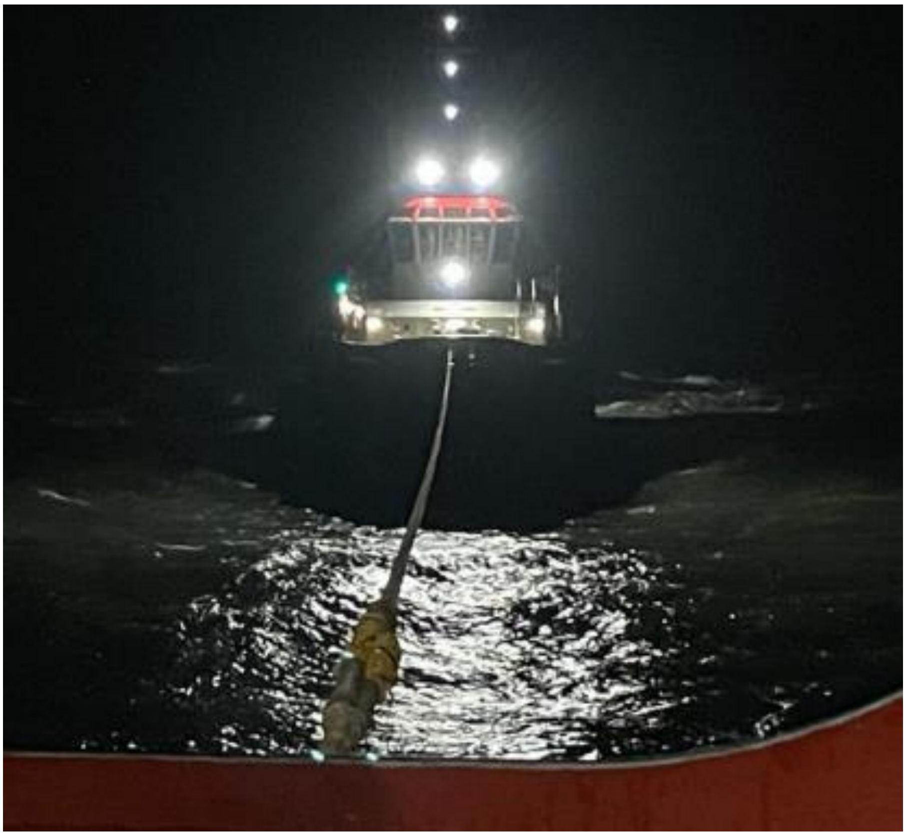


Figure 24: View of the FAIRPLAY 25 from the stern of the MUMBAI MAERSK[44]

[44] Source Figures 23 and 24: German Central Command for Maritime Emergencies (CCME), various photographs, 03-04/02/2022.

3.1.3 Subsequent events

All tanks on board the MUMBAI MAERSK are immediately sounded again, and the crankshaft deflection of the two main engines is measured[45]. As no damage to either ship or engines is evident, most of the tugs are stood down, as are all other bodies and personnel involved in the operation. Non-crew members on board the MUMBAI MAERSK, the NEUWERK, and the MELLUM are taken back ashore.

After the ship's chief engineer’s approval following the necessary checks, the NEUWERK and the SOVEREIGN tow the MUMBAI MAERSK into the German Bight for trials of her two main engines and their steering gears until around 0830. These trials are inconspicuous, whereupon the VTS issues the entry permit for Bremerhaven (condition: escort tug or tugs with an overall total bollard pull of at least 80 t).

The CCME concludes its role of overall operational command within the 'MUMBAI MAERSK runs aground' incident at 0930 on 04/02/2022.

In the next tidal window and escorted by two tugs, the ship sails to Bremerhaven under her own steam, where she is duly made fast at the pier by 1445.

An inspection of the underwater hull by divers, necessary for confirming the ship's class, along with all class surveys, is to be carried out at the ship's next scheduled port of call (Århus in Denmark), due to shallow water and, in particular, poor underwater visibility in Bremerhaven. To this end, an interim permit to proceed is issued in Bremerhaven following an inspection of all tanks, cofferdams, cargo holds, etc., by the classification society, the Ship Safety Division (BG Verkehr), and the insurer.

The diving inspection in Århus on behalf of the classification society reveals that, apart from paint abrasions, the ship has sustained no damage due to the accident (e.g., to the bottom, bulbous bow, stem and sternpost areas, propellers, sea chests, transverse thrusters, engines, etc.). The certificate of class can be reissued without conditions.[46]

[45] If the crankshaft of a large diesel engine is rotated slowly ('turned') with the crankcase flaps open, a possible deflection of the crankshaft can be measured. This shows up in the change in the opening of the individual crank web pairs relative to each other ('deflection') over 360°. Such a measurement is an integrity check carried out every time a ship is laid up, including dry dockings.

[46] Source: American Bureau of Shipping, Survey and Class Confirmation Report, 09/02/2022.

3.2 Investigation

3.2.1 MUMBAI MAERSK

The MUMBAI MAERSK, built in 2015, is the penultimate vessel in a series of 31 fully cellular container ships, the so-called 'EEE Class'[47] of the Danish shipping company Mærsk Line A/S. The EEE ships are all ULCSs (ultra-large container ships).

The MUMBAI MAERSK is powered by two MAN 7G80ME-C95T2 engines, each with a rated output of 31,000 kW, built under licence by Doosan. The ship has two spade rudders and two inward-rotating propellers (port: right-handed, starboard: left-handed). In pilotage waters, usually all four steering gear units (two per rudder) are in operation. The minimum speed for full steering capability is 6 kts.

In the laden condition and at half ahead, the wheelhouse poster specifies a full turning circle with a diameter of 10.68 cables (one cable = one-tenth of a nautical mile), equivalent to 1.98 km. The maximum stopping distance under the same conditions is about 23 cables (4.26 km).

The three Port State Control inspections before the accident did not reveal any anomalies.

3.2.2 Onboard visit

A team of three BSU investigators boarded the MUMBAI MAERSK on 05/02/2022 for an inspection while the ship was in Bremerhaven. Interviews were to be conducted with the involved crew members, and technical data and documents secured for the investigation.

Prior to the on-board visit, Waterway Police Bremerhaven were visited, where the BSU team was provided with radar and VHF radio recordings.

Immediately after being met by the master, the fleet safety superintendent, and Maersk's global security and quality manager, the crew members who had been present on the bridge at the time of the accident were questioned about the sequence of events. The third officer (3/O) was interviewed first, followed by the master (although the original master had been relieved) and finally the helmsman (see also Chapter 3.2.4 below).

During the inspection of the bridge between two interviews, the second officer (2/O) demonstrated the ECDIS system, among other things. The BSU verified and documented the settings.

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[47] EEE (or 'Triple-E'): Series of sister ships to which MUMBAI MAERSK belongs. The name stands for 'economy of scale', 'energy efficient', and 'environmentally improved'. The name of every ship in this series begins with 'M' (e.g., MUMBAI or MARY)

3.2.3 Rest periods

The pilot commenced his duty after a sufficient rest period, more than 20 hours after completing his previous assignment as a radar advisor.

The bridge team had also complied with the required rest periods before approaching Bremerhaven.

3.2.4 Bridge team

In addition to the pilot and master, the third officer, who was officer of the watch (OOW), and a helmsman were on the bridge at the time of the accident. All of them were part of the active bridge team.

At the time of the accident, the master had 44 years of seafaring experience. Before joining Maersk in 2002, he worked for another shipping company for 20 years, where he served as master for 13 years. He initially joined Maersk as a third officer, as required by Maersk company policy. Since 2006, he has again been employed as master. He has been commanding ships of comparable size for about ten years, EEE Class ships since 2018.

The pilot has been a seafarer since 1985, with interruptions for his vocational baccalaureate and studies. Since 1995, he has had a management position, becoming a master in 1998. He has been a licensed pilot in the Weser II / Jade pilotage area since 2002.

The third officer began his seafaring career as a cadet with Maersk in 2016. He served as an officer for the first time in 2019. His regular service on board began in Wilhelmshaven in November 2021; it was his first time on the MUMBAI MAERSK. He had completed a previous assignment on a sister ship.

3.2.5 Weather and environmental conditions [48]

The prevailing meteorological conditions were wintry, but not extreme during the night of 02-03/02/2022. The air temperature was 5 °C. The flood tide stream, which had set in at about 2000 and reached a maximum speed of 1 m/s at about 2215, was setting in an easterly to north-easterly direction when the accident happened. By 2315, it had decreased only slightly to 0.7-0.9 m/s.

There was a moderate south-westerly breeze of 4 Bft. Visibility stood at about 20 km, and the water level at the time of the accident, shortly before the next high tide at 0116 on 03/2/2022, was about 3.5 m above chart datum. In the fairway before the entrance

[48] Source: Federal Maritime and Hydrographic Agency (BSH), currents off Wangerooge/Spiekeroog on 02/02/2022 between 2015 and 2315 local time (CET), 17/02/2022.

to the Neue Weser, this corresponded to an actual water depth of 17.5–19 m. The water depth at the shallowest point of the dumping ground was about 8.0 m.

3.2.6 Voyage planning

3.2.6.1 Basic principles and requirements

Chapter V Regulation 34 of the SOLAS Convention[49] states that a voyage must be planned in accordance with the IMO Guidelines for Voyage Planning (Resolution A.893(21)). Moreover, those recognised procedures in the maritime industry that are acknowledged as best practices are also described in the current 'Bridge Procedures Guide' of the International Chamber of Shipping (ICS).

Further references:

- STCW Code[50], Part A, Chapter VIII, Section A-VIII/2, Part 2;
- IMO Resolution MSC.232(82) – Revised Performance Standards for Electronic Chart Display and Information Systems (ECDIS)
- IMO MSC.1/Circ.1503/Rev.1 – ECDIS – Guidance for Good Practice

Generally speaking, voyage planning is divided into four phases: appraisal (evaluation, gathering of information), planning (planning of the voyage), execution, and monitoring.

The ship operator's safety management system (SMS) contains various procedural instructions that are relevant to voyage planning, including:

- P019 – Passage Planning
- Form 203 Checklist – Passage Planning
- P021 – ECDIS
- A021a – ECDIS Safety Settings Quick Reference Guide
- P033 – Under Keel Clearance and Squat

3.2.6.2 Voyage Appraisal & Planning – before the voyage

The second officer – referred to below as VPO (voyage planning officer) – planned the voyage from Rotterdam to Bremerhaven on 01/02/2022. The following sources were consulted for the appraisal according to the passage plan[51]:

- up-to-date charts of appropriate scale;
- various books and tables (including the ICS Bridge Procedures Guide and Chapter VIII of the STCW Code), as well as general navigational publications

[49] SOLAS: International Convention for the Safety of Life at Sea.

[50] STCW Code: Seafarers' Training, Certification and Watchkeeping Code.

[51] Passage Plan: Comprehensive navigation plan that fully outlines a ship's voyage, for safe navigation of the ship from berth to berth.

of the ADMIRALTY (UK Hydrographic Office; NP100, NP136-1, NP231, NP294, NP314, NP735, NP5012));

– relevant local regulations (not specified in further detail);

– Sailing directions
    - e-NP28 Dover Strait Pilot (13th ed.)
        - Chapter 9 'Approaches to Hoek van Holland and Hoek van Holland to the Rhine',
    - e-NP55 North Sea (East) Pilot (12th ed.)
        - Chapter 2 'Offshore waters including deep-water through routes',
        - Chapter 4 'Texel to the German Bight',
        - Chapter 6 'The Jade and the Weser',

– ADMIRALTY Digital Radio Signals,

– ADMIRALTY Digital List of Lights,

– ADMIRALTY TotalTide.

In addition, the last page of the passage plan lists what should be marked on the (electronic) navigational chart, if it enhances safe navigation:

The following should be marked on the chart, where it enhances safe navigation:

- Parallel indexing (not from floating objects unless they have been first checked for position)
- Chart changes
- Methods and frequency of position fixing
- Last position from previous chart carried forward to next chart
- Prominent navigation and radar marks
- No-go areas (the excessive marking of no-go areas should be discouraged - see below)
- Landfall targets and lights
- Clearing lines and bearings
- Transits, heading marks and leading lines
- Significant tides or current
- Safe speed and necessary speed alterations
- Changes in machinery status
- Minimum under keel clearance
- Positions where the echo sounder should be activated
- Crossing and high density traffic areas
- Safe distance off
- Anchor clearance
- Contingency plans, emergency anchoring positions
- Abort positions
- VTS and reporting points, etc.

Figure 25: Notes on marking special information on the navigational chart[52]

[52] Source: Passage plan of the MUMBAI MAERSK for the voyage from Rotterdam to Bremerhaven, 05/02/2024.

The following additional guidance is provided:

"Charted passage planning information should not obscure printed details, nor should information on charts be obliterated by the use of highlight or felt-tip pen, red pencil, etc. No-go areas[53] should be highlighted, but should be reserved for those areas where the attention of the navigator needs to be drawn to a danger such as shallow water or a wreck close to the course line. Extensive use of no-go areas should be discouraged. No-go areas vary with change of draught and tide and will therefore also vary with the time of passage. They should not therefore be permanently marked. All previous courses to the one in use should have been erased."

The passage plan that the ship operator provided for the BSU does not contain any information as to which contour line or alarm management settings should be used in the ECDIS (see Annex 9) for specific sections of the route. The ECDIS is the primary navigation instrument on board the MUMBAI MAERSK. Paper charts are not used. However, internal SMS procedural instruction P021 – ECDIS specifies which safety settings are to be made:

Confined waters

Shallow Contour	=	Deepest draft
Safety Contour	=	**Deepest Draft + Squat + UKC – Tide***
Safety Depth	=	Safety Contour
Deep Contour	=	**2 x Deepest draft**

Deep sea waters

Shallow Contour	=	Deepest draft
Safety Contour	=	Deepest Draft + Squat + UKC
Safety Depth	=	Safety Contour
Deep Contour	=	100 M

Figure 26: ECDIS contour settings according to P021[54]

SMS document A021a – ECDIS Safety Settings Quick Reference Guide also recommends that the shallow contour should not be displayed on the same depth contour as the safety contour, but that the next shallower depth contour is to be selected, if possible. Furthermore, if it is necessary to cross the safety contour, then all unsafe depths along the route must be marked as no-go areas.

The settings for contour lines (Shallow Contour, Safety Contour, Deep Contour) and Safety Depth, as listed in Table 1 (Chapter 3.2.7.2), were applied but not adjusted when entering shallower waters. The investigation team could observe these values from the VDR data, but they were not recorded in the passage plan.

The planned route from Rotterdam to Bremerhaven ran via the German Bight Western Approach traffic separation scheme (TSS) and the Jade Approach TSS, where the pilot was scheduled to embark in the northern third of the southbound traffic lane. A safety

[53] No-go-area: An area not navigable by the ship in question.

[54] Source: MAERSK SME Department, MAERSK SMS: 'P021 – ECDIS'. UKC (under keel clearance) indicates the UKC_{min} required according to the SMS. Information as of 26/06/2021.

corridor (see Annexes, p. 118) with a width of 1 nm (0.5 nm on each side of the route) was planned up to waypoint 18, the eastern end of the German Bight Western Approach TSS (width of the traffic lane: 2 nm). No safety corridor was set between this waypoint and the berth in Bremerhaven for the remainder of the voyage via the Jade Approach TSS. The route continued in a southerly direction, crossing the entrance of the northern, westbound lane and the exit of the southern, eastbound lane of the Terschelling German Bight TSS. An east-south-easterly course was then plotted toward the Neue Weser. In the approach to the Neue Weser fairway, water depths of less than 20 m prevailed after buoys 2a and 4, meaning the MUMBAI MAERSK had to pass the 20 m depth contour, designated as a safety contour. The procedure described as Method 1 in the NP232 Admiralty Guide to ECDIS Implementation, Policy and Procedures was selected. In contrast to Method 2, the safety contour is not reduced, but rather left at the previously calculated value and consciously crossed. In the process, the depths highlighted in black and white, which are below safety depth, are designated as no-go areas along the entire route within the safety contour. In NACOS Platinum, own safety lines (see Annexes, p. 118) should connect the next lower depth soundings (shown in light grey), taking into account the quality and reliability of the chart information for that area (CATZOC[55]), and thus enclose all shallow depths on the hatched side of the own safety line.

Within the safety contour, both own safety lines and red-hatched areas were used as symbols to mark no-go areas (see Figure 27). In addition to the user symbols relevant to the current voyage to Bremerhaven, the user symbols for the Jade were also visible during the voyage.

The right side of Figure 27 shows that the own safety lines delimiting the safe fairway are both oriented in the same direction – the hatching of both lines points downward, meaning the look-ahead sector (see Annexes, p. 118) would not generate an alarm if the own safety line were touched, even if the corresponding alarm was enabled. Moreover, the own safety lines do not encompass all unsafe depths, but are restricted to the Neue Weser fairway from buoy pair 3a/4a and parts of the Wangerooge fairway. Additional own safety lines were plotted around various buoys within both TSS – also with the hatched side of the line on the safe side, rather than the unsafe side.

[55] CATZOC: The ‘Category Zone of Confidence’ indicates the accuracy with which information on depths or positions (e.g., water depths, shallow-water areas, wreck positions, etc.) is shown in a navigational chart section and/or can be relied upon when used (categories A-D). Depending on the category, an increasing tolerance must be added to the information in order to navigate safely in the area.

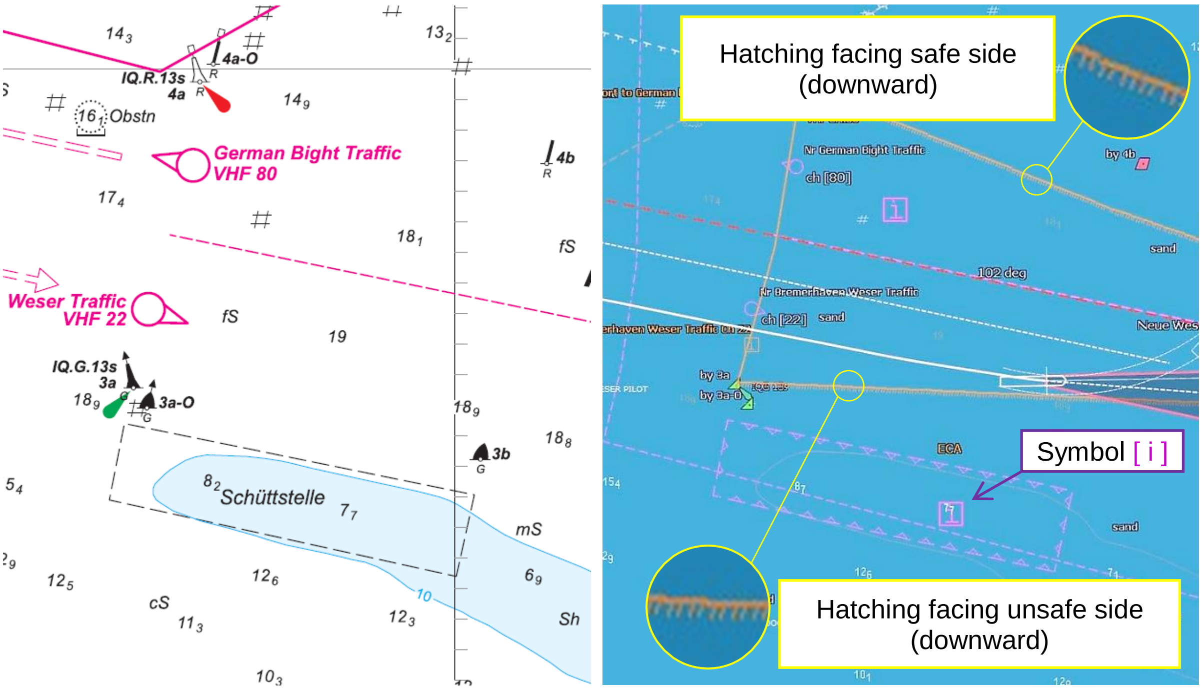

Figure 27: Image showing the dumping ground on the navigational chart (paper versus ECDIS on the MUMBAI MAERSK)[56, 57]

Figure 27 above also shows that the dumping ground is difficult to identify on the (electronic) navigational chart with the ECDIS settings that were active on board the MUMBAI MAERSK. The 10 m depth contour is not part of the highlighted contour lines and, as opposed to the paper chart, the dumping ground is not labelled, but rather marked with an [i] symbol. In order to obtain more information about this area, a so-called pick report[58] would need to be called up by right-clicking with the mouse.

Figure 28 below shows the dumping ground – on the left at a zoom level of 1.5 nm and on the right at 3 nm – but with the Shallow Contour set to the 10-meter depth contour, as recommended in SMS Document A021a. The shallower areas of the sandbank, at the tip of which the dumping ground is located near buoys 3a and 3a-O, are more clearly visible.

56 Source left: Federal Maritime and Hydrographic Agency, Navigational Chart 1230 (detail), 2022.

57 Source right: VDR of the MUMBAI MAERSK, ECDIS screenshots at various times. MFD 04, ECDIS mode, 212737 UTC (night mode, range 1.5 nm); brightened by the BSU for better clarity in this report.

58 Pick report: Context menu which is accessible by right-clicking with the mouse and provides additional information on objects on an electronic navigational chart that are not visible with the current ECDIS setting.

Figure 28: Dumping ground in the ECDIS (BSH system lab) with Shallow Contour set at 10 m[59]

All items in SMS Document 203 – Passage Plan Checklist – were ticked 'Yes' for the voyage from Rotterdam to Bremerhaven and provided with explanations, including 'Abort positions (no way of return positions) marked' with the note 'MARKED ON ECDIS'. During the BSU's on-board visit on 05/02/2022, a corresponding user symbol (text annotation) was visible on the ECDIS shortly after waypoint 20 (see Figure 28). However, the recordings on the VDR do not show this user symbol, which indicates that the corresponding list of user symbols, if already created at the time of the accident, was not being displayed.

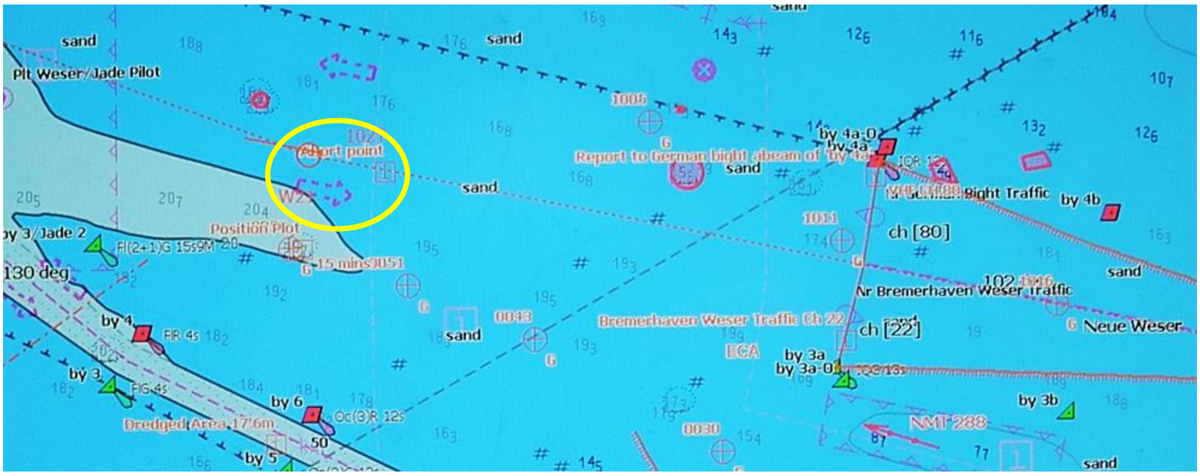

Figure 29: ECDIS screenshot of 05/02/2022 – 'Abort point' visible[60]

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59 Source: BSU, ECDIS in day mode; left: range 1.5 nm (overscaled x1.1), right: range 3 nm.

60 Source: BSU, own image taken on the day of the on-board visit, 05/02/2022.

3.2.7 Voyage Execution & Monitoring – during the voyage

3.2.7.1 Basic principles and requirements

International and national regulations

- STCW Code,
    - Part A 'Mandatory Standards Regarding Provisions of the Annex to the STCW Convention',
        - Chapter II 'Standards Regarding the Master and Deck Department', Section A-II / 1 'Mandatory Minimum Requirements for Certification of Officers in Charge of a Navigational Watch on Ships of 500 Gross Tonnage or More', Section A-II / 2 'Mandatory Minimum Requirements for Certification of Masters and Chief Mates on Ships of 500 Gross Tonnage or More',
        - Chapter VIII 'Standards Regarding Watchkeeping', Section A-VIII / 2 'Watchkeeping Arrangements and Principles to be Observed' – Part 3 'Watchkeeping Principles in General', Part 4-1 "Principles to be Observed in Keeping a Navigational Watch";
- SOLAS,
    - Chapter V „Safety of Navigation",
        - Regulation 27 'Nautical Charts and Nautical Publications',
        - Regulation 34 'Safe Navigation and Avoidance of Dangerous Situations',
        - Regulation 34-1 'Master's discretion';
- COLREGs [61];
- IMO Resolution A.893(21) "Guidelines for Voyage Planning";
- German Traffic Regulations for Navigable Maritime Waterways (SeeSchStrO).

Additional requirements of the ship operator

- SMS, including
    - P021 – ECDIS,
    - A021a – ECDIS Safety Settings Quick Reference Guide,
    - P022 – Arrival / Departure Preparations,
    - P033 – Under Keel Clearance and Squat,
    - P035 – Navigating under Normal Circumstances,
    - P036 – Safe Distance from Shore,

[61] Internationale Regeln von 1972 zur Verhütung von Zusammenstößen auf See.

  - P070 – Look-out,
  - P081 – Bridge Team Management,
  - P096 – Navigation with Pilot on Board,
  - P154 – Navigation in Confined Waters,
  - P235 – Steering Gear and Auto Pilot,
  - P449 – Watchkeeping - Change of Watch,
  - P680 – Navigation in German Bight;
- BRM training within the company.

3.2.7.2 Using the integrated navigation system

A NACOS Platinum advanced integrated navigation system[62] from Wärtsilä SAM Electronics GmbH is installed on board the MUMBAI MAERSK. It combines several applications, including radar, ECDIS, conning, AIS, automation and VDR. Depending on the configuration, it is possible to switch between different applications at the workstation screens, the so-called multi-function displays (MFDs). The system also makes it possible to display the radar image as an overlay or the electronic navigational chart as an underlay in both radar and ECDIS modes.

On the day of the accident, the MUMBAI MAERSK's NACOS Platinum system was operating with software version 2.1.03.33. Both the navigational charts and the chart display on the ECDIS were up-to-date.

Various settings, which must be adjusted according to the static and dynamic data of the ship, are essential for safe navigation when using the ECDIS as the primary navigation instrument. These settings influence the display of the chart and individually configured user information, as well as the alarm management. Depending on the section of the voyage, some of the settings must be adapted to the navigated sea area and the status of the ship (e.g., draught, speed, manning of the bridge). A selection of those parameters to be set during the voyage, and those which were considered in the course of this investigation, is described in the Annex (Section 9).

The pilot and the master each had an ECDIS and a radar display with individual setting options at their disposal on the main console – MFD 01 and MFD 05 on the port side, and MFD 04 and MFD 02 on the starboard side. Although the conning display was active in the middle of the main console, its settings at the time of the accident cannot be traced, as the conning display is not part of the VDR recordings. The pilot used his Portable Pilot Unit (PPU) throughout the entire advisory process.

[62] An integrated navigation system can display all integrated applications on any screen (without the need for dedicated radar screens, for example).

The settings listed in Table 1 were made on the MFDs at or after 2109 (after crossing the German Bight TSS – passage of the line between buoys TG 7/Weser 1 and TG 9/Weser 2) and were not changed up until the grounding at 2306, unless otherwise stated:

Table 1: Settings on the ECDIS MFDs of the main console

Setting	**ECDIS master (MFD-04)**	**ECDIS pilot (MFD-05)**	**Radar master (MFD-02)**	**Radar pilot (MFD-01)**
Range	3 nm (≈1:45.000[63])	6 nm	6 nm	12 nm
	from 2212 1,5 nm (≈1:22.000) (overscale x1,3)	from 2124 3 nm	from 2121 3 nm	from 2134 3 nm
	from 2254 0,75 nm (≈1:12.000) (overscale x2,5)		from 2234 1,5 nm	from 2233 1,5 nm
	from 2255 1,5 nm			from 2249 3 nm
Shallow Contour	20 m (input value: 13 m)			
Safety Contour	20 m (input value: 16 m)			
Safety Depth	16 m			
Deep Contour	30 m (input value: 26 m)			
Isolated dangers	Shallow Water Danger: On Shallow Water Pattern: Off	Off Off	Off Off	Off Off
Display category	All (all available information is displayed without exception) In addition: - Light Descriptions - Full Length Light Sectors - Show Names of Objects	All (–) In addition: - Light Descriptions - Show Names of Objects - Highlight Info	All (–) In addition: /	Standard In addition: /
Chart symbols	Symbols: Simplified Areas: Symbolised			
User symbols	visible			Not visible
	Both lines of the text annotations		One line of text	
ECDIS alerts	Crossing Safety Contour: Off Navigation Hazard Ahead: Off	Off Off	Off Off	Off Off

63 Source: International Hydrographic Organisation (IHO), S-57 APPENDIX B.1 – Annex A – Use of the Object Catalogue for ENC. Edition 4.1.0, p. 22. 2018.

	Crossing Special Area: Off	Off	Off	Off
	Look-Ahead Sector: Length: 1 nm / 6 min, Width: 500 m Show on Chart: Off	Off	Off	Off
ECDIS hazards	Show Crossing Safety Contour on Chart: On	Off	Off	Off
	Show Navigation Hazards Ahead on Chart: Off	Off	Off	Off
	Show Crossing Special Areas on Chart: Off	Off	Off	Off
Vectors & trails	Reference: Ground[64] Vector: 12 min (T) Trails: / Prediction: 360 s	Ground 6 min (T) / 360 s	Water[65] 12 min (T) 6 min (T) 360 s	Water 12 min (T) 3 min (T) 360 s

The MFDs in ECDIS mode were used exclusively for displaying the electronic navigational chart and AIS information (Sleeping: All AIS), not for the additional display of a radar overlay. The electronic navigational chart was displayed as an underlay on the MFDs in radar mode.

In the 'All (–)' display category (MFDs 02 and 05), it is not immediately clear which chart information has been hidden without calling up a menu. Information from the 'Standard' category can also be hidden.

Figure 29 and Figure 30 show the effects of the settings listed in Table 1 regarding the presentation of information on the radar and ECDIS displays. As can be seen in the images, the radar echoes of the aids to navigation in the pilotage area were sometimes extremely weak, or not recognisable at all. This is because both radar displays were using the same S-band radar, and anti-clutter sea was left unchanged at approximately 25-30 %. Contrary to the master's own instructions at the “Bridge Discipline Meeting” on 13/11/2021, an X-band radar was not used.

Neither the master's ECDIS display nor that of the pilot was oriented on the ship's current position all the time. Unlike in true and relative motion modes, it is possible to view a chart section independently and at a distance from the ship's own position in browse mode, which is really intended for route planning, however. The master made use of this option for the first time at 2116 to obtain a picture of the situation in port, but then immediately centred the chart back on his own ship's position. He then spent

64 Ground stabilised: Vectors and trails are computed on the basis of the speed over ground (bottom track) → for navigation

65 Water stabilised: Vectors and trails are computed on the basis of the speed through water (water track) → for collision avoidance.

some 42 minutes in total with the ECDIS display on the port view between 2153 and 2249. The pilot's ECDIS was also in browse mode for an extended period of time, and not operated (because the pilot mainly uses his own PPU and does not interfere with the settings made on board, as he stated himself). This resulted in the ship exiting the displayed chart section at 2112. More an hour later, at 2224, the system was switched back to relative motion mode, making the ship's own position visible again.

From 2155 (71 minutes before she ran aground), the MUMBAI MAERSK remained continuously within the safety contour, which was set at the 20 m depth contour. VDR data show that the 'Crossing safety contour alarm' ECDIS alert was not enabled, meaning there was no audible alarm. However, the 'Show crossing safety contour on chart' ECDIS hazard was enabled only on the master's ECDIS display (MFD 04), meaning that the look-ahead sector was continuously highlighted in red on the ECDIS display after crossing the safety contour. The ECDIS hazard and alert settings were not changed after crossing the safety contour (see Table 1).

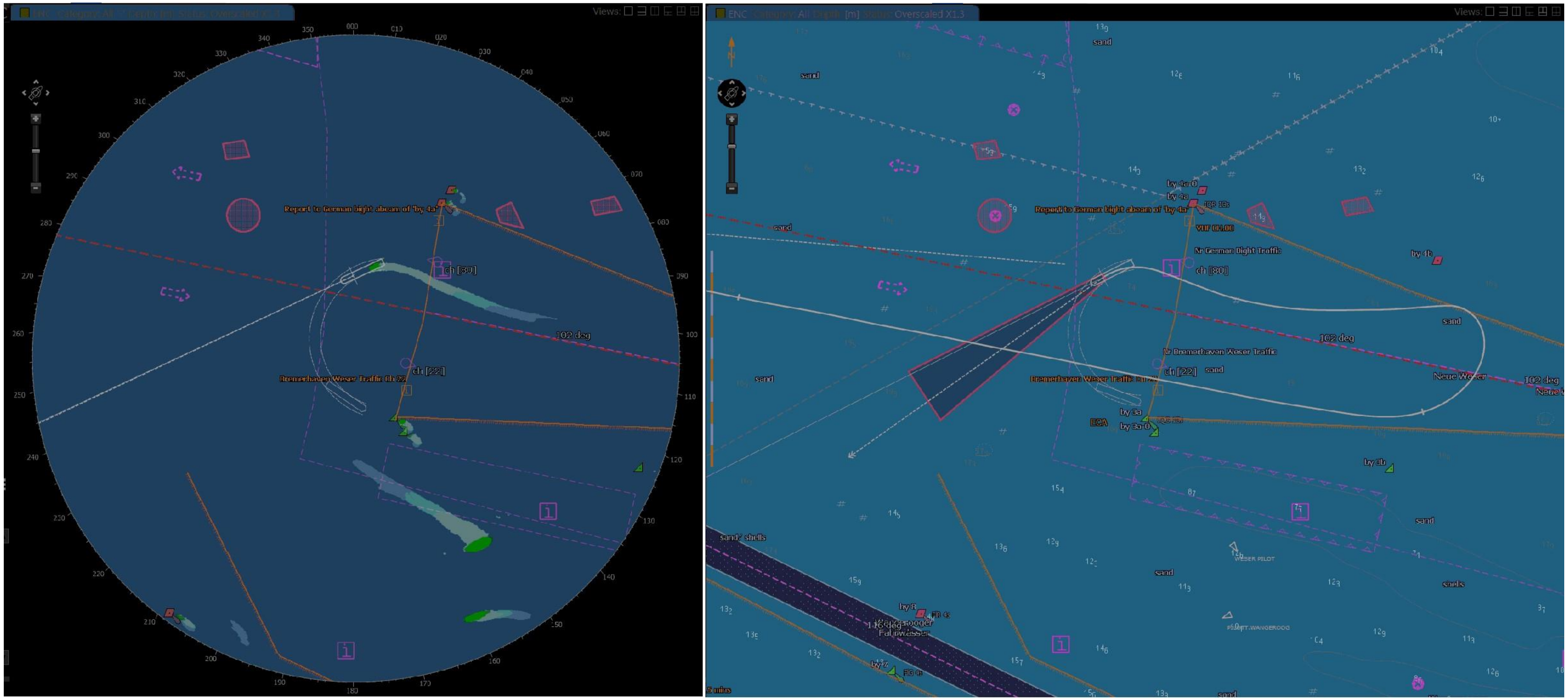

Figure 30: The master's radar and ECDIS display (MFDs 02 and 04) at 2256[66]

[66] Source: VDR of the MUMBAI MAERSK, screenshots of the radar and ECDIS at various times, brightness unchanged.

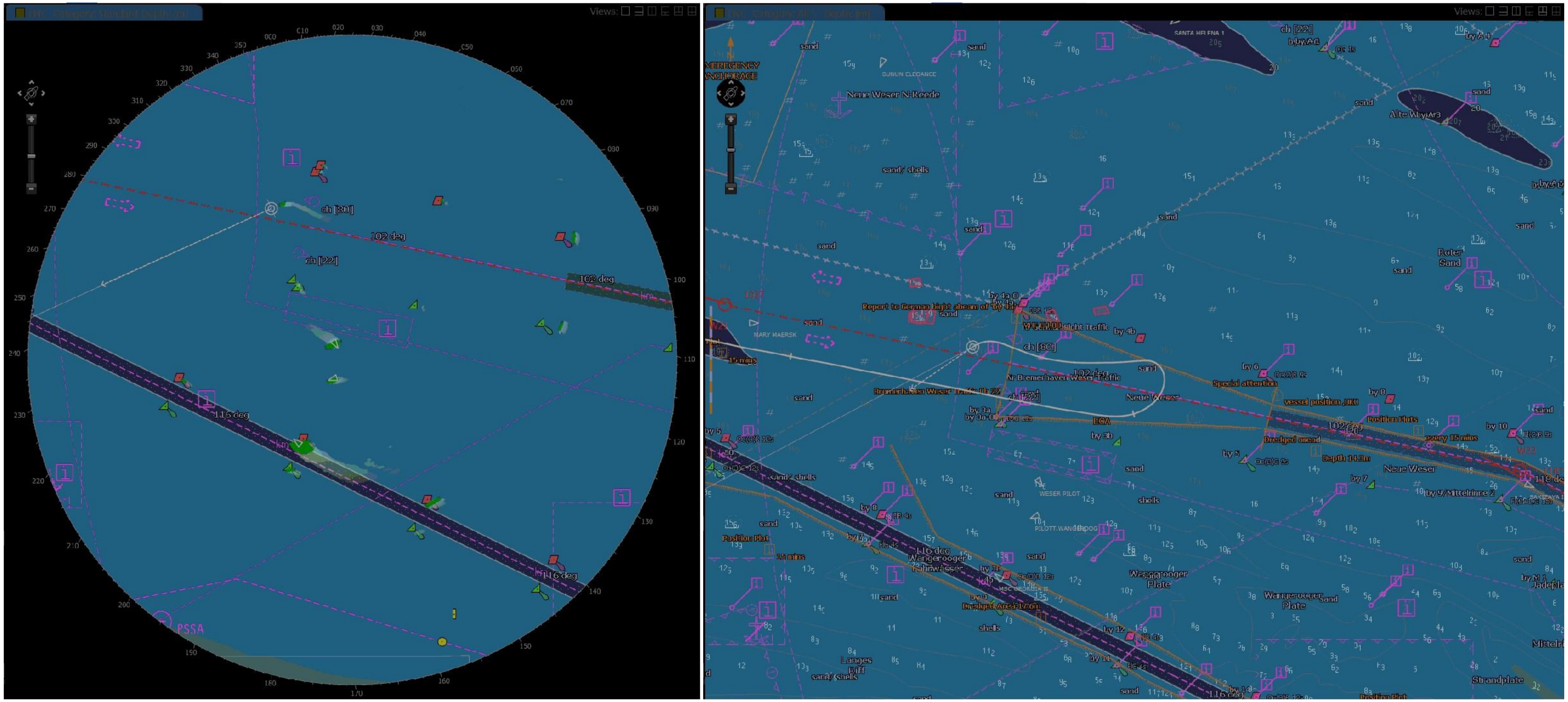

Figure 31: The pilot's radar and ECDIS display (MFDs 01 and 05) at 2256[67]

[67] Source: VDR of the MUMBAI MAERSK, screenshots of the radar and ECDIS at various times, brightness unchanged.

3.2.7.3 Master / Pilot Information Exchange (MPX)

"Each pilotage assignment should begin with an exchange of information between the master and the pilot. This exchange is a prelude to a successful passage under pilotage and is a key component of effective BRM during the passage."[68]

A helicopter winched down the pilot onto the MUMBAI MAERSK at 2018 in the southern part of the Jade Approach TSS, and he arrived on the bridge shortly afterwards. The MPX (until about 2030) covered the following points:

- MUMBAI MAERSK is scheduled to enter before MARY MAERSK;
- ETA[69] at buoy pair 3/4 (entry into the dredged Neue Weser fairway) at 2130;
- CMA CGM LAMARTINE and MAERSK KANSAS must have cast off from their berths before the MUMBAI MAERSK is permitted to enter the fairway;
- ETA at standby position in Bremerhaven is 2330;
- speed increase to about 12 kts;
- MUMBAI MAERSK's draught is a good 13 m, and
- crew is steering the ship using autopilot.

3.2.7.4 Task distribution and collaboration

The master was already on the bridge at the start of the available VDR recordings at 1900. According to the logbook, he assumed command of the ship from the third officer, who was on watch, at 2010 for the approach to Bremerhaven. An explicit handover, as required in various instructions of the ship operator and the master, could not be heard in the audio recordings from the VDR.

The third officer and the AB on watch (8-12 watch) collected the pilot from the compass deck shortly after. Meanwhile, the master was alone on the bridge for a few minutes. He then acted as navigator and implemented the pilot's recommendations regarding the speed of the ship and courses to be steered. The AB acted as lookout for most of the time, and from 2226, during the first turn between buoy pair 3b/4b, he steered by hand until autopilot was engaged again at 2238. Manual steering was also used for the second turn at 2251. The third officer acted as co-navigator and lookout but was hardly involved in the communication until shortly before the grounding. The pilot took charge of external communication and, together with the master, also acted as navigator for much of the time.

The pilot handled external communications, which the captain monitored. Throughout the voyage, the situation changed several times: at some points, the captain had the

[68] Source: International Maritime Pilots' Association (IMPA), 'IMPA Guidance on the Master-Pilot Exchange (MPX)', retrieved 14/04/2023.

[69] ETA: estimated time of arrival.

conning[70], while at others, the pilot took over. No explicit agreements were made regarding these transitions.

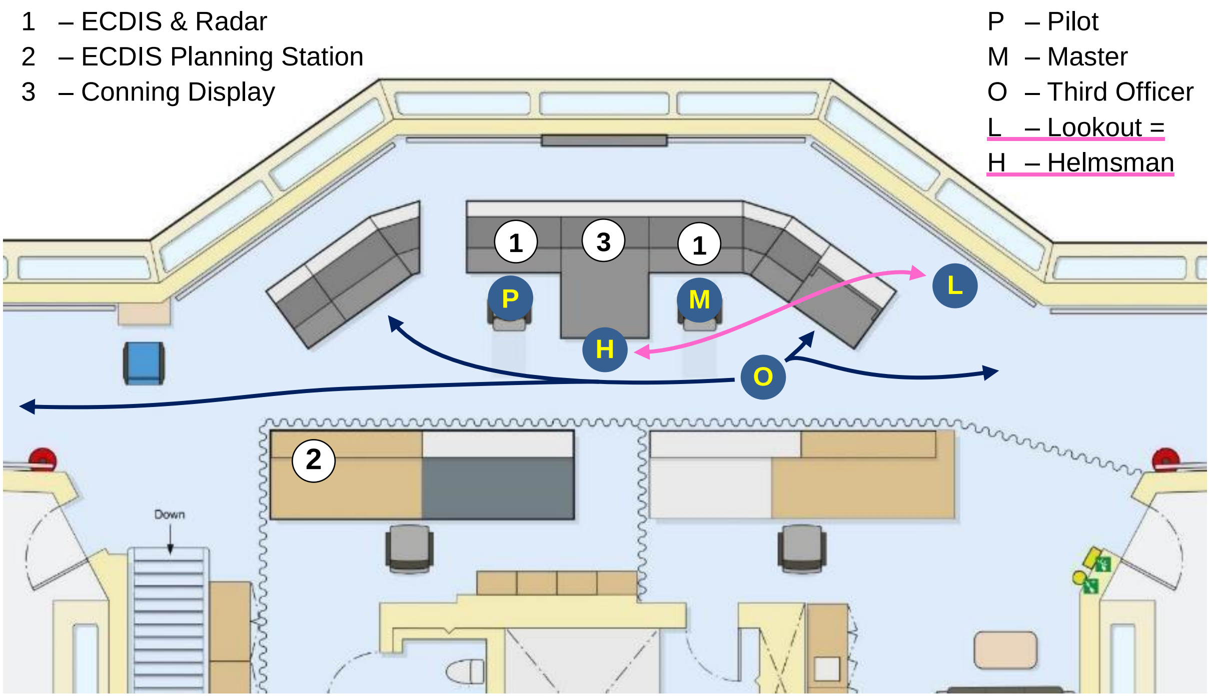

Figure 32: Bridge layout, equipment and manning[71]

The pilot communicated with the bridge team in English and with the following bodies in German:

- German Bight Traffic (VTS)
- Bremerhaven Weser Traffic (VTS)
- Alte Weser Radar (radar advisor)
- Pilot station ship WESER
- Bremerhaven Port (Port Operations Office)
- Pilots on the following ships:
    - MARY MAERSK
    - CMA CGM LAMARTINE
    - SAKIZAYA INTEGRITY

[70] 'to con': to steer, command, or supervise the navigation of a vessel; 'conning': directing a vessel by issuing commands to the helmsman. (Source for both: Dluhy and Fabarius, Schiffstechnisches Wörterbuch, Volume 2, English-German).

[71] MAERSK Line A/S, MUMBAI MAERSK Deck Operating Manual, Illustration 7.1a, Bridge Layout, Issue 1, 2019. Edited by the BSU.

- MAERSK KANSAS
- MSC GEORGIA II

3.2.7.5 Alteration of the passage plan before entering the Neue Weser fairway

It had already been discussed during the MPX that the MUMBAI MAERSK was dependent on the timely departure of two other ships (CMA CGM LAMARTINE, MAERSK KANSAS) for entry into the Neue Weser fairway (see Chapter 3.2.7.3). At about 2130, the information concerning the CMA CGM LAMARTINE's loss of an anchor already pointed to a delay, and as time went on it became increasingly likely that it would not be possible to enter the fairway as planned due to the lack of reports from the MAERSK KANSAS, and the CMA CGM LAMARTINE's winch problems. The speed was reduced to a minimum.

From about 2145 there was an increase in external communication about the situation in port concerning the delays of the CMA CGM LAMARTINE and the MAERSK KANSAS. In addition to communicating by VHF radio, the MUMBAI MAERSK's pilot also called various colleagues on other ships by mobile phone. As the passage progressed, the time required for external communication increased steadily and, as the PNR[72] approached, so did the time pressure and need for up-to-date information. The MUMBAI MAERSK's Danish master evidently understood most of the pilot's communication in German with the various external bodies. The pilot verified this, multiple times. However, the information was not always communicated in detail to the Indian third officer, who was acting as co-navigator.

At 2200, the option of turning back out of the pilotage area was discussed for the first time during a conversation with the VTS, and the pilot and master subsequently agreed to continue towards the PNR with the current heading. The team did not discuss exactly where the PNR would be for a ship the size of the MUMBAI MAERSK, and how they should proceed after a possible turning manoeuvre. At this point, the pilot had no doubts that the turn could be completed within the buoy lines. The MUMBAI MAERSK was still some 2 nm off buoy pair 3a/4a and sailing at a speed over ground (SOG) of 6.4 kts, about 0.3 nm south of the planned route on the radar reference line in the middle of the fairway. The pilot clearly communicated to the master that they would not be permitted to enter the Neue Weser fairway until the pier was clear. The master relayed this information to the third officer.

At 2204, VTS and pilot agreed that course and speed should be maintained for the time being. The captain monitored the VHF communications. Initially, a turn was not planned. The pilot stated that the PNR was at buoy pair 5/6. This information was not shared in English with the rest of the bridge team. However, this pushed the PNR further back, as the ship was permitted to enter the fairway behind buoy pair 3a/4a.

[72] PNR: Point of no return (point at which it is no longer possible to turn around).

Again, there were no discussions about the next steps or planned manoeuvres (position where manoeuvre is initiated[73], turning circle, speed, possible route after the turn, etc.). According to the pilot, the reason for this was that no turn was planned at that point.

At 2221, the pilot issued an instruction for the course to be altered to 5° port. This brought the MUMBAI MAERSK closer to the middle of the fairway after passing buoy pair 3a/4a. The helmsman carried out the course alteration.

At 22:23, AWR announced that the LAMARTINE was "afloat". Shortly after, the pilot spoke with VTS. When asked where else the MUMBAI might be able to turn, he said that there might already be difficulties at the current position (between buoy pairs 3a/4a and 3b/4b). In an emergency, a turn would still be possible further upstream at Bremer Kreuz or Hoheweg Reede.

The captain monitored the radio exchange. Following this, he and the pilot again discussed the other vessels in the fairway, the issues causing delays, and possible time windows for entering port later in the voyage.

Master and pilot agreed that the PNR had been reached before the ship entered the narrower, dredged part of the Neue Weser fairway. While the pilot was still sharing his thoughts on how to proceed in the case of a port manoeuvre, the master switched off the autopilot and the helm was put to hard to port (36°) at 2226.

During the turn, the ECDIS-prediction caused doubts as to whether it would be possible to turn within the buoy line or whether there would be a dangerous close-quarters situation with buoy 4b. An alternative plan to keep the buoy to port was mentioned to the radar advisor. The pilot then also mentioned this option to the master. A plan for such a manoeuvre was not formulated. Moreover, the fact that there were water depths of less than the safety depth and manually plotted no-go areas behind the buoy was not addressed, either. The ship was ultimately turned safely within the buoy line with a distance to buoy 4b of about 0.21 nm. The course alteration was more than 180° – from an original course over ground (COG) of 099° to 265° – and the manoeuvre required approximately 0.6 nm of space.

During the turn, at 2234, the pilot contacted the Port Operations Office and then spoke with the radar advisor shortly afterwards. Since the MUMBAI MAERSK was still to enter before the MARY MAERSK, another turn became a possible option. The planned course after the turning manoeuvre within the buoy line was not discussed within the bridge team – this course may well have deviated from the track-defined route, depending on the position after the turn. At 2237, the pilot inquired about the bow

[73] So-called “wheel-over point”: position at which a ship must initiate a course alteration in order to safely move to the intended new route or remain on a planned route.

thruster. He also exchanged information with the captain regarding nearby vessels. They agreed that they should initially maintain the reduced speed, wait until the MAERSK KANSAS had set off and the LAMARTINE was at the 'Robbennordsteert' in the Neue Weser, before starting to turn back. The third officer asked whether the speed could be reduced, to which the pilot agreed. At the beginning of this conversation, at 2237, the HDG was 294° (equivalent to 297° COG). The current ROT[74] stood at 18.3°/min. During the conversation, at 223806, the helm was put to amidships. At this point, the HDG stood at 276° (equivalent to 273° COG).

The turn was stabilised as the ship's HDG was at 271° (equivalent to 266° COG) and the vessel was approaching the middle of the fairway again. The autopilot was then engaged. Immediately after switching back to autopilot, at 2239, the pilot corrected the course steered (HDG) by 5° starboard to 275°, which corresponded to a COG of about 268°. The MUMBAI MAERSK thus approached the radar reference line in the middle of the fairway again. At this point, there was still no specific plan for a further course of action. However, the option to turn again back and enter, as soon as the pier became available, remained open.

In the following minutes (2241–2249), the pilot first spoke to the pilot of the MARY MAERSK, then with the VTS, and later with the pilots of the MARY MAERSK and the MSC GEORGIA II. Meanwhile, after a consultation between the master and the third officer, the HDG was revised by a further 5° starboard to 280° (radius: 1 nm) without any audible input from the pilot. At this point, and subsequently until 2249, the master's ECDIS was centred on the port, and neither water depths nor isolated danger areas (isolated/shallow water dangers) were shown on the radar screen's chart underlay. The pilot's solidifying plan to turn around again – the CMA CGM LAMARTINE was underway and the MAERSK KANSAS had half-completed her turn by 2246 – was not clearly communicated to the bridge team in English. The pilot informed the MARY MAERSK and MSC GEORGIA II about the planned manoeuvre. His statement was: "[…] I will go further north in a moment, under the Neue Weser Reede Nord, and then turn over port."

The new HDG of 280° was reached at 2249 (equivalent to approximately 276° COG). Following the external calls, the pilot issued instructions for the engine telegraph to be set to half ahead and the HDG to be altered by a further 10° starboard to 290°.He explained the situation regarding the MSC GEORGIA II to the master. Meanwhile, the MUMBAI MAERSK continued to approach the middle of the fairway up to about 0.12 nm. From around 2251, the distance to the radar line gradually increased. In a conversation with the VTS, the pilot once again confirmed that the MUMBAI MAERSK was to enter before the approaching MARY MAERSK. According to the Federal Waterways and Shipping Agency (GDWS), this information originated from the Port

[74] ROT: rate of turn.

Operations Office (POO). The pilot made certain that the captain had understood the exchange with VTS, which the captain confirmed. Further explanations regarding the traffic sequence followed.

At 2253, the pilot re-established contact with the radar advisor, informing him of the agreed plan to turn over port and come to a reciprocal course. He added that he needed to complete the turn before the MARY MAERSK, in order to maintain the planned entry sequence.

During a conversation with a colleague, referring to the constant need to gather information himself, the pilot remarked: "I wish I had three hands today."

During the autopilot course alteration to 290°, the lookout was ordered back to the helm by the pilot. At 2253, the new HDG was 290° (equivalent to approximately 290° COG; SOG = STW[75] = 8.0 kts). The master viewed the MARY MAERSK's AIS data and informed the pilot of her SOG of 11 kts.

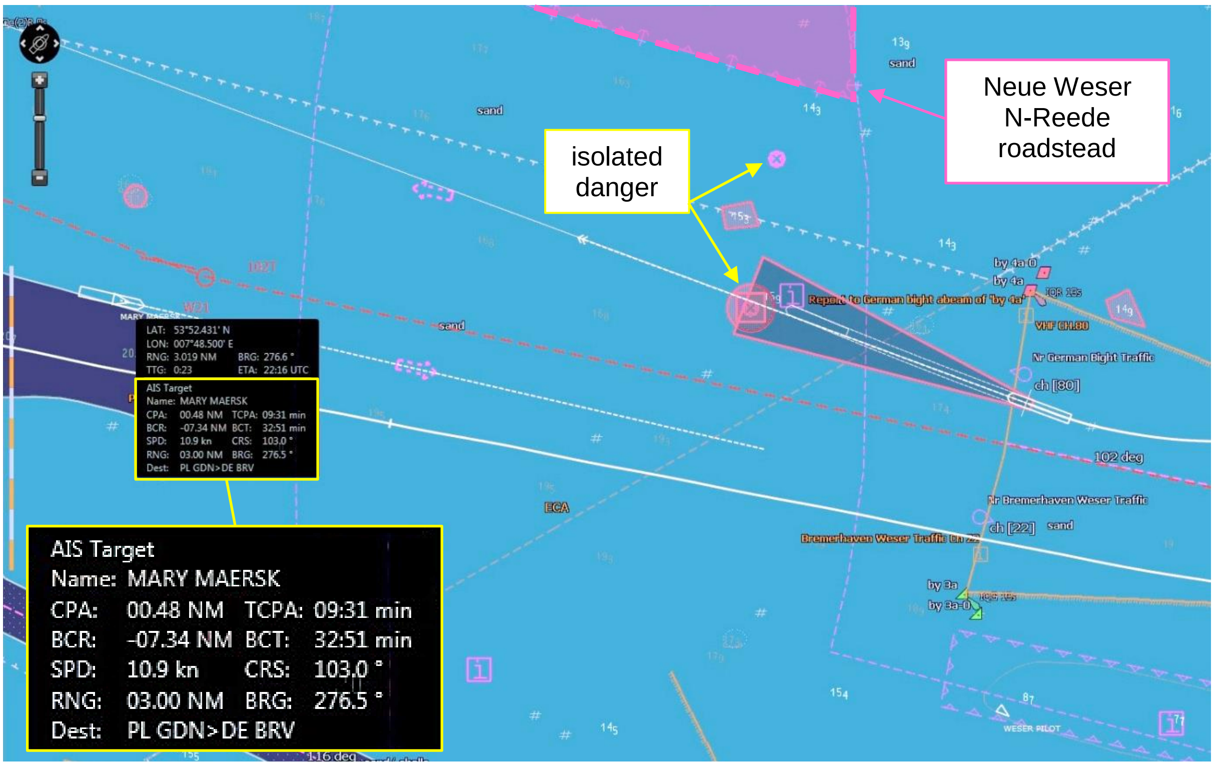

Figure 33: The master's ECDIS display (MFD 04) at 225337[76]

[75] STW: speed through the water.

[76] Source: VDR of the MUMBAI MAERSK, ECDIS screenshot at various times. Brightened for better clarity in this report, as well as comments and highlighting of the roadstead by the BSU.

3.2.7.6 Second reciprocal-course manoeuvre

At 2254, the pilot asked: "Shall we start to turn now, Captain?" The master immediately replied: "Yes, we can do that." Immediately after the master's positive response, the pilot issued the helm order hard to port. At this point, the ship was about 0.18 nm north of the extended radar reference line and had passed buoy pair 3a/4a by half a ship's length. The SOG was 8.3 kts (equivalent to 8.4 kts STW). The pilot informed the captain that the MARY MAERSK intended to stay clear to the north to allow the MUMBAI MAERSK sufficient space for its turning manoeuvre. Beforehand, the bridge team had not discussed when and where a safe point for a new turn would be (position at which the manoeuvre is initiated, turning circle, speed, possible obstacles, contingency plans, etc.). Due to the oncoming MARY MAERSK (distance about 2.7 nm) and an isolated danger directly ahead (distance about 0.8 nm), the space for manoeuvring was limited to the west (see Figure 33). According to the pilot, the isolated danger did not influence the decision to initiate the turn early. Instead, the approaching traffic from both the west and the south was the determining factor.

Over the next two minutes, the pilot communicated with the MARY MAERSK and the SAKIZAYA INTEGRITY by radio. The further schedule for the planned transit was discussed. At 2256, the 360 s prediction indicated a course towards buoy 3a, with a ROT of 22°/min.

At 2258, the third officer quietly voiced his concerns concerning the close approach to buoy 3a. The ROT remained almost constant at between 20.5 and 22.5°/min. The prediction indicated the closest point of approach (CPA) to the chart position of buoy 3a to be about the breadth of the ship. The weak radar echoes (S-band) of buoys 3a and 3a-O were about 60 m south-east of the charted position. The pilot was confident about the turn, but acknowledged that the passage would be tight.

The pilot's mobile phone rang at 2258, but he did not take the call immediately. Shortly afterwards, the radar advisor provided information about the MUMBAI MAERSK's current position by radio, and the phone rang again at the same time. This time, the pilot took the call and spoke to his colleague on the CMA CGM LAMARTINE for about 30 seconds. He ended the conversation by explaining that he had to be careful not to run over a buoy. By his account he did not, however, truly have concerns that the buoy would be run over.

At 2300, radio communication between MARY MAERSK and the radar advisor revealed that MARY was now scheduled to enter the port the following day. The pilot informed the captain of this change. Immediately afterward, the captain said: "I think we should take it [the buoy] on the port side." At this point, the prediction was touching the radar echo of buoy 3a, ROT = 20.4°/min, SOG = 8.0 kts, STW = 7.2 kts. The pilot agreed and ordered rudder amidships. Even before the rudder had reached the midships position, he issued the helm order hard to starboard, immediately followed by amidships and starboard 10, after which the ROT to port decreased to 0°/min within one minute.

At 230051, the pilot reported the manoeuvre to the pilot station ship WESER and the radar advisor. The radar advisor stated that the MARY MAERSK was heading to the anchorage. He also said: "You'll pass buoy 3a to port. I guess that looks better."

At 2301, the pilot recommended to put the rudder to “hard to port”. This was intended to reduce the turning radius and ensure that the MUMBAI MAERSK stayed as close as possible to the buoy line. As the rudder was set to “hard to port”, ROT gradually increased again to port. At 2302, possibly after a quiet conversation between the master and third officer, the master interrupted the pilot's remarks about the INTEGRITY and the MARY MAERSK: "We have one patch here. It says 8.9 metres." After the pilot acknowledged this, he continued to ask: "What does yours [the PPU] say?" The pilot replied: "Yes, but we will stay close to the buoy line and try to turn back," and, shortly after, asked: "Maybe we can come to full ahead for a moment?" The master executed this immediately, and the pilot promptly reduced the rudder angle to port 10, and then immediately to amidships. At this point, the prediction touched the northern edge of the 10 m depth contour and was about 60 m south of buoy 3a-O's radar echo. However, it was only visible on the master's MFDs, as both of the pilot's MFDs were set to a range of 3 nm. After the rudder angle had been reduced, the ROT to port dropped from 22°/min to about 15°/min within a few seconds. The pilot then issued the helm order starboard 10. The ROT reduced further and the prediction then pointed directly at the shallow dumping ground. The 10 m depth contour was only one ship's length ahead. The bridge team accepted the pilot's orders. At 2303, the third officer reported from the port bridge wing that the unlit buoy 3a-O was now abeam and the master then said: "Let's come around here." The pilot acknowledged this and issued the order port 10, which the master immediately corrected to hard to port. At this point, the ROT stood at 5°/min to port.

At 230331, the rudder was at hard to port, and the easterly depth reading on the spoil site of 8.7 m was about one ship's length ahead. The SOG stood at 10.9 kts. It was calm on the bridge until 2304. Quiet, indistinct conversations are heard on the VDR recordings. The ROT increased to 22°/min and then dropped abruptly, while the SOG also began to reduce. The pilot asked about the depth beneath the keel. According to the master, the echo sounder still indicated 1.2 m at 230450. At this point, the MUMBAI MAERSK's bow was immediately north of the 8.7 m depth reading, and the radar echoes of buoys 3a and 3a-O were no longer visible. The first alarms sounded at 2305, and the ROT and SOG dropped rapidly in the following 30 s. The master was the first to voice the fact that the ship had run aground.

3.2.8 Sediment management in the German Bight

Because of the location of the dumping ground on which the MUMBAI MAERSK ran aground – situated directly next to the fairway – the BSU took a closer interest in selection, deposition, and positioning of disposal sites, as well as their management. The question arose as to whether the location of this dumping ground had contributed to the outcome of the MUMBAI MAERSK's grounding.

For the most part, the BSU received the basic information for this chapter during a video conference with representatives of the Waterways and Shipping Office Weser-Jade-Nordsee.

Sediment management refers to centrally planned and coordinated measures for dealing with sedimentary deposits in a specific body of water. In the process, the relevant guidelines and exact function of the body of water in question, as well as the nature of the sediments must be taken into account.

In places where silt and other deposits impair the function of a body of water (e.g., in navigable channels or harbour basins), they are removed from the bottom by special dredgers and dumped in other locations chosen specifically for this purpose. Such a location is known as a disposal site, dumping ground, spoil site, or spoil ground.

A distinction is made between cohesive (silt) and non-cohesive (sand) sediment. Cohesive sediment refers to extremely fine-grained soil constituents, such as clay, clayey silt, and silt. The assumption is that they remain in suspension for a long time after they have been relocated to a transfer site and are then distributed over a large area by the currents. Heavier sands, gravels, stones, and mixtures thereof are referred to as non-cohesive sediment. The assumption here is that they will sink quickly due to their own weight and thus remain at the transfer site.

Tidal and flowing waters, especially estuaries, are subject to constant change due to the redistribution and introduction of sedimentary deposits by tides and other currents. Accordingly, sediment management is a continuous task in such areas.

3.2.8.1 Statutory requirements

Sediment management is conducted within a rigid framework of international and national regulations that are primarily aimed at preserving the marine environment. The most important ones are listed below:

International provisions:

- *London-Convention (1972)*: Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter.[77]

[77] Source: Federal Law Gazette, London Convention, Federal Law Gazette II 1977, p. 165, 1977.

- *OSPAR-Convention (Oslo-Paris Convention, 1992)*: Convention for the Protection of the Marine Environment of the North-East Atlantic.[78]
- *Helsinki-Convention (1992)*: Convention on the Protection of the Marine Environment of the Baltic Sea Area.[79]
- The *Conservation Objectives of the NATURA 2000 NATURA 2000* special protection area system, in accordance with EU Directives 92/43/EEC (Habitats Directive: Flora, Fauna, Habitat; Conservation of Natural Habitats) and 79/409/EEC (Birds Directive).[80]
- EU-Directives 2000 / 60 / EG[81] (Water Framework Directive) und 2008 / 56 / EG[82] (Marine Strategy Framework Directive).

National provisionss:

- *Joint Transitional Arrangements for the Handling of Dredged Material in German Federal Coastal Waterways* (GÜBAK) of 2009, an agreement based on the three international conventions referred to above between the Federal Republic of Germany and Germany's coastal federal states. Also provides for chemical and biological examinations of sediment samples.[83]
- *Federal Waterways Act*, (WaStrG). In particular, Section 7(3) WaStrG, which states that no individual permits are required for the sovereign duty to maintain federal waterways.

Accounting for these rules and regulations, the Federal Waterways and Shipping Administration (WSV), as the body executing this sovereign duty, establishes a consensus with Germany's coastal states on the maintenance work to be performed. Safeguarding the needs of landscape and water-resources management, nature conservation, and maintenance of the countryside excludes many locations from use as a dumping ground. After the selection criteria for dumping grounds described below are applied, clearly delimited and defined locations remain and can be designated as such.

3.2.8.2 Selection criteria for dumping grounds

Before a dumping ground is selected, hydro-morphological and sedimentological examinations of the planned area and its subsoil are carried out. For example, the longitudinal direction of a spoil site will always be parallel to the direction of the tides or ocean currents, ideally following existing shoals and their shape. Furthermore,

[78] Source: Federal Law Gazette, OSPAR Convention, Federal Law Gazette II 1994, p. 1355, 1994.

[79] Source: Federal Law Gazette, Helsinki Convention, Federal Law Gazette II 1994, p. 1355, 1994.

[80] Source: Website of the Federal Ministry for the Environment and Consumer Protection (BMUV), Natura 2000, 2023.

[81] Source: Official Journal L 327/00, Directive 2000/60/EC, 2000.

[82] Source: Official Journal L 164/19, Directive 2008/56/EC, 2008.

[83] Source: Website of the Federal Institute of Hydrology, 'Joint Transitional Arrangements for the Handling of Dredged Material in German Federal Coastal Waterways (GÜBAK)', 2009.

economic criteria and, in particular, environmental regulations (see above) must be observed.

The distance between the dumping ground and maintained fairway sections is considered as an economic factor in the preliminary deliberations (e.g. time spent on a dumping operation, fuel consumption of the dredgers due to the covered distances, etc.). The water depth must also be sufficient for the dredgers, including when their hopper flaps are open. For example, to be able to dump without any complications, many of the vessels in use today require a water depth of 11 m under the keel, which can only be achieved under certain tidal conditions.

This reduces the options available to just a few locations that are suitable for use as a spoil site. The potential available space is less of a limiting factor than the large number of existing requirements and protected areas, as well as the lengthy duration of the authorisation procedures. These factors mean that it is not easy to relocate dumping grounds or increase their size.

3.2.8.3 Maintenance of dumping grounds

As a rule, every point on the bottom of a federal waterway is sounded at least once a year. Depending on necessity (for example, at points in the River Elbe fairway that are subject to particularly dynamic change), the sounding frequency may increase to as often as once every fortnight in some areas. Depth soundings outside these areas are carried out less frequently and depend on the degree of typical morphological changes of the waterbed.

Continuous surveying of spoil sites, including their access routes, is the instrument used to determine the remaining total capacity of all dumping grounds. This is one of the most important components of sediment management. Additional sedimentological examinations are conducted for each spoil site every five years in accordance with the GÜBAK (see above). The physical characteristics and composition of the sediment, and undesirable components, such as heavy metals or other toxins, as well as the hydrodynamics around the dumping ground are determined.

Dumping grounds are always evenly filled to avoid 'mounds' at individual points of the discharge area. At the same time, dumping grounds with an exceptionally large and even height compared to surrounding areas do not pose a problem, because they are always laid parallel to the direction of the current (i.e., in the direction of sediment transport), as described above. Parallel fairway channels, even those directly adjacent, are not at risk even in severe weather conditions. This also applies to the dumping ground on which the MUMBAI MAERSK ran aground, especially as it consists mainly of cohesive sediment, i.e., is relatively static. The sounding data of recent decades confirm this (provided to the BSU in tabular form).

Dumping grounds are usually marked on navigational charts. Depending on their location, they are marked locally with buoys or other navigation marks, or not marked at all.

3.2.8.4 Exhaustion of dumping grounds

In principle, dumped sediment does not entirely remain on the dumping grounds. Depending on its cohesion, it disperses more or less widely with the movement of the current. Accordingly, a distinction is made between spoil sites in which most of the material remains in place, so-called “non-dispersive disposal sites”, and those in which most of the sediment – intentionally – disperses to other locations, so-called “dispersive disposal sites”. The latter are often located in areas with greater water depths and stronger currents. Both types of dumping ground are therefore not designed as final disposal sites, but rather for continuous operation, although the length of time it takes for dispersal varies considerably.

The dispersal of sediment from dispersive disposal sites in the German Bight is intentional, e.g., to widen, raise and stabilise the tidal flats of the wadden sea. Firstly, this supports the protection measures against high tides and storm surges, as strong wave activity loses its intensity on wide shallow water zones early on. Secondly, the elevation of these areas is a measure against the rise in sea levels caused by climate change. In this context, those dumping grounds used specifically for this purpose are referred to as “input areas” (for the tidal flats). Silt, for example (a material that is only slightly cohesive), is ideal for this, as opposed to sand (which is highly cohesive).

Available capacities for dumping sediment therefore relate to the sediment type (cohesive or non-cohesive) and nature of the dumping grounds (dispersive or non-dispersive), which are exclusively used for the disposal of the corresponding sediment type. If a spoil site approaches the limit of its capacity, it will not be used for a while to allow nature time to distribute the sediment. The complete depletion of a dumping ground therefore takes an extremely long time, or never happens at all.

There are currently no “spare” areas that could be used as new dumping grounds in the future, and only one ongoing application procedure for the expansion of such a site. This could lead to capacity problems in the Jade-Weser area in future due to the increase in dredged material and restriction of certain spoil grounds. However, according to WSA Weser-Jade-Nordsee, this is not expected before at least 2025.

3.2.8.5 Jade-Weser spoil ground

The WSV's internal designation for the dumping ground on which the MUMBAI MAERSK ran aground is 'Umlagerungsstelle Jade-Weser' [Jade-Weser spoil ground]. It has been marked as a dumping ground on relevant navigational charts since 1981 (e.g., Overview Chart 1230 covering the mouth of the Jade and the Neue Weser – Langeoog to Wangerooge, see Figure 34). Since it is not located in a fairway, it is considered a secondary area for depth soundings and sounded once each year. One million cubic metres of sediment have been deposited there every year since 2012.

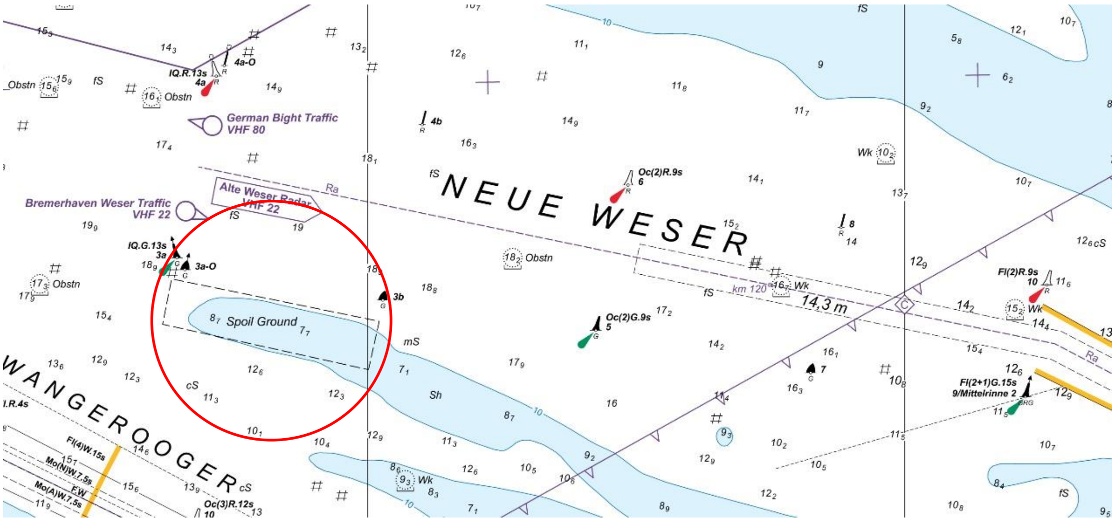

Figure 34: Jade-Weser spoil ground in Chart 1230[84]

3.2.9 Arrival planning for the Weser, Ems, and Jade

On the day of the inspection, the BSU's investigating team secured the MUMBAI MAERSK's VDR. *Inter alia*, it contained recordings of the conversations on the bridge before and during the accident. In combination with the radio traffic, which was also recorded and transmitted to the BSU via the vessel traffic services in Wilhelmshaven and Bremerhaven, this provided a comprehensive picture of the evening's communications.[85] The recordings of VHF channel 80 ('German Bight Traffic', VTS Wilhelmshaven), channel 22 ('Bremerhaven Weser Traffic', VTS Bremerhaven), as well as the ship-ship channels 06 and 10 were requested for the period between 2200 on 02/02/2022 and 0330 on 03/02/2022. A comprehensive, consolidated transcript, which included the conversations on the bridge, was created using all communication channels.

Further information on the course of a ship's approach to Bremerhaven was derived from discussions with the chairmen of the Weser II/Jade Pilots' Association and the Bremerhaven Harbour Pilots' Association, as well as with the management teams and other staff members of the two VTS stations referred to above.

3.2.9.1 Sequence of an approach

One to two weeks before a ship approaches Bremerhaven, liner services, agencies or shipping companies send ETAs[86] for each ship to the respective terminal of call.

[84] Source: Federal Maritime and Hydrographic Agency, Navigational Chart 1230 (detail), 2022.

[85] Source: VDR of the MUMBAI MAERSK, transcript of radio traffic, bridge microphones and VHF channels 6, 10, 22, and 80, 02-03/02/2022.

[86] ETA: Estimated time of arrival.

Although most container ships operate in liner services with scheduled timetables, the actual time of arrival is confirmed or readjusted in this manner.

The individual terminals use this information to draw up advance plans for vessel turnaround (roughly in the order of arrival). Higher priority is given to the so-called 'mainliners', i.e., large container vessels that carry out intercontinental transport and are required to keep a distance of one hour from each other on arrival and departure. Lower priority is given to the so-called 'feeders' or 'feeder ships', i.e., smaller container ships responsible for the onward distribution of containers within Europe. The planning also considers tidal windows for those ships that depend on them. These plans, compiled by the various terminals, are made available to the Port Operations Office (POO) of the Port Authority Bremen (PAB).

The preliminary overall traffic flow plan is drawn up by the POO with this data. Subsequently, it is approved by the VTS stations and the harbour pilots. The VTS Nautical Supervisors decide whether the procedure can be carried out as planned in terms of coordination and shipping police requirements (e.g., compliance with the rules for extraordinarily large vessels, control of traffic frequency within the tidal windows, availability of towing capacity at the berths, etc.). At this point, the influence of the shipping agencies representing the vessels involved should also be considered. As can be expected, they have a vested interest in ensuring swift transits and minimal waiting times. Harbour pilots approve the schedule in terms of the safety and feasibility of manoeuvres (e.g., whether lockage operations, berthing and/or turning manoeuvres are actually possible based on the speed and direction of the wind, the vessel’s draught, ship type/freeboard, tidal situation, etc.).

The finalised and approved traffic flow plan is then made available to relevant parties, i.e., it goes back to the terminals and, for example, the maritime pilot dispatchers (from the Weser II/Jade Pilots' Association). These dispatchers work in 12-hour shifts during which they assign pilots to incoming and outgoing ships, contact them at the appropriate time and dispatch them to the relevant ship at all times. The POO assigns the harbour pilots.

The traffic flow plan changes continuously until the day of arrival. Delays, cancellations, unexpectedly quick turnarounds, schedule changes, etc. can occur at any time. The Terminal → POO → VTS/Harbour Pilot planning loop is then repeated each time. However, the majority of ships keep their schedule relatively accurately. With the exception of short-term changes that are unavoidable and/or unpredictable, the traffic planning is finalised one or two days in advance.

If a large container vessel is approaching Bremerhaven, she is manned by a pilot at the pilot boarding point. There are times when a pilot boards beforehand, e.g., in the Jade Approach TSS, where they are transferred by helicopter, which means that the ship does not have to reduce her speed to the same extent as for a pilot tender. As described in Chapter 3.1, this was the case with the MUMBAI MAERSK (see also Figure 5).

From there, all ships in the German Bight and approaching Bremerhaven have sufficient time to communicate with one another and with the VTS and to establish the sequence specified in the traffic flow plan, if it is not yet correct on arrival. Then they enter the narrow channel, or "track"[87], of the Neue Weser, level with buoy pair 5/6, one by one. Once inside, it is no longer possible to change the arrival order without complications.

Arrangements are made by the pilots or, in the case of exempt vessels[88], by the respective ship's command. All radio communication is carried out in the language of the pilotage area, German.

Plots do not normally have the so-called 'conning' of the ship (command of the ship, including the operation of the different manoeuvring devices) during the approach. Navigational recommendations and helm orders are issued orally and implemented accordingly by the watch officer or rating, or the ship's command.

For navigation, pilots use the ship's INS or MFDs, which can be set to their preferences at the beginning of a pilotage (usually by the officer of the watch) as well as, in particular, their portable pilot unit (PPU, see Figure 35). This is a tablet or laptop on which the data required for navigation are either measured using an own GPS sensor and/or are available in a constantly updated form via mobile data feeds (often more up to date than the commercial correction frequency of electronic and paper charts allows, e.g., in the case of sounding data or daily deviations from the water level forecast), or are downloaded from the ship's sensors via the so-called "pilot plug".

This means that pilots are partially independent of the ship's technology and sensor data and are even more up to date in certain areas. The pilot stated that he primarily uses ECDIS for cross-checking his PPU, and avoided relying on the MUMBAI MAERSK's ECDIS. This was based on his experience that shipboard ECDIS settings often vary and are sometimes incorrect.

[87] A "channel" is a natural or artificially deepened, marked waterway with sufficient depth for navigation, while the "track" represents a linear orientation within the fairway, often marking the ideal line or the centre of the channel.

[88] Exempt vessel: Smaller ship whose master is exempted from the obligation to take on a maritime pilot. A certain number of approaches with a pilot on board and a test must be completed, and sufficient knowledge of the German language demonstrated for such an exemption.

Figure 35: Example of a PPU design[89,90]

If there are disruptions in the overall traffic flow plan – such as cancellations, delays, rescheduling at the terminals, or similar issues – which trigger many chains of additional changes in previously unaffected areas, then all involved parties must improvise. Terminals, POO, VTS, shippers and liner services sometimes have quite different interests, which must be coordinated with each other. In the process, the VTS assumes the role of communications hub. In such situations, it is sometimes the case that the planning status of certain bodies involved has not yet reached the VTS, but that the pilot should already be included in a decision. The pilot usually gathers this information independently, e.g., by calling a colleague on another ship or the dispatcher (who in turn communicates with the terminals) using his mobile phone, or by making enquiries with the VTS, POO, etc. by radio or phone.

The harbour pilot boards the ship and takes charge of advising her when she enters the Bremerhaven port area. In the case of large container vessels, a turning manoeuvre is always carried out first, and then the berthing manoeuvre. As a rule (there are exceptions), the starboard side of the ship is made fast at one of the berths at the Stromkaje quay, all of which are located on the eastern side of the River Weser (see Figure 36).

This usually takes just under an hour – hence the one-hour gap between two mainliners over the entire duration of the entry – but it can be reduced to 45 minutes in an

[89] Source of navigational chart: SevenCs GmbH, 'ORCA Pilot G2', 2023.
[90] Source of device: Amazon product page, Panasonic 'Toughbook CF-20', 2023.
Montage by the BSU. Product names and logos were removed in both cases.

emergency. The seaward pilot remains on board during the turning and berthing manoeuvre. After the ship has been brought alongside, both pilots disembark at the berth.

Departing ships follow a similar procedure in reverse. Berth management at the terminals plays a role here as well. All parties are keen on achieving a quick turnaround at the terminal (arrival, clearance, and departure). In addition, for each departing ship, the next incoming ship is already waiting to occupy her berth. A tolerance of 30 minutes applies, which the VTS must compensate for through control measures, before a genuine delay is assumed. Only then is the POO informed and the traffic flow plan readjusted if necessary.

The harbour pilot boards a ship 20 minutes before scheduled departure. In normal circumstances, ships already face the direction of departure (see above) due to turning before berthing. After casting off from the pier and shortly before entering the Neue Weser channel, the pilot changeover is carried out and the seaward pilot then advises the ship all the way to the German Bight.

When a tidal window “opens”, the first step is the departure of all large vessels reliant on that specific tidal window, followed by the entry of all similar vessels. Departures can be carried out at a higher frequency, because the hourly interval between two large ships only applies when they enter (time buffer for the manoeuvres beside and alongside the pier). Smaller units use the one-hour gaps between the incoming mainliners in both directions and/or are not dependent upon the tidal window.

Figure 36: Port area of Bremerhaven

with container terminals and Weser navigation channel[91]

3.2.9.2 Shipping police permits

Section 57 SeeSchStrO (German Traffic Regulations for Navigable Maritime Waterways) lists those vessels that require a 'shipping police permit' from the relevant waterways and shipping office, and includes 'exceptionally large vessels'[92]. This permit

[91] Source: Google Earth, Bremerhaven port area and the River Weser, retrieved 2023.

[92] Exceptionally large vessels are those that exceed the dimensions for a maritime fairway or channel in terms of length, width, or draught, as officially published under para. 60(1) of the SeeSchStrO. The following dimensions require a permit (see also Section 2(1)(10) SeeSchStrO and notices of WSD Nordwest):

must be applied for in good time and may be granted for an "appropriate" period of time with conditions and requirements attached, for the purposes of, for example, "avoiding or balancing off any cause liable to affect the safety and easy flow of traffic".[93]

Weser:

Extraordinarily large vessels are constrained by their draught and dependent upon tidal windows and the specially dredged channel of the Neue Weser for their entry and exit ('channel-bound'). A separate shipping police permit must be granted and issued in writing for every extraordinarily large vessel that navigates the Weser. In practice, such permits are always issued for one year and are identical for sister ships. The Bremerhaven-based Waterways and Shipping Office Weser-Jade-Nordsee issues shipping police permits for the River Weser.

EEE vessels, and as such the MUMBAI MAERSK, were also granted such a permit for the "Sea-Bremerhaven-Sea" route. The following is a list of some of the requirements and conditions contained in the document for the River Weser that are relevant to the approach on the evening of the accident: [94]

"2. When entering the River Weser pilotage area, a free berth must be available for the ship at the Stromkaje quay in Bremerhaven."

"3. The ship must approach with the tide early enough to ensure it is still possible to safely complete the necessary turning manoeuvre, and berth with her starboard side."

"5. Encounters with channel-bound vessels are prohibited in all course-alteration areas."

"7. Encounters with channel-bound ships are prohibited between buoys 33/34 and Bremerhaven, i.e., in the 220 m channel. Encounters with other vessels exceeding a length of 180 m or draught of 8 m may only take place after timely consultation with Vessel Traffic Service Bremerhaven and between the ships. In particular, this applies in wind forces of 6 Bft or more." (Note by BSU: See also Figure 36.)

"Exceptionally large vessels shall be those vessels exceeding any one or more of the following dimensions including the indicated projecting load (the draught values as max. draught in fresh water) being applicable, on the understanding that the designated water depths do, in fact, exist, and that at least median values may be expected for the tide at High Water in tidal waters, respectively, for the water level in non-tidal waters. […]"

2.2 River Weser

2.2.1 Route from The Sea to Bremerhaven ("Stromkaje" Quay) and from Bremerhaven to the Sea

Length: 350 m

Width: 46 m

Draught 14.50 m (freshwater)

[93] Source: Section 57 SeeSchStrO, Shipping Police Permits, 1971.

[94] Source: WSA Jade-Weser-Nordsee, Shipping Police Permit 39/2021 (Jade/Weser), 2021.

Inter alia, the document also contains the following information:

- “Entering the River Weser pilotage area (Restriction/Condition 2) means passing buoy pair 3a/4a.”
- “‘Free berth’ (Restriction/Condition 2) means: The ship(s) occupying the berth designated for the ship must have completed the port manoeuvres – particularly a turning manoeuvre – and be underway without obstruction, in order to permit Condition 7.”
- “To permit Condition 7, an incoming ship destined for the berth of the outgoing ship, and expected to encounter restrictions due to her dimensions, may only enter the River Weser pilotage area after the latter has cast off and is underway.”
- “Deviations from the above requirements and conditions are only permitted after consultation with Vessel Traffic Service Bremerhaven. […]”“

Elbe:

The WSA Elbe-Nordsee also issues shipping police permits for extraordinarily large vessels on the River Elbe. In addition to similar aspects in both documents (prohibition of encounters, reporting obligations, etc.), the permit for EEE ships on the River Elbe also specifies numerically defined conditions for entry, e.g., maximum draught, maximum height above the waterline, maximum wind force, or certain necessarily functioning items of bridge equipment (DGPS, updated ECDIS, etc.).[95]

In particular, the regulations for the River Elbe state that two pilots generally staff extraordinarily large vessels. Following an inquiry by the BSU, WSA Elbe-Nordsee justified this requirement, which has already existed 'for many years' for container ships with a length in excess of 340 m, as follows: [96]

- “The first pilot is responsible for navigation and the second for communication.”
- “From the manoeuvring stand, the view of the immediate surroundings of such ships is limited.”
- “To gain an overall view of the surroundings, the navigator must change their position frequently. The bridge of such a ship spans her entire breadth.”
- “The breadth of the vessel in relation to the fairway is so large that the boundaries on each side of the fairway cannot be seen [visually, BSU note].”

[95] Source: WSA Elbe, Shipping Police Permit 34/2022 (Elbe), 2022.
[96] Source: WSA Elbe-Nordsee, email, 2022.

- “Since the bridge is located in the forward third of such ships due to their design, loaded containers always obstruct the view aft. The frequent change of position on the bridge and the associated absence from the manoeuvring stand, where the radar installations are located and communication is centralised, is compensated for by the presence of a second person.”
- “In emergencies or near-miss situations in particular, the second person is indispensable. For example, the task of observing the immediate vicinity can be assigned to them in its entirety. Due to their precise knowledge of the pilotage area and underwater topography, they are able to provide the first person, who monitors the overall situation, with preliminary assessments of their observations, thus significantly reducing the time needed to make decisions.”
- “Ships of this size in particular do not have much manoeuvring space on the River Elbe, which necessitates rapid decision making when navigating the fairway.”

3.2.9.3 Approach on the evening of the accident

On the evening of the accident, the MUMBAI MAERSK was duly staffed by a pilot from the Weser II/Jade Pilots' Association.

As detailed in the section describing the course of the accident (Chapter 3.1), the approach of the MUMBAI MAERSK to Bremerhaven that evening was characterised by constant unforeseen and spontaneous changes to the traffic flow plan.

The closer the ship approached buoy pair 5/6 and thus the narrow fairway channel of the Neue Weser, where turning back would have been difficult, the more urgent the question became as to whether entry within the intended tidal window would be possible. For this, the requirements of the shipping police permit (see above) remained the main focus. In particular, according to the permit the berth had to be clear before entering the pilotage area (with passing buoy pair 3a/4a).

To cope with the continuously changing situation, the MUMBAI MAERSK's pilot communicated almost constantly with a wide variety of bodies: by phone with his colleagues on the CMA CGM LAMARTINE, the MAERSK KANSAS and the MARY MAERSK, as well as with the POO and the dispatcher, and by radio repeatedly with the VTS, the radar advisor, and again with the POO. Of course, all of this was in addition to the usual consultations during navigation, such as with the MSC GEORGIA II, the SAKIZAYA INTEGRITY, or the pilot station ship WESER, which was in the area, as well as the continuous radar assistance which was audible in the background.

The first turn was not completed until after the self-set time had been exceeded by ten minutes and the vessel had already entered the pilotage area (passed buoy pair 3a/4a, see above). This was based on the gradually increasing but ultimately futile hope that the LAMARTINE would soon vacate her berth. However, because the turn was completed before the vessel passed buoy pair 5/6, when it would have entered the narrow channel of the Neue Weser, as well as in consultation with the VTS, which issued a spoken approval of the procedure, both chairmen of the Weser II/Jade Pilots' Association rated the manoeuvre as unproblematic (see Figure 37 below).

The timing of the second turn was dictated by the perceived pressure of the closing tidal window and at the same time by the directly oncoming MARY MAERSK. The fact that the MUMBAI was scheduled to sail into Bremerhaven before the MARY had only been finalised minutes earlier. Since the pilot had not anticipated a fast U-turn, the MUMBAI MAERSK was closer to the radar reference line than to the northern buoy line (see Figure 37).

It became evident when listening to the radio communication from the evening of the accident that the pilots did not call each other as the respective radio stations (i.e., by the ship's name, such as 'MUMBAI MAERSK', or the name of the station that was coordinating or providing advice, such as 'Bremerhaven Weser Traffic'). Instead, the first names of the people manning the respective radio stations were used. That evening, five (!) of these first names began with the same letter, forcing the BSU investigating team to create a table in which these names were assigned to the radio stations, in order to be able to actually follow the communication.

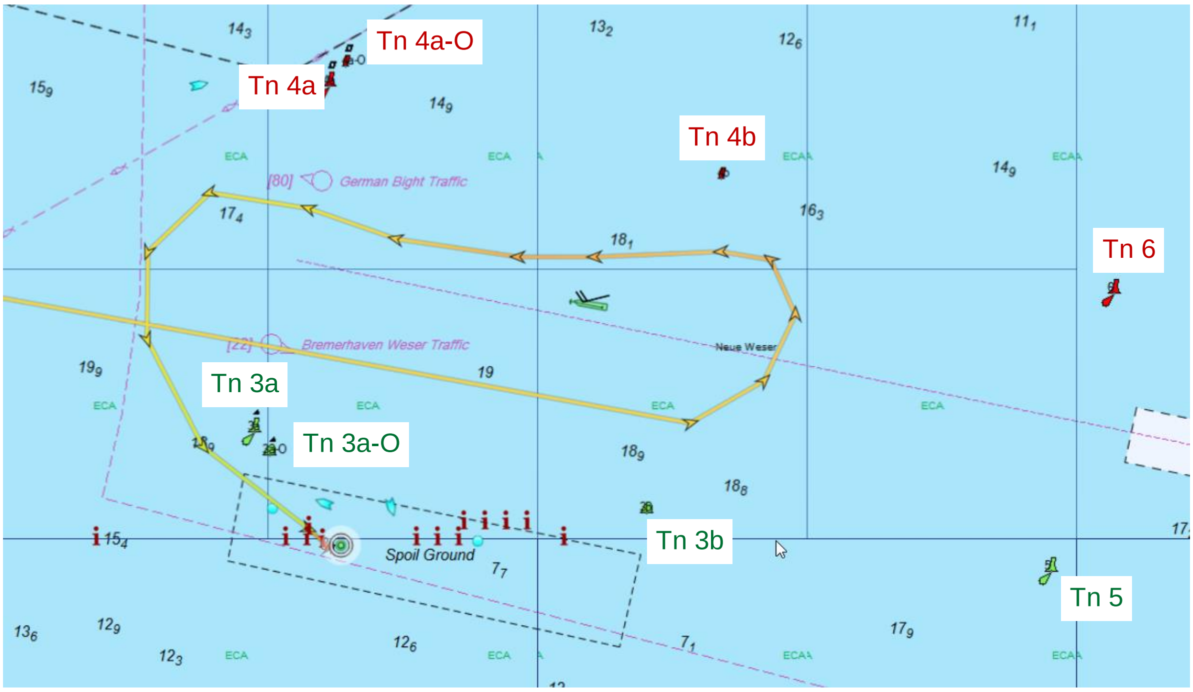

Figure 37: Track up to the grounding, incl. both turning manoeuvres[97]

[97] Source: MarineTraffic screenshot of details of the MUMBAI MAERSK's track on the day of the accident, 02/02/2022.

3.2.9.4 The HVCC in Hamburg

To gain an idea of how approach plans are drawn up in other ports, another look at Hamburg seemed appropriate. Although the Elbe and the Neue Weser pilotage areas differ from one another in terms of the Elbe's length and large number of places where encountering restrictions apply for large vessels, Hamburg is also a universal port at which different types of ship call. Moreover, draught restrictions apply on the Elbe, too. Accordingly, ships of a certain size or with a certain draught are also dependent on the tidal windows there.

Like Bremerhaven, Hamburg is a so-called 'hub' or 'transhipment port' where containers imported by large ships from overseas are redistributed regionally by smaller feeder ships, as described in Chapter 3.2.9.1, in a “hub-and-spoke” system. Feeder ships therefore shift[98] multiple times in transhipment ports to collect containers from the various terminals destined for their other ports of call.

The arrival planning for the River Elbe and port of Hamburg is prepared by a body specifically responsible for this: the Hamburg Vessel Coordination Center (HVCC). This task emerged as a by-product of a more efficient berth planning process and is based on the framework regulations set out in the SeeSchStrO (rules for vessel encounters, etc.) as well as the associated notices to the SeeSchStrO (tidal windows, etc.).

The HVCC was established in 2004 as a collaboration between two Hamburg container terminal operators. The original idea behind the collaboration between the two companies was to optimise the routes of feeder ships that need to shift multiple times within the port of Hamburg. The aim was to minimise idle periods, waiting times for ships and containers, restows[99], as well as unnecessary, possibly duplicate runs (and thus fuel costs and emissions).

In 2009, the 'Feeder Logistics Centre' (FLC) was established to centralise this coordination. Over the years that followed, rotation planning was continually optimised to include not only the internal rotations within the port but also the inbound/outbound schedules of feeder ships and their stowage plans for the port of Hamburg.

This approach was extended to include larger ship sizes in 2015. The reason was that close-quarters situations were becoming increasingly frequent on the River Elbe due

[98] Shift: Moving a ship over a short distance. In this case, changing berth within the same port. Although supplementary phrases such as 'with tugs', 'with the aid of own mooring lines' or 'without own propulsion', which can be found in certain definitions, are possible forms of shifting, regular sailing from one end of a port to the other also falls under this term.

[99] Restow: The act of placing a container ashore in port, in order to access or place containers below it and/or change its stowage position, and then reloading it onto the same ship shortly thereafter. Restows hardly ever occur when handling mainliners, as large quantities (e.g., complete hatches) are usually destined for one port. Since it is often the case that only a few containers are transported for each port of call in feeder shipping, stowage planning as well as loading and unloading are not possible without restows.

to the growing size (and, in particular, breadth) of ships calling at Hamburg. This, combined with an overall increase in call frequency, gave rise to the decision to optimise the approach of large inbound ships, too. To achieve this, the 'Nautical Terminal Coordination' (NTC) was established for these vessels, which was later merged with the FLC under the umbrella of the HVCC.

All vessels with a breadth of ≥ 28 m were then classified as 'large ship', as this is the threshold at which close-quarters situations with the largest ship sizes with a breadth of approximately 60 m are restricted at certain points of the River Elbe. The term refers not only to container ships, but to all ship types calling at Hamburg.

Planning for the arrival, turnaround and departure of large ships is primarily based on the following principles:

- All operators work hand in hand, a smooth and optimised process being the common goal for everyone. This also means that there may be situations in which one operator must hold back for the benefit of another, but also that, over time, all parties are thus affected (for better or worse), and ultimately, everyone benefits.
- Any information required for planning is shared digitally. Where the situation reports from the different vessel traffic services used to be the main source of information about traffic on the River Elbe, or the individual terminals for berthing information, this information now appears on a single digital platform (a dashboard). Each operator sends the necessary data and everyone can view this information in real time (e.g., voyage data, berth registrations, digital ordering of service providers, stowage planning, cargo change requests, terminal rotation, etc.). These rights of access are, however, subject to a fee. The VTS centres do not use this dashboard.
- The previously usual bilateral communication channels between the various operators are replaced by centralised communication, where all information converges in real time. This means that communication is more focused and less frequent (because the same information only needs to be communicated once, rather than being relayed to four different operators by phone, for example).
- For a comprehensive picture, data from upstream and downstream ports is added. In some cases, the data exchange is more extensive, e.g., with Rotterdam and Le Havre. Information from other ports is obtained via publicly accessible ship information websites. Incoming large ships are plotted automatically from Gibraltar onwards (or as early as possible).
- This information is merged into a plan of all traffic within, arriving at, or leaving the port, which changes dynamically with the circumstances. Close-quarter situations between large vessels are resolved and re-planning in the event of

delays is comprehensive (even including cargo). All this results in a traffic flow plan, which must be compiled as a planning basis in any case. Individual passage plans are drawn up for all large ships, giving their required cruising speeds from the ports of departure to subsequent ports, via the Elbe and Hamburg. These passage plans are provided to all ship operators free of charge, as there is an overriding interest in every ship adhering to them.

- In Hamburg, the developed traffic flow plan also is first coordinated with VTS Brunsbüttel (responsible for the River Elbe) and Hamburg and approved by them. Certain weather conditions (such as strong wind) may mean that planned close-quarters situations are not permitted. The VTS centres are still responsible for actual traffic regulation and the final coordination of vessel movements on the river and in the port.
- The system relies on the voluntary acceptance of the participating shipping companies and terminal operators. If no agreement can be reached, the competent authorities, particularly the VTS centres, decide.
- Since all information converges centrally, it is possible to respond to short-term changes or emergencies more quickly than if several bodies were communicating bilaterally back and forth in succession.

In principle, however, it must be noted that the HVCC would not have been involved in the short-term changes that caused the problems on the evening of the accident, even in Hamburg. Responsibility would have remained with the VTS station and the Nautical Centre.

3.2.10 Simulations

After analysing the available data and documents related to the accident, the investigation team had various questions regarding the manoeuvres carried out on the evening of the accident. How might slightly or significantly different decisions have altered or influenced the outcome of the manoeuvres?

The ship-handling simulator at Bremen University of Applied Sciences was made available to the investigation team for one day. The aim was to classify the decisions made, at least from a navigational perspective, and to test alternative manoeuvring and abort options. Pilots from both Weser pilots' associations train there regularly in their own pilotage areas, with the ship type in question (Maersk 'EEE') and others. Accordingly, both sea area and ship were already available as virtual models. The BSU supplied:

- precise depth sounding data from the day of the accident (which had been determined immediately after the accident) via the WSV for fine tuning the sea area model in the simulator;

– the AIS data provided by VTS Bremerhaven of the ships in the vicinity and in the relevant period, from which automatically moving models of these “neutral” vessels could be created;

– the MUMBAI MAERSK's manoeuvring data from before and during the accident, which was obtained from the VDR (position, speed, the engine’s actual rated speed and that ordered on the telegraph, rudder angle, etc.);

– an ECDIS track of the route actually navigated on the day of the accident, with waypoints every 30 seconds during the turning manoeuvres (otherwise every minute), and

– pre-drawn schematics showing the required manoeuvres.

The day was supervised by staff of the university's Institute for Simulation, who incorporated the data into the model beforehand and/or prepared it accordingly.

The results of the simulations are summarised below. The majority of the manoeuvres were performed in day mode for better visualisation.

The simulations differed from the actual conditions on the night of the incident in several aspects. The model did not respond in exactly the same way as the MUMBAI MAERSK, as the simulated vessel had a shallower draught (available only in a slightly modified form due to technical constraints) and had to be adjusted using different parameters. Additionally, in reality, the buoys were approximately 60 m southeast of their charted positions due to wind and current.

The BSU acknowledges that the results cannot be fully transferred to real-world conditions. The aim was to assess whether the executed manoeuvres had been appropriately assessed and interpreted.

3.2.10.1 Simulation of the course of the accident

To enable the investigation team to develop a feeling for the ship and her manoeuvring characteristics, the track navigated on the evening of the accident was followed twice, with the same actions being taken at the correct positions (same rudder angles at the same speed at the same time, etc.) wherever possible. A few tweaks to the model (see above) made it possible to achieve a good approximation of the actual course of the voyage on the second run.

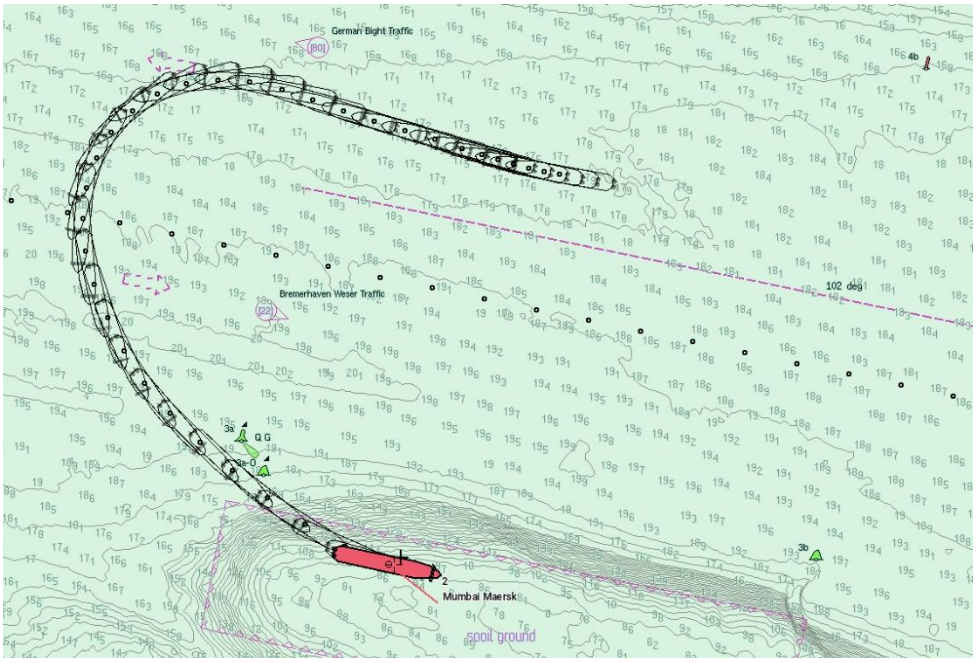

Figure 38: Simulated original manoeuvre[100]

3.2.10.2 Turn with constant hard-over rudder angle

In the second trial, the U-turn (180°) was to be executed with a continuous hard-to-port rudder, without the 'straightening' or opening of the turning radius which was carried out on the evening of the accident. The investigating team had questioned whether the manoeuvre could have been completed without running over buoy 3a if the vessel had continued to proceed with a hard-over rudder angle instead of widening the radius with the aid of a starboard rudder angle.

The manoeuvre began at approximately the marked point ○ of the reciprocal course track (see Figure 39, rough schematic prepared in advance by the BSU for the simulator team). The turn was initiated as on the evening of the accident (time, location, rudder angle). However, this manoeuvre did not result in buoys 3a and 3a-O being passed. As feared by the master on the evening of the accident, buoy 3a was run over.

[100] Source: Trainer ECDIS of the simulator at Bremen University of Applied Sciences, screenshots of various tracks of the executed manoeuvres, 2022.

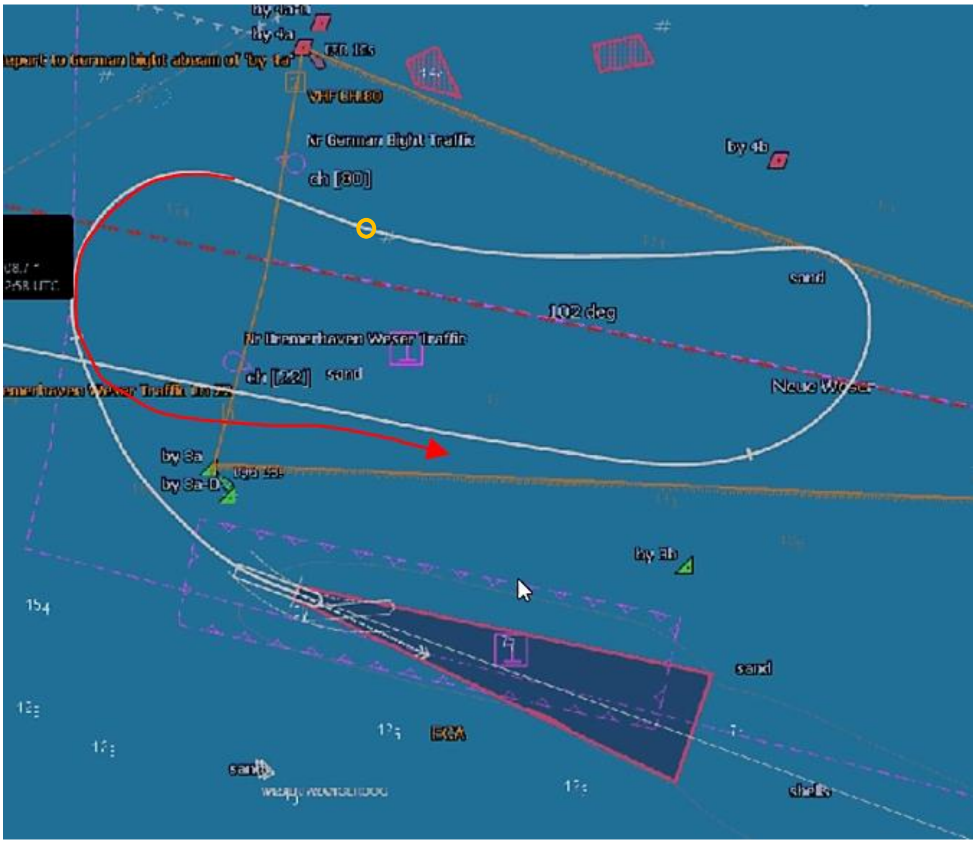

Figure 39: Turn with constant hard-over rudder angle: BSU schematic[101]

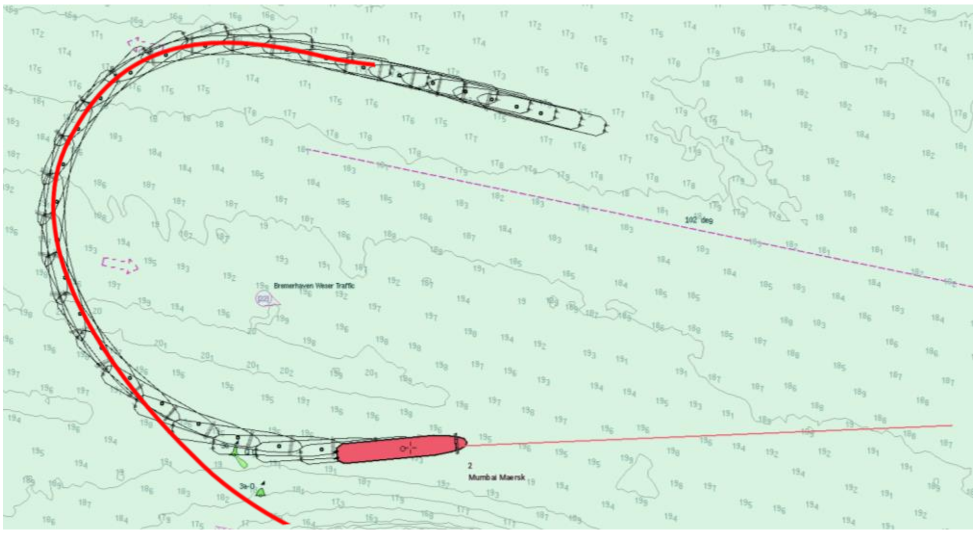

Figure 40: Turn with constant hard rudder angle

Original track (red) shifted onto simulator track[102]

[101] Source: VDR of the MUMBAI MAERSK, ECDIS screenshot at various times, 02/02/2022.

[102] Source: Trainer ECDIS of the simulator at Bremen University of Applied Sciences, screenshots of various tracks of the executed manoeuvres, 2022.

3.2.10.3 Start further north

In the third trial, the initial reciprocal course was to be steered further north.

The manoeuvre began at the same position as the previous one, but approximately 200 m further to the north. The ship remained well clear of the buoys, which stayed in sight the entire time.

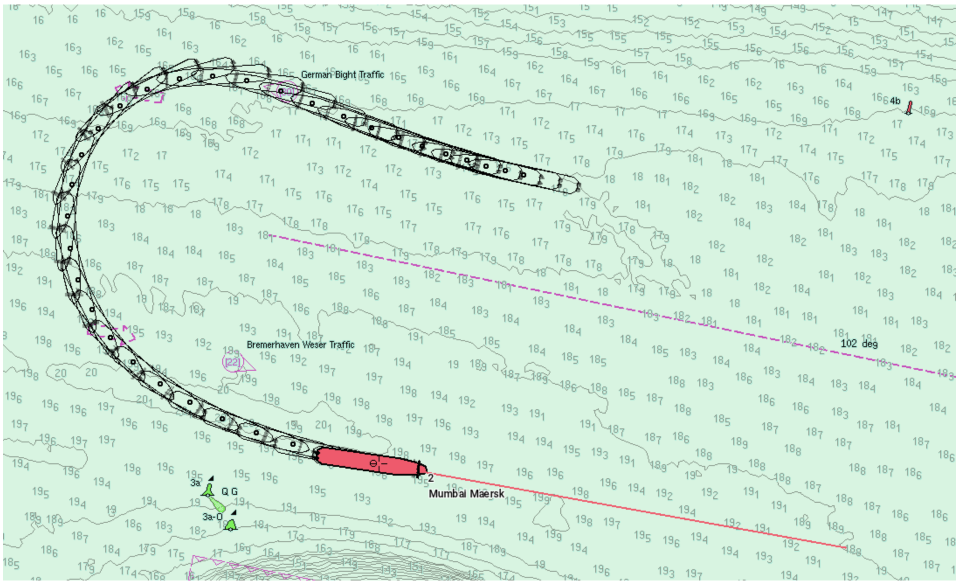

Figure 41: Start further north: track navigated during the simulation[103]

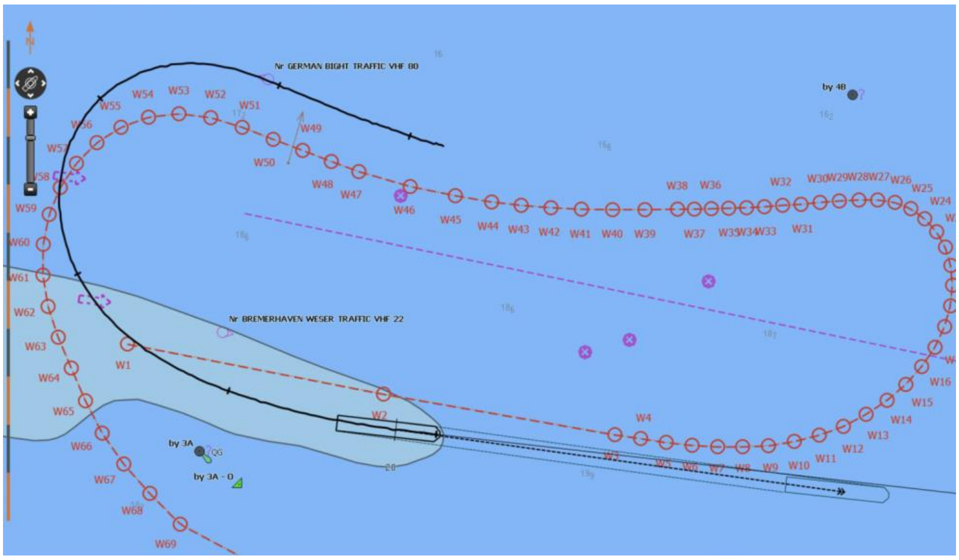

Figure 42: Start further north: comparison

Steered (black) and original track (red)[104]

[103] Source: Trainer ECDIS of the simulator at Bremen University of Applied Sciences, screenshots of various tracks of the executed manoeuvres, 2022.

[104] Source: Ship ECDIS of the simulator at Bremen University of Applied Sciences, screenshots of various tracks of the executed manoeuvres, 2022.

3.2.10.4 Initiate reciprocal course further west

This trial involved continuing the reciprocal course further in a westerly direction on the track steered by the ship, and only later returning to the original course. The available water depth west of the spoil site.

The position and timing of the U-turn had to be chosen with consideration of the traffic situation. Before the manoeuvre was initiated, the MUMBAI MAERSK's sister ship, the MARY MAERSK, was approaching on a reciprocal course, and the much smaller container ship MSC GEORGIA II approached from the south-east during the last 90° course alteration.

For an assessment of the spatial conditions, the tracks of the other two vessels (sailing automatically, as mentioned) were not altered The MARY MAERSK turned away from the MUMBAI at a distance of approximately three ship’s lengths.

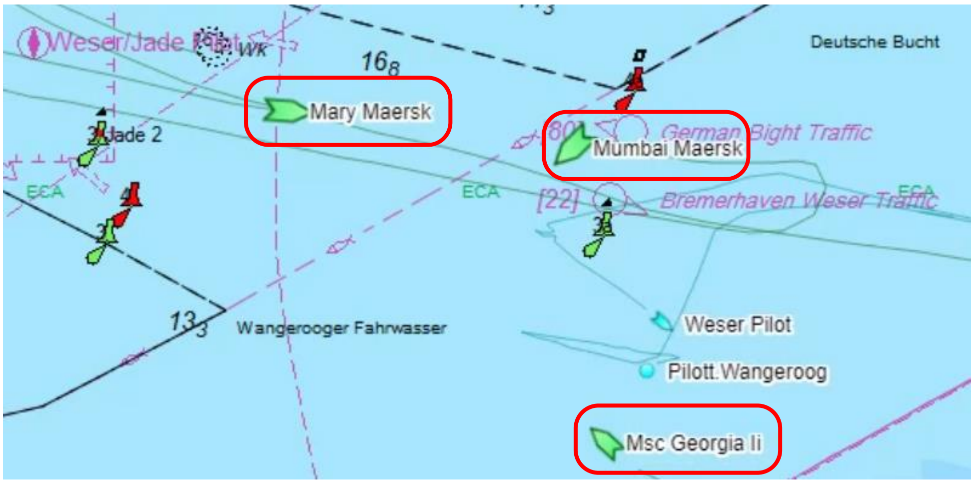

Figure 43: Further west: actual traffic situation before the second turn[105]

The closest passing distance to the MSC GEORGIA II was small (about twice the breadth of the MUMBAI, see Figure 45), but the manoeuvre did not result in a collision. The investigating team assumes that, in reality, such a close approach would have been anticipated and avoided, e.g., through mutual consultation and a course adjustment by MSC GEORGIA II.

There was no dangerous approach to the buoys, the spoil site, or other vessels. The manoeuvre took about 20 minutes longer.

[105] Source: MarineTraffic screenshot of an animation of the traffic situation on the evening of the accident, 22/02/2022.

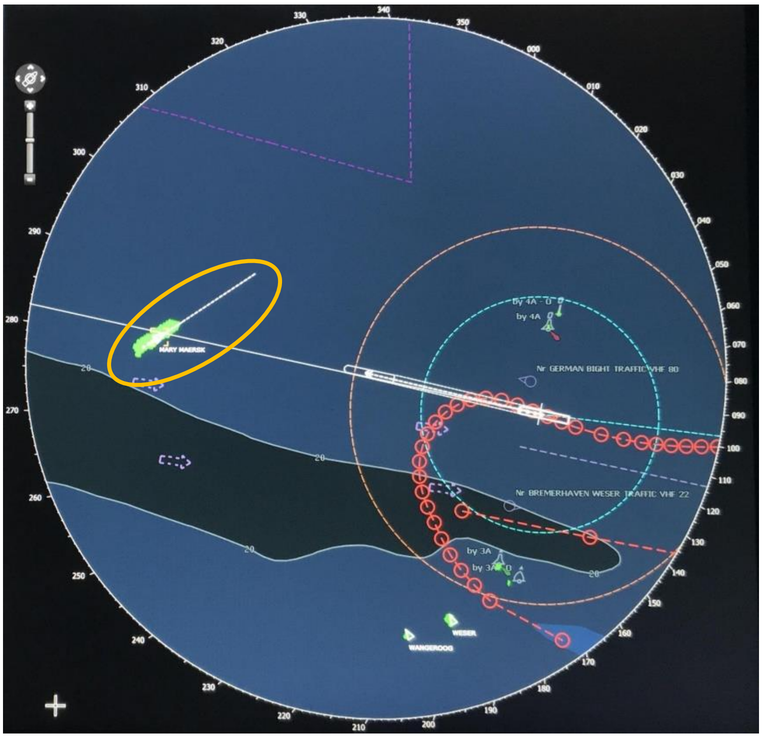

Figure 44: Further west: radar image [106]

Photograph in the simulator

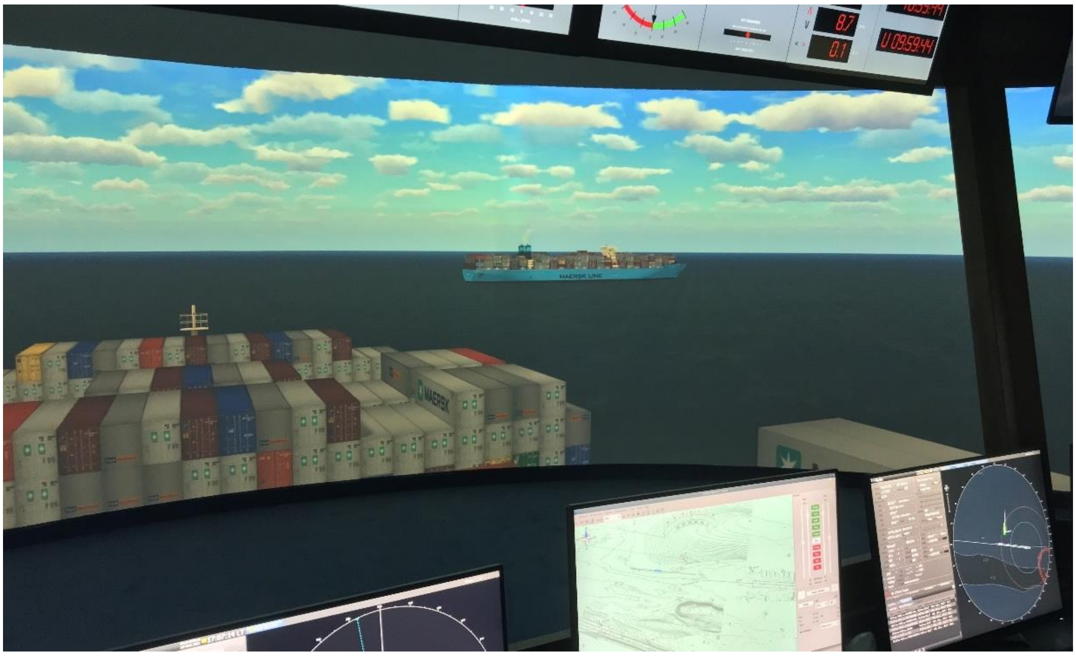

Figure 45: Further west: view of the MARY MAERSK ahead

[106] Source: Ship MFD in radar mode, the simulator at Bremen University of Applied Sciences, screenshots of various tracks of the manoeuvres steered, 2022.

shortly after initiating her turn [107]

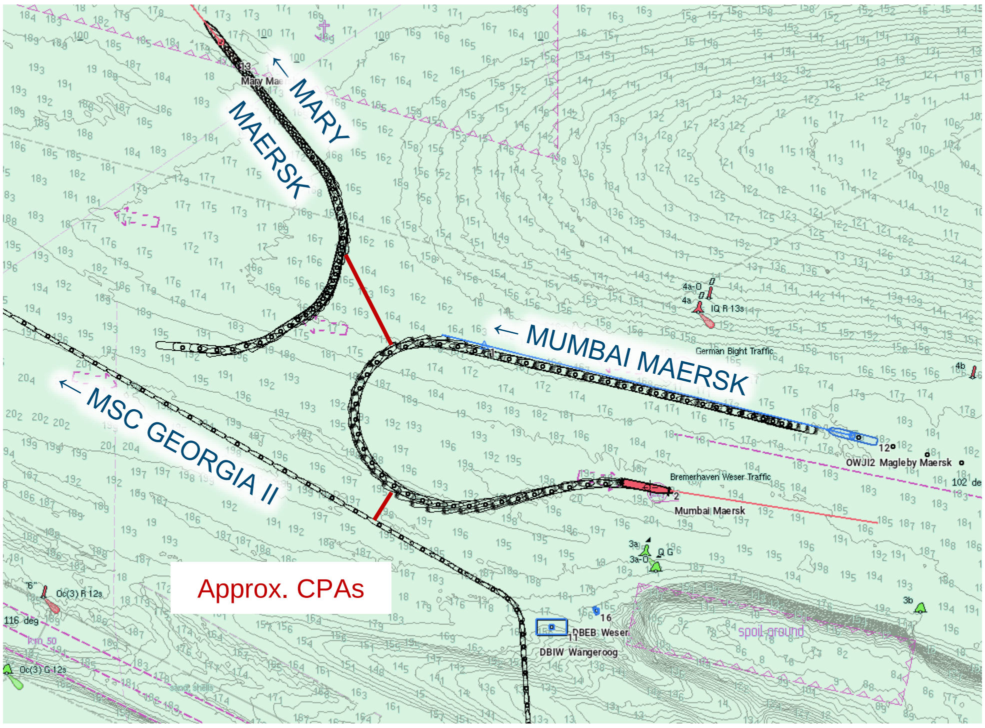

Figure 46: Further west: closest points of approach

track navigated during the simulation [108]

3.2.10.5 270° turn

In the fifth trial, the last 90° of the course alteration was to be executed to starboard, i.e., as a 270° turn.

The aim was to execute this manoeuvre in such a way that the decision to sail a full circle was made at the moment when, in reality, it was decided to increase the turning radius to avoid sailing over buoy 3a. Accordingly, the full circle was not to begin as soon as the vessel reached the southerly course, but slightly later.

The current offset the ship, especially her stern, toward the spoil site with considerable force. Although the simulation could be completed without grounding, the lowest depth of water beneath the keel was about 1.8 m, which cannot always be regarded as safe (possible risk of propeller and/or engine damage due to significantly increased propeller resistance caused by churned-up silt, etc.). The speed dropped from about 11 kts to 6 kts due to the shallow-water effect over the spoil site.

[107] Source: Bridge of the simulator at Bremen University of Applied Sciences, photograph of situation, 2022.

[108] Source: Trainer ECDIS of the simulator at Bremen University of Applied Sciences, screenshots of various tracks of the executed manoeuvres, 2022.

During the simulation, the MSC GEORGIA II had to be watched. In reality, she would, of course, have been warned and would have given way (for which she would have had sufficient space and water depth).

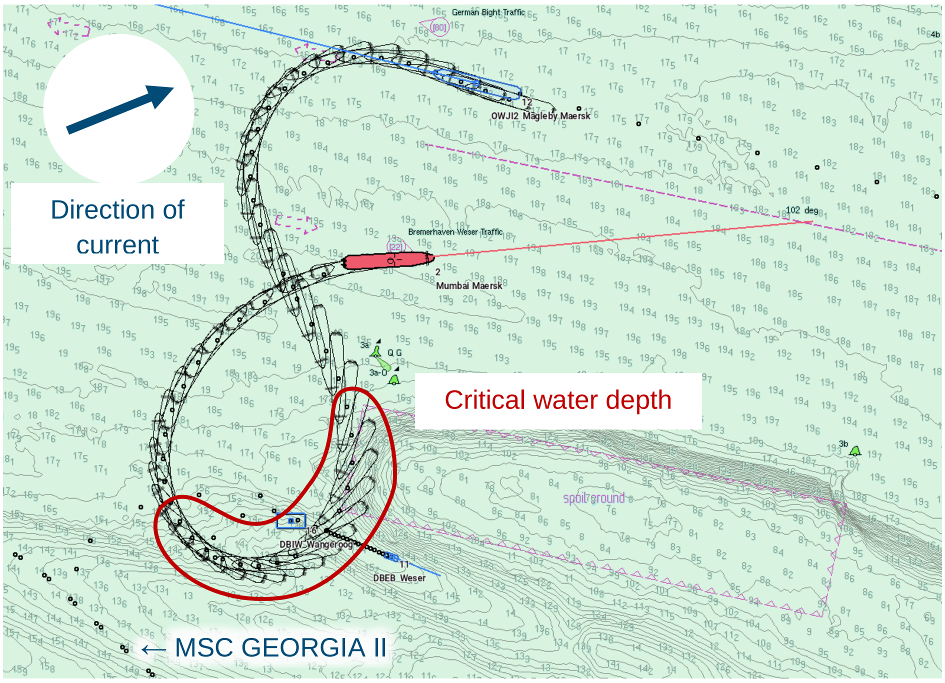

Figure 47: 270° turn: set and drift, spoil site

Track navigated during the simulation[109]

The stern sweeps over the dumping ground during this manoeuvre, as the above figure shows. This manoeuvre would also have posed a threat of grounding.

3.2.10.6 Passage between the buoy and spoil site

The intention in this sixth trial was to pass between buoys 3a/3a-O and the spoil site, as planned by the ship.

Based on the experience gained during the previous trials, the simulation of this manoeuvre was not carried out.

The simulator team placed the ship directly between buoy 3a-O and the spoil site to illustrate the proportions. Including the ship's breadth of 59 m, the clearance between buoy 3a-O and the 13 m depth contour would have been 200 m at the time of the accident. In addition, buoy 3a-O is not illuminated, and due to shadowing/'blind spots' at this distance from the ship and her extremely high bridge, the buoy is difficult or impossible to detect. Furthermore, this theoretical value neither considers that the buoys were slightly displaced to the south-east by the flood tide at the time of the

[109] Source: Trainer ECDIS of the simulator at Bremen University of Applied Sciences, screenshots of various tracks of the executed manoeuvres, 2022.

accident, further reducing the passing distance, nor the lateral component of the hull's movement resulting in an increased passage width.

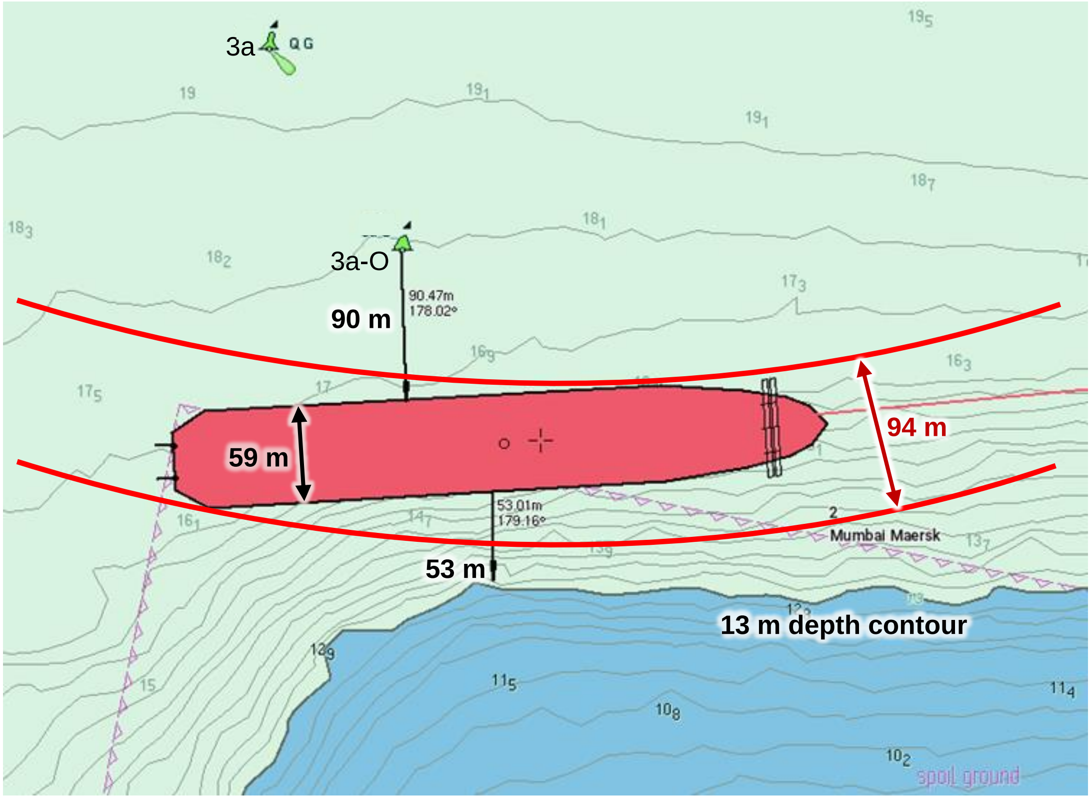

Figure 48: MUMBAI MAERSK between buoy 3a-O and the spoil site[110]

3.2.10.7 Semi-automated manoeuvre with "curved heading line"

The intention here was to execute a largely automated manoeuvre using the autopilot in HDG mode[111] (making use of the "curved heading line" feature).

HDG mode stood out as a possible alternative because the course alterations could have been executed under virtually ideal conditions (constant radius, no delays due to the chain of command between helmsman and ship's command). The associated manoeuvre was to be initiated and executed without prior planning, virtually in real time, as would have been the case on board due to the short-term nature of the incoming information regarding approach planning.

[110] Source: Trainer ECDIS of the simulator at Bremen University of Applied Sciences, screenshots of various tracks of the executed manoeuvres, 2022.

[111] In HDG mode, the autopilot keeps the ship on the pre-set heading (= course steered, direction of the keel), regardless of external influences such as wind or current. If the keel direction is correct, such influences can cause lateral displacement over ground, if not accounted for and adjusted.

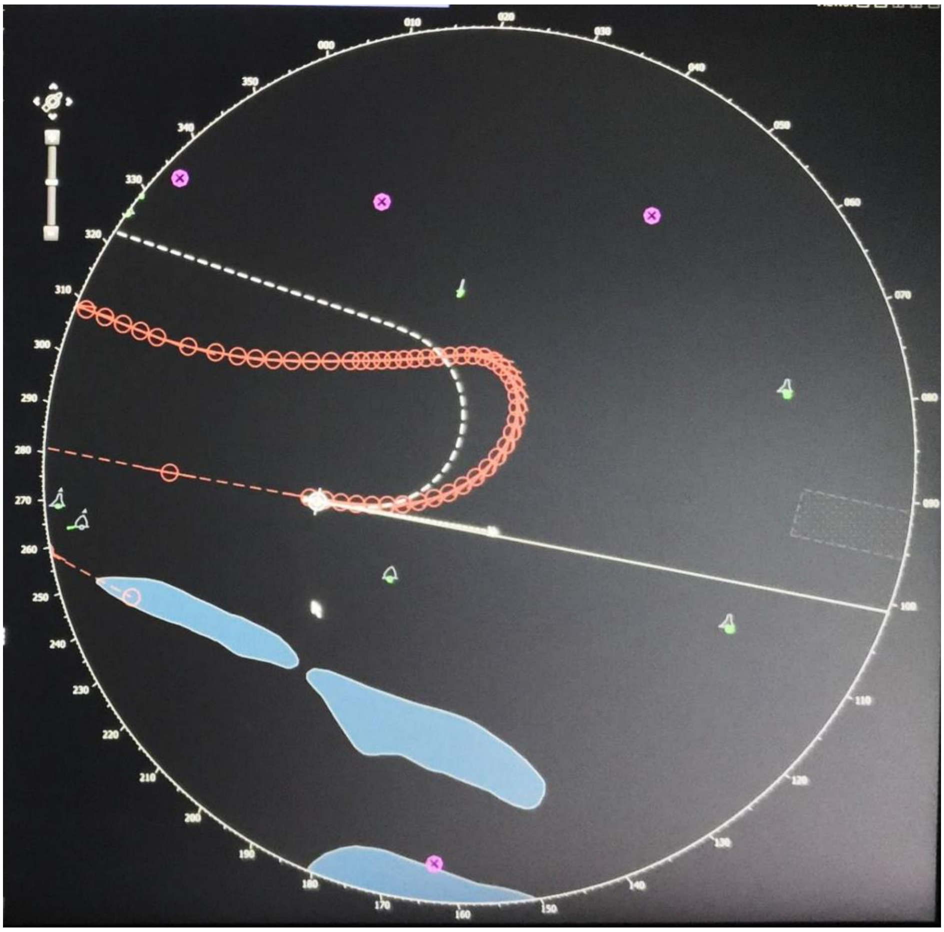

Figure 49: Curved heading line, heading mode: planned track (white) [112]

Actually steered track on the evening of the accident for comparison (red)

When making the first turn, it was noticeable that the ship did so with an offset to the east, i.e. further east than originally planned, apparently due to the control algorithm. The radius was larger than intended (planned: 0.4 nm). In the north-eastern 'corner' of the loop, when the influence of the flood tide stream on the MUMBAI MAERSK's stern should have reduced the turning radius (as it did on the evening of the accident), the control system altered the rudder angle such that the radius continued to be sailed evenly. However, since this happened with an easterly offset and with a radius enlarged by the flood tide stream, the ship ran over buoy 4b.

[112] Source: Ship ECDIS with trackpilot of the simulator at Bremen University of Applied Sciences, screenshots of various tracks of the executed manoeuvres, 2022 (night mode).

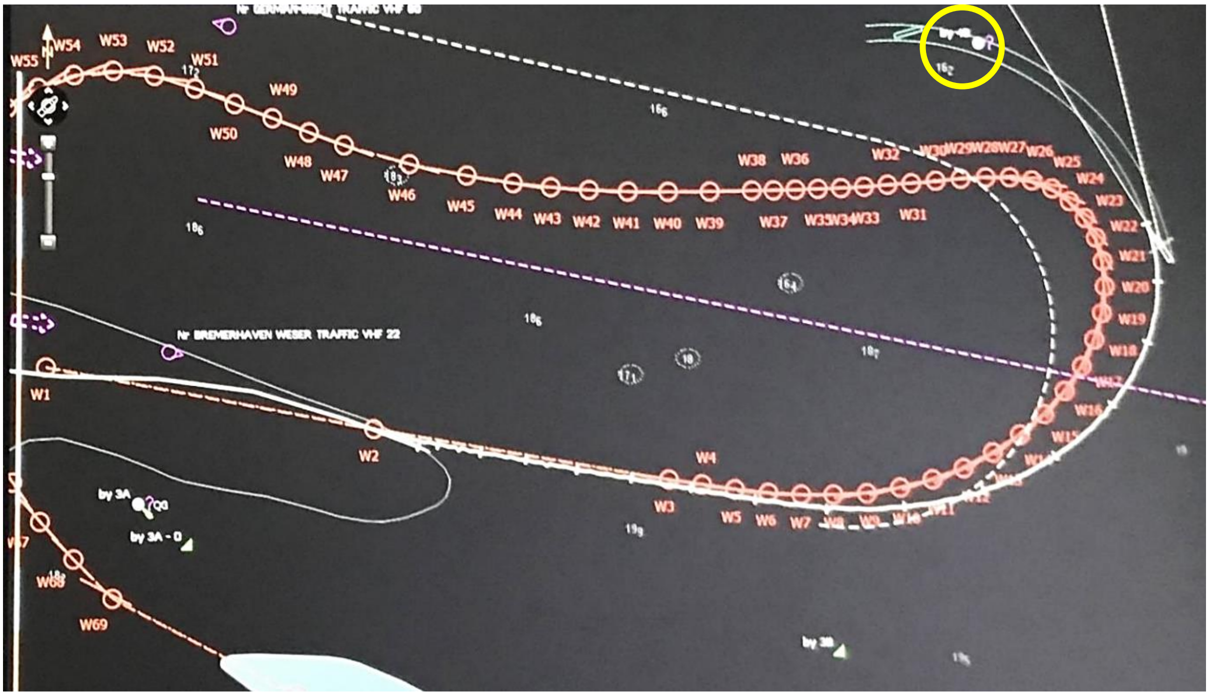

Figure 50: Curved heading line, heading mode

Planned track (white dashed, left) and track actually steered (white, right), buoy pair (see yellow outline)[113]

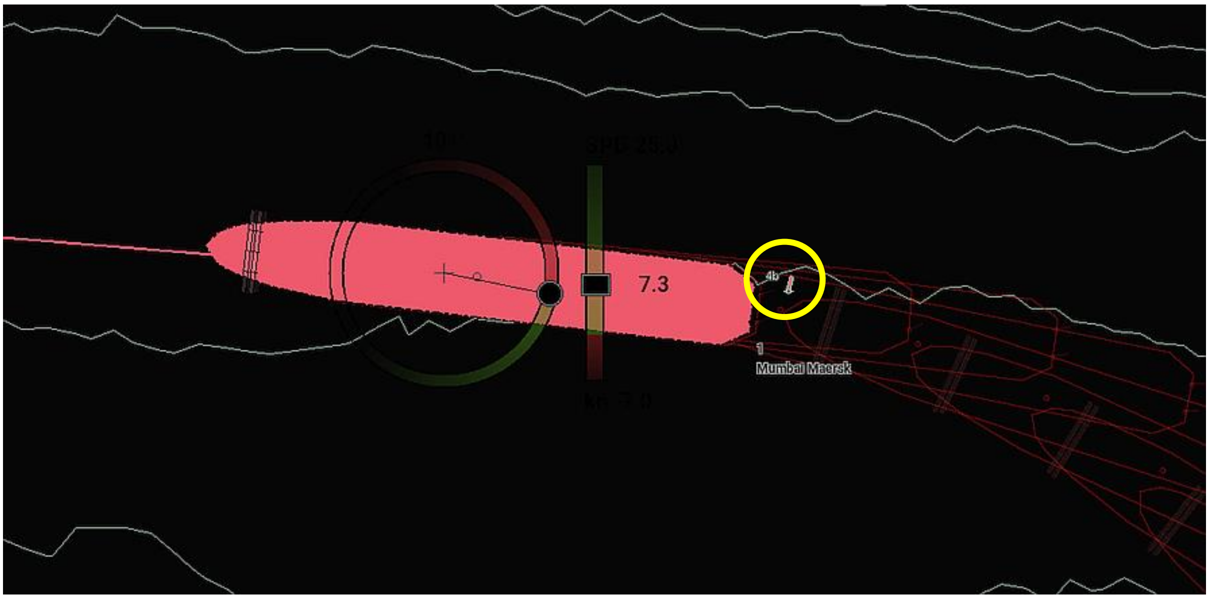

Figure 51: Curved heading line, heading mode

Track with ship's outline; run-over buoy 4b (see yellow outline)[114]

[113] Source: Ship ECDIS with trackpilot of the simulator at Bremen University of Applied Sciences, screenshots of various tracks of the executed manoeuvres, 2022 (night mode).

[114] Source: Trainer ECDIS of the simulator at Bremen University of Applied Sciences, screenshots of various tracks of the executed manoeuvres, 2022 (night mode).

The simulator team explained that the underlying algorithm in HDG mode does not work with GPS positions, but rather with the speed through the water (from the speed log) and rate of turn. This means that the control system would not “notice” the offset and drift in this situation, and that these factors should have been considered by the operator in advance.

Based on the experience gained during the first turn, the second (the U-turn) was executed in course mode[115], also using the curved heading line. This manoeuvre was carried out without any problems.

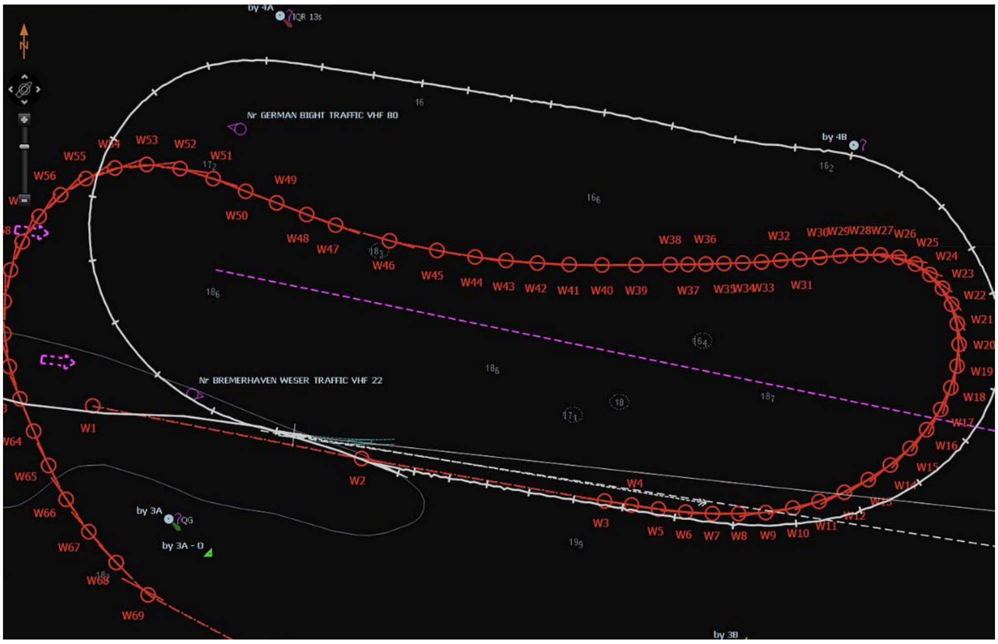

Figure 52: Curved heading line, course mode

Total track steered

When comparing these two methods of turning (with autopilot and the track planned in advance), course mode (the method that compensates for set and drift due to current and wind) obviously delivers the more successful result. This was especially true under the prevailing tidal conditions: As described, the flood tide stream acted on the MUMBAI MAERSK's stern during both turns on the day of the accident.

Neither of the other semi-automated manoeuvres with curved heading line resulted in smaller radii than with manual steering. Accordingly, the turning circle could not be made smaller even in course mode, only more precise.

[115] In course mode, the autopilot automatically steers the ship along a predefined course line over ground. External influences such as wind and current are compensated. The direction of the keel does not necessarily have to stay constant or correspond to the steered course over ground.

4 ANALYSIS

4.1 Non-contributing factors

After examining all available documents and data, as well as conducting further investigations and research, the following factors can be ruled out as having possibly caused or contributed to the accident:

- Fatigue → *All members of the bridge team had adequately long rest periods immediately before their duty or watch, as well as in the preceding days*.
- Use of outdated navigational charts or an outdated presentation library → *The ENCs in use were up to date and complete, all symbols were correctly displayed in the ECDIS*.
- Failure to consider ECDIS safety settings (ECDIS alerts and hazards) → *The dumping ground could not have been detected by the look-ahead sector in time to avoid a grounding*.
- User-unfriendly navigation system → *By integrating all navigation tasks into a single hardware and software platform, along with a wide range of functions for all four phases of voyage planning, the bridge team had access to a suitable system. Chart system, radar screens and conning display could be viewed simultaneously at any time by both pilot and captain.*
- Location of the spoil ground → *Due to its position parallel to the prevailing tidal currents, there is no lateral erosion of material into the navigational channel. The buoyage (marking of a channel with buoys), particularly buoys 3a and 3a-O, clearly separates the fairway from the spoil ground.*
- Long-term planning of vessel arrivals → *The changes to the ships' arrival schedule were caused by simultaneously occurring, unforeseen changes at short notice, which could not have been anticipated in advance.*

4.2 Contributing factors

The investigation identified the following factors that can potentially have contributed to the course of the accident:

- Incomplete marking of no-go areas along the route and cluttered ECDIS displays → *Unsafe waters were not clearly identifiable at first glance*.
- Captain's ECDIS centred on the port for more than 50% of the time → *The captain could not focus fully on the surrounding sea area and was distracted from the navigation of the vessel.*
- Representation of the dumping ground in the electronic navigational chart, especially in night mode within the shallow contour → *Due to a low contrast and*

the large amount of chart information shown, the spoil site, which was not identified as such at user level, was difficult to see.

- Inadequate MPX and planning of forthcoming manoeuvres after deviating from the passage plan → *The required manoeuvring space under the prevailing environmental conditions at the time of the accident (especially wind and current) and navigational chart information on the surrounding area were not sufficiently evaluated before initiating the reciprocal-course manoeuvres*.
- Performance of several tasks simultaneously, especially by the pilot, as well as a high volume of communication → *Not all tasks could be given sufficient attention at all times*.
- Safe navigation, manoeuvre planning, and evaluation became secondary → *The primary focus shifted to reaching the berth within the closing tidal window and to the communication associated with this task. Safe navigation of the vessel, along with planning and assessment of upcoming manoeuvres, received less attention.*
- Reduced situational awareness among the bridge team → *A high level of external communication, inadequate internal communication as well as the way the MFDs were employed all contributed to, among other things, limited perception of the navigational situation and insufficient anticipation of dangerous situations*.

4.3 Voyage planning and execution

The investigation identified various safety aspects in connection with voyage planning and execution, which are evaluated below.

4.3.1 Voyage Appraisal & Planning – before the voyage

The MUMBAI MAERSK's ship operator provided various procedural instructions, document templates, tools and aids for voyage planning in the SMS. The notes in the passage plan about marking specific information in the navigational chart (see Figure 25) and, in particular, the additional information on no-go areas mainly concern the use of paper charts. Accordingly, they are not fully applicable to the MUMBAI MAERSK (primary navigation instrument: ECDIS) and at times misleading (reference to the use of felt-tip pens etc.). Neither the SMS template for the passage plan nor the relevant procedural instructions contain any guidance or options for entering alarm indications or contour lines.

A combination of various factors contributed to the spoil site near buoys 3a and 3a-O not being perceived as an unsafe sea area at first glance:

1. No-go areas on the planned route were not consistently labelled as such. The own safety line ended at buoys 3a and 3a-O.

2. The shallow contour was not reduced and therefore displayed on the same depth contour as the safety contour – on the 20 m depth contour, facilitated by the unavailability of a 15 m depth contour in the ENC. The much shallower water over the sand bar and the spoil site near buoys 3a and 3a-O was therefore not highlighted.
3. A spoil site is an area in which the water depth is subject to change and significantly shallower than that of the immediate surroundings. It is marked in ENCs with a magenta-coloured, dashed and inwardly jagged contour line, as well as a [i] symbol, but not with the label 'Spoil Ground' as on paper charts. However, immediately adjacent to the fairway it would have been appropriate to be able to identify the spoil site quickly. A user symbol would have been a suitable way of highlighting this. The low contrast between the magenta lines and indications in night mode within the shallow contour (see Figure 30 and Figure 31), combined with an overload of additional magenta chart information on the ECDIS (see 4.3.2.2), may have contributed to the discharge area not being recognised as a hazard.

The investigation of the voyage planning indicates that the VPO is not fully aware of how to handle various features of the NACOS Platinum ECDIS:

1. User symbols for the approach to the Jade estuary (Wangerooge fairway) were not hidden. In the TSSs in the German Bight, various text annotations for other routes were also displayed. This contributed to the screen being cluttered with various items of information.
2. When own safety lines were used, they were sometimes plotted the wrong way round, i.e., with the hatched side of the line pointing to the safe fairway. In addition, own safety lines were plotted incompletely at various points and did not completely enclose unsafe sea areas. In the approach to the dredged fairway of the Neue Weser and along the Wangerooge fairway, the lines appear to be merely an additional visual fairway boundary. They do not link individual water depths of greater safety depth (grey depth information) along the shallower waters, and thus do not clearly separate safe and unsafe sea areas. Between buoy pairs 3a/4a and 5/6, there are safe depths outside the own safety lines, meaning that the lines artificially restrict the manoeuvring space. A safety-depth setting as on the day of the accident, on the other hand, results in unsafe depths within the lines further south on the Wangerooge fairway.

4.3.2 Voyage Execution & Monitoring – during the voyage

4.3.2.1 Navigation and communication timeline

Based on the available VDR data, a timeline containing the following information was created to analyse various aspects, such as situational awareness, bridge resource management, and communication:

- course alterations;
- speed alterations;
- range of the ECDIS and radar displays;
- use of the autopilot;
- the pilot's communication on VHF and mobile phone;
- communication on the bridge;
- other radio traffic (heard on the bridge).

The timeline covers the period from 2200 until the grounding at 2305 and can be viewed in Figure 53:

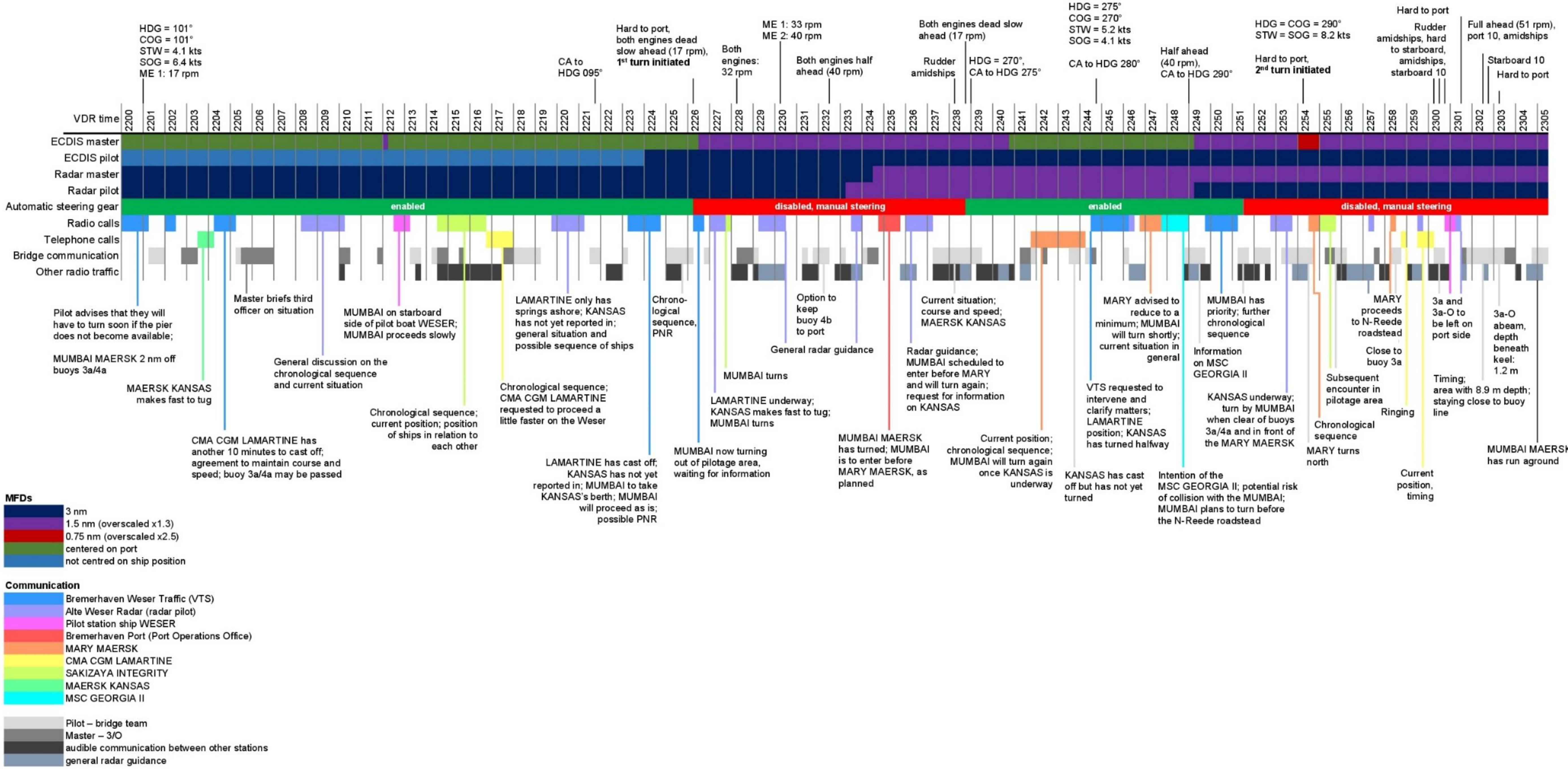

Figure 53: Timeline for navigation and communication from 2200 onwards[116]

[116] Source: VDR of the MUMBAI MAERSK, sensor data, 2022. All times are VDR time.

4.3.2.2 Using the integrated navigation system

The inclusion of irrelevant user symbols on the ECDIS screens used by the pilot and master contributed to a cluttered display (see Chapter 4.3.1). All available chart information, along with additional details on navigational marks and other objects, was displayed on the ECDIS screens of both the captain and the pilot. This resulted in overloaded displays.

Both radar images did not contain certain key items of chart information, such as water depths, for the pilotage area. Since the pilot's radar display did not show any user symbols, the (incomplete) plotted own safety lines and other no-go areas were not visible. The chart underlay on the radar displays could therefore not act as an adequate back-up for the electronic navigational chart, e.g., when the ECDIS displays were not centred on the ship's own position.

For extended periods, the master only used the chart information on the radar for voyage monitoring, because his ECDIS was centred on the port and the pilot's on the TSS. Accordingly, during the first passage of the dumping ground south-east of buoys 3a and 3a-O and up until shortly after the first hard-to-port rudder angle (2153-2224), only the two radar displays with a 3 nm range were focused on the ship's position and surrounding sea area. Briefly switching the ECDIS from the port view to the ship's own position for about 15 s at 2212 hardly offered sufficient time to evaluate all relevant chart information on the surrounding sea area.

The exclusive use of S-band radar with anti-clutter sea (sensitivity time control) resulted in poorer resolution and visibility of radar targets at close range. It would have been easier to identify the actual position of buoys in the Neue Weser fairway with an X-band radar, and possibly a weaker anti-clutter sea setting.

Since all ECDIS alerts were switched off on the four available MFDs, there were no audible alarms when crossing the safety contour or approaching navigation hazards and special areas. The look-ahead sector was only used on the master's ECDIS, as this was the only ECDIS to have one of the ECDIS hazards (crossing safety contour) activated. Due to the disabling of the other ECDIS hazards ('Show navigation hazards ahead' and 'Show crossing special areas'), dangerous objects and areas were not highlighted. Exceptions included contour lines and isolated dangers. Since the settings were not changed when crossing the safety contour, and the look-ahead sector was therefore permanently highlighted in red, it was easy to overlook predicted hazards or they were more difficult to recognise.

If the safety contour is deliberately crossed (as was the case here, see Chapter 3.2.6.2), the alarm (audible and/or visual) for nearing the own safety lines (NACOS Platinum) must remain activated to preserve the integrity of the ECDIS anti-grounding function. This function necessitates clearly defining navigable areas by manually marking no-go areas within the safety contour. This was not implemented.

The look-ahead sector is limited in that it is based on the current course over ground (COG). Accordingly, if the ship is turning during a course change, it is possible, especially in pilotage areas, that the look-ahead sector will generate alarms when dangerous areas or objects that are still ahead are touched. However, with the rate of turn during the course alteration, these would never be reached. In a pilotage area, especially in narrow, winding fairways, it can therefore be useful to switch off the corresponding alarms and to only keep visual highlighting of the ECDIS hazards enabled, for example. Moreover, during a course alteration away from a planned route – as in the present case – it is also possible that dangerous areas and objects (such as buoys 3a and 3a-O and the dumping ground beyond them) will not be recognised by the look-ahead sector function in time, because the vector of the ship (over ground) is calculated from speed and current COG, and therefore, unlike the curved heading line or prediction based on the rate of turn, does not 'point around the corner'.

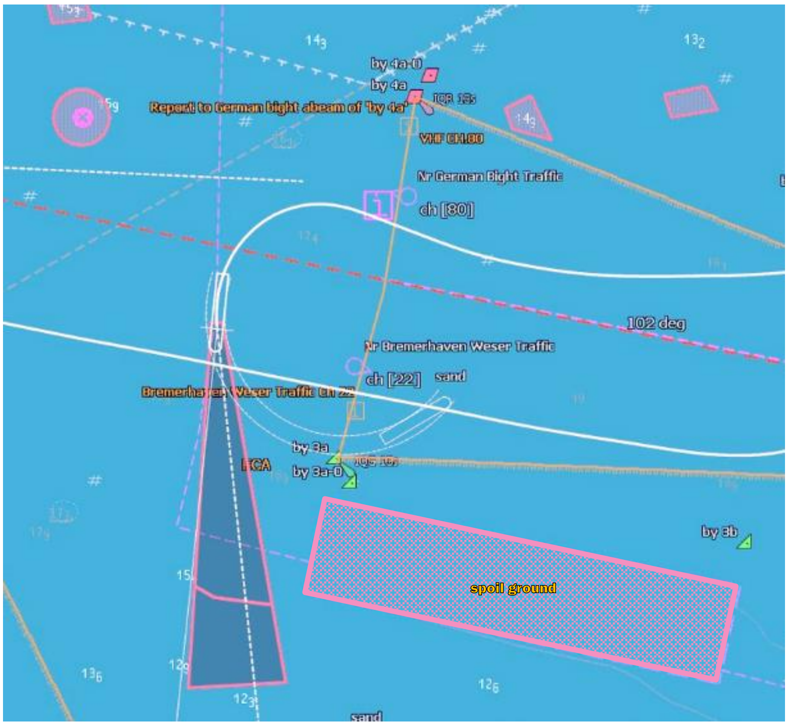

Figure 54: Spoil ground with highlighted user symbol[117]

Accordingly, even if the ECDIS alerts and hazards had been activated, the system would not have issued a timely warning during this course alteration situation. It would

[117] Source: VDR of the MUMBAI MAERSK, ECDIS screenshots at various times, 02.02.2022.

not have been possible to evaluate the alarm and take appropriate action in time to avoid ground contact.

4.3.2.3 Master/Pilot Information Exchange (MPX)

The MPX on board the MUMBAI MAERSK did not comply with IMO Resolution A.960(23) (Annex 2, Section 5) or the recommendations of the International Maritime Pilots' Association (IMPA). The following aspects were neither part of the MPX nor discussed in detail subsequently:

- shipboard voyage planning and navigation hazards along the planned route;
- weather, water depths, tides and currents;
- dimensions and manoeuvring characteristics of the MUMBAI MAERSK;
- contingency plans with possible abort points[118] and point of no return (PNR).

The MUMBAI MAERSK's bridge team had already called at Bremerhaven several times before and the pilot was familiar with the class of ship (Maersk EEE Class, second generation). However, the 'IMPA Guidance on the Master-Pilot Exchange (MPX)' reads: "The information exchange should not be abandoned for ships that call on a frequent basis; such vessels have the potential to induce complacency."[119]

After the MPX, the master said: "We are relying on two other ships. That's not good." The pilot agreed with him and both doubted, based on previous experience, that the CMA CGM LAMARTINE and MAERSK KANSAS would cast off in a timely manner. Abort points, the PNR and possible manoeuvres (turning circle, speed, available sea area, influence of environmental conditions on manoeuvrability, courses to be steered afterwards, etc.) were not discussed. Environmental conditions (wind, current) were not addressed, either. Such preparations for the worst-case scenario (MUMBAI MAERSK cannot enter and must turn) would still have been possible at this point without causing additional time pressure.

4.3.2.4 Alteration of the passage plan before entering the Neue Weser channel

As was the case here, a deviation from the planned route at short notice may become necessary during the course of a voyage. Marking no-go areas on the chart helps the bridge team to quickly decide on the extent to which the ship can deviate from the route without jeopardising her safety. The alteration of the passage plan must be agreed upon between the master and pilot. Following that, it must be communicated to all other members of the bridge team. It must be guaranteed that all bridge team members have an up-to-date mental model. This is the only way to ensure that all team members

[118] Abort points: Points at which the route may still be altered after a technical failure or other emergency on board, e.g., in the direction of an emergency anchorage.

[119] Source: International Maritime Pilots' Association (IMPA), IMPA Guidance on the Master-Pilot Exchange (MPX), 2023.

have the same perception of the situation and can perform their respective tasks effectively.

Quite a while before entering the pilotage area, it became increasingly clear that the MUMBAI MAERSK would not be able to enter the Neue Weser fairway as planned. No new passage plan was discussed. Manoeuvring decisions were made on the spot.

During the manoeuvre, the pilot communicated with four external bodies: the VTS, radar advisor, SAKIZAYA INTEGRITY, and Port Operations Office. The BSU had the impression that insufficient attention was given to the navigation of the vessel between the radio transmissions.

The turn after the first manoeuvre was steadied extremely late, and the MUMBAI MAERSK sailed very close to the centre of the fairway. After the rudder was put to amidships, the bridge team did not alter course significantly to starboard (further north). To maintain a clear distance of at least 0.3 nm from the fairway centreline for the next reciprocal-course manoeuvre, a course over ground (COG) of approximately 285° would have been required. As a result, the necessary manoeuvring space for the second turn was lost.

4.3.2.5 Second reciprocal-course manoeuvre

Before an initially unplanned manoeuvre, an evaluation must be made as to whether the available sea area (traffic, depths, navigation hazards) is adequate for the planned manoeuvre. Moreover, the fact that environmental influences can affect the ship's manoeuvring and handling characteristics must be considered.

The second reciprocal-course manoeuvre was initiated at an earlier time than communicated by the pilot to the radar advisor immediately beforehand. The MUMBAI MAERSK was not yet clear of the buoys, and a dangerous close-quarters situation with them developed during the turn. As with the first turn, the pilot was heavily involved in external communication. He was communicating with five external bodies: MARY MAERSK, SAKIZAYA INTEGRITY, radar advisor, CMA CGM LAMARTINE, and Bremerhaven Weser Traffic.

The consequences of the master's proposal to keep buoy 3a to port were neither addressed nor discussed. Measurements in the ship-handling simulator at Bremen University of Applied Sciences showed that it is not possible for a ship such as the MUMBAI MAERSK to pass safely between buoy 3a-O and the dumping ground, especially in the course of a turn. During the second turn, the swept path of the ship was about 94 m[120]. Accordingly, provided that the chart information was completely

[120] Source: BSU (own calculation based on an estimation of the turning radius).

reliable and the buoys were located at precisely the charted positions, the clearance on either side of the ship would have been less than a ship's breadth.

The reliability of the shipboard chart information was specified as Category (CATZOC) B, which corresponds to a positional accuracy of +/- 50 m and a depth accuracy of 1.00 m + 2% of the depth (at a depth of 13 m, i.e., 1.00 m + 0.26 m = 1.26 m). This further restricts the safe manoeuvring space. The master and the third officer had less accurate information on the water depth than that depicted in Figure 54. Moreover, the depth information of a dumping ground cannot be reliably estimated. The distance between the chart position of buoy 3a-O and the magenta-coloured boundary of the dumping ground is only about 120 m. Because the buoys were situated further south-east on the day of the accident (see radar images), and due to the MUMBAI MAERSK's swept path of 94 m, as well as the positional inaccuracies in the chart information, which are not insignificant, the BSU believes that her passing between dumping ground and buoys without running aground or alliding with buoy 3a-O was not possible.

In addition to the factors mentioned in Chapter 4.3.1, an excessive reliance on the accuracy of the chart information (position of the buoys and the dumping ground) may well have contributed to the decision to consider keeping the two buoys on the port side. Neither the pilot nor the radar advisor objected to the plan of keeping the buoys to port. Instead, if anything, they agreed with it (radar advisor: "In that case, that looks better."). Therefore, there was initially no reason for the master and third officer to question this plan. It was only when passing north of the buoys had already become impossible due to the reduction in rate of turn that the third officer noticed a depth indication on the navigational chart of significantly less than 10 m. The characteristics of the sea area beyond the fairway buoys had presumably not been taken into account – neither the shallow water depth in general nor the position of a dumping ground there.

The increase in propeller speed and the subsequent starboard rudder angle ultimately led to the grounding at a speed of approximately 11 kts. The final hard-to-port command had no effect. Due to the vessel’s forward motion and its position relative to buoy 3a-O and the dumping ground, it had become impossible to generate a sufficient rate of turn to port to avoid the head-on grounding.

4.3.2.6 Bridge Resource Management (BRM)

Not all the resources and information available to the crew were focused on voyage monitoring, and the surrounding sea area was not evaluated carefully enough using chart information. Insufficient situational awareness on the part of the members of the MUMBAI MAERSK's bridge team resulted in dangerous situations not being anticipated. The main focus of the communication was on chronological sequences and subsequent encounters between the various ships, and less on safe navigation.

Not all tasks could be given the necessary attention due to the distribution of tasks among the bridge team and, in particular, because pilot and third officer took on several tasks simultaneously.

"Mistakes cannot always be avoided, but good procedures and teamwork create measures to detect these mistakes and mitigate their effects."[121] "Under the 'challenge and response' approach, bridge team members are encouraged to challenge operational decisions at all levels."[122] This is also called for in the ship operator's SMS Document P081 on bridge team management. If a team member's action is not understood or deviates from the agreed plan, clarification should be sought so that the intended action can be explained, changed, or adjusted to ensure the safety of the ship. For effective collaboration, all team members should have the same perception of the situation, as well as understand the intended measures and how they are to be executed. To achieve this, it is advisable to share one's own 'mental model' with the other members of the bridge team, e.g., by employing the 'thinking aloud' technique. Thoughts and intentions, their reasons and desired results are expressed early on. A passage plan with clear boundaries enables every team member to intervene in critical phases. "The absence of a detailed, mutually agreed-upon passage plan deprives bridge team members of the means to effectively monitor a vessel's progress, compromising the principles of bridge resource management."[123]

The third officer did not have a radar display at his disposal. He could only track the ship's position on the navigational chart and monitor progress along the route on the ECDIS planning station (see Figure 32), for example. Accordingly, it was not possible for him to perform his role as co-navigator properly at all times. Language barriers also contributed to this. It was difficult for him to get involved, as the manoeuvres executed were not discussed within the team early on, no new passage plan was developed, and manoeuvres were initiated on the spur of the moment.

"The bridge should be free from distractions, and all non-essential activity should be avoided."[124] This includes confining internal and external communication to the safe navigation of the ship. However, pilots are not only a part of the bridge team, but also a part of the port team. In addition to navigating the ship, they often have to communicate with other parties outside the ship. A high level of VHF traffic can be a major distraction in busy ports.

[121] Source: International Chamber of Shipping, Bridge Procedures Guide, p. 23, 2022.

[122] Source: International Chamber of Shipping, Bridge Procedures Guide, p. 29, 2022.

[123] Source: Di Lieto, Hederström, Listrup, Nijjer, 'Mental models in confined waters', Seaways (06/2018), 2018.

[124] Source: International Chamber of Shipping, Bridge Procedures Guide, p 30, 2022.

This was also the situation in the case at hand. Between 2200 and the grounding at 2305 (VDR time), the pilot spent almost half of his time engaged in external communication on VHF or his mobile phone (see Figure 52).

The 'sharing the mental model' approach also applies to the pilot: "The pilot should always be expected to explain instructions exchanged with other ships, pilot boats, tugs, and vessel traffic services to the master and bridge team in English or a defined working language common to all personnel involved."[125]

Especially as a member of the 'shore team' comprising pilots, radar advisors, VTS, and the Port Operations Office, the pilot of the MUMBAI MAERSK actively ensured that any new information was shared with all parties. This resulted in an extremely high volume of communication with ten different people, partly due to the partially inadequate radio and communication discipline (e.g., the use of first names instead of the designations of the radio stations).

The pilot also attempted to share his mental model with the bridge team. He explained parts of his external communication to the team, primarily the master. While the master appeared to understand large parts of the pilot's communication in German, meaning fewer explanations were necessary, the third officer was somewhat left on the sidelines. Both the pilot's and the master's mental models were dominated by traffic planning (arrival times and encounters in the pilotage area, position of the ships in relation to each other). This was also reflected in the master's use of the ECDIS, which was directed at the port for about half of the time between 2200 and the grounding at 2305 (VDR time). Mental models relating to alternative manoeuvres and the course of the voyage were not shared.

The following indications of a partial loss of situational awareness were found:

- The first turn was already initiated so spontaneously that it only became apparent during its execution that the available manoeuvring space was limited. The flood tide stream assisted the vessel's turn by acting on the stern.
- After this turn, the MUMBAI MAERSK navigated closer to the radar line than to the northern buoy line. Due to the high volume of communication in the final phase of the turn, the BSU had the impression that the vessel's movement was only corrected at a late stage.
- Since the second turn was also initiated spontaneously, the investigation team is of the opinion that the tight manoeuvring space between the wheel-over-position and buoy 3a can only have been recognised in the course of the turn. An evasive manoeuvre – bypassing buoy 3a-O on its south as planned – had to be initiated, involving an increase of the turning radius. This put the MUMBAI

[125] Source: International Chamber of Shipping, Bridge Procedures Guide, p. 34, 2022.

MAERSK on a course toward the dumping ground, which could no longer be altered.

- An attempt was made to pass between the dumping ground and buoy 3a-O.
- The dumping ground and the associated shallow was only recognised and addressed by the crew of the MUMBAI MAERSK and all other parties at an extremely late stage.

The contributing factors summarised in Chapter 4.2 also played a role in this part.

4.4 Approach planning

4.4.1 General coordination

A fundamental weakness that evening was the failure to report, or the delayed reporting of, departing vessels' delays to the traffic control centre. As a result, both the VTS station and the incoming vessels lacked crucial information. Reactions to the various and repeated changes in the traffic management plan, as well as the necessary adjustments at multiple other points, had to be made and coordinated at very short notice. The departure delays of CMA CGM LAMARTINE and MAERSK KANSAS did not simply cause two changes to the traffic management plan, but many. Each of the numerous reported delays, which repeatedly pushed back departure times, altered the schedule once again and triggered a cascade of planning activities in different areas in the background (see also Chapter 3.2.9.3).

Short-term rescheduling activities are not centrally coordinated in Bremerhaven. Rather, they take place simultaneously at the various mentioned bodies (terminals, both VTS stations, harbour pilots, river pilots, tug owners, agencies etc.) without each party knowing the planning of the other. As a result, they must also be coordinated with one another after each adjustment to account for the changed circumstances.

This method of incorporating short-term changes means that the plans of the various operators only become known gradually, as it takes longer for an overall picture to emerge. If individual pieces of information are gathered independently at an early stage, there is a risk that only an interim status will be obtained, with subsequent changes needing to be gathered again or potentially missed.

4.4.2 Coordination on board

The individuals directly involved in the incident, particularly the pilot of the MUMBAI MAERSK, who was responsible for the communication in German, were in a state of considerable planning uncertainty and heightened stress throughout the observed period. This resulted from the fact that they felt they constantly needed to obtain information themselves – on the one hand, due to the unforeseen delays in the departure of the vessels occupying the berths, and on the other, due to the impact of these delays on the existing traffic management system.

The pilot remained in continuous communication with the VTS station. However, the coordination of vessel arrival sequences was not seamless at all times. The vessel frequently communicated separately and consecutively with each shore-based station in an attempt to obtain complete information, as there were multiple changes to the arrival sequence, or because the designated sequence conflicted with the actual positions of vessels in the fairway.

Vessel Traffic Service Bremerhaven argued that they believed it would have been sufficient if the pilot had waited until all information had reached the VTS station, allowing it to act as a central information hub. In the opinion of the BSU, this would probably have meant not keeping the planned time slot – which, however, all parties were apparently trying to achieve.

4.5 Pilot allocation

The comparison between the Elbe and Weser/Jade areas shows that many circumstances of the incident evening correspond to the conditions on the Elbe, which the WSA Elbe-Nordsee uses to justify the allocation of two pilots to EEE-class vessels and other ships of comparable size (see Chapter 3.2.9.2). These include:

- restricted overview of the immediate surroundings from the conning position due to its location and dimensions of the bridge;
- a high volume of communication combined with challenging navigation work (especially when turning);
- restricted manoeuvring space in certain areas;
- the need for a second pair of eyes, as one person was already fully occupied with external communication and traffic management planning;

  The second person could have focused entirely on monitoring the immediate vicinity and, with their in-depth knowledge of the pilotage area and underwater topography, provided preliminary assessments to the communicating pilot, who would have focused on maintaining overall situational awareness. This would have shortened decision-making timeframes and improved the quality of decisions.
- The pilot was forced to manage the high volume of communication on the bridge without additional local expertise, while simultaneously ensuring safe navigation. Additionally, time constraints and pressure, combined with a constantly changing situation, created a continuous stream of necessary communications with the port, VTS centre, radar advisor, and other vessels.

4.6 Communication

The fact that the radio stations were not named as such, but rather first names were used, contributed to the master's inability to develop full situational awareness. It is impossible for external parties to understand which radio stations are involved when these are not addressed properly.

Increased communication by mobile phone can be a problem in certain situations because only the person on the phone can hear the other party's replies. In a time-sensitive situation, as was the case here, there is often insufficient time to keep the rest of the bridge team adequately informed. Although this basically also applies to radio communication in the pilotage area’s language, the mobile phone adds a further means of communication to those that exist. This exacerbated an already overloaded situation on the evening of the accident.

5 CONCLUSIONS

After investigating and evaluating all available information, the BSU has arrived at various conclusions. Building upon this, specific safety recommendations are then provided to avoid similar accidents in the future.

5.1 Voyage Appraisal and Planning – before the voyage

- The accident highlighted the importance of ensuring that the passage plan includes information on the settings of contour lines for different voyage segments and alarm management. At the same time, the relevant procedural instructions for voyage planning have to be internally consistent. Unsuitable safety settings on the ECDIS can, on the one hand, render warnings and alarms meaningless or so intrusive that they are ignored or disabled. On the other hand, an impractical display of objects and isolated hazards within the safety contour – particularly when crossing it is unavoidable – can make it more difficult to identify shallow areas, for example.
- The delayed recognition of the discharge area and the associated risk of grounding resulted from the difficulty in distinguishing safe from unsafe waters at a glance. No-go areas must therefore be consistently marked with appropriate user symbols to ensure they are reliably identified, even in time-critical situations.

5.2 Voyage Execution and Monitoring – during the voyage

5.2.1 Using the integrated navigation system

- The settings that had been made on board the MUMBAI MAERSK were unsuitable for effective voyage monitoring and contributed to the impairment of situational awareness. The alarm settings must be configured according to the respective voyage segment.
- The automated alarms and warnings via the COG-based look-ahead sector did not constitute an appropriate addition to the manual monitoring of the surrounding sea area, especially during the turning manoeuvres.
- The BSU is of the opinion that the MFDs used by the navigator should not allow prolonged use of the ECDIS in browse/planning mode while underway for viewing areas away from the vessel's own position, especially if the cursor is not moved. Onboard MUMBAI MAERSK, this contributed to a reduction in situational awareness, as the vessel's progress was not continuously monitored on the navigator's ECDIS.

5.2.2 Chosen manoeuvres

- Prior manoeuvre planning and foresighted positioning of the ship in the fairway would have enabled both turning manoeuvres to be executed safely. Sufficient manoeuvring space was, in fact, available between the buoy pairs in the approach to the dredged Neue Weser.
- The widening of the turning circle during the return turn ultimately led to the vessel's grounding. A turn between buoys 3a and 4a would have been safely possible if the manoeuvre had started further north or west. However, even at the chosen starting position, grounding would not necessarily have occurred without the intervention, though contact with buoy 3a could not have been ruled out.
- The BSU believes that the evasive manoeuvre that was ultimately chosen – passing between the buoy and the discharge area – would always have failed. This is especially true given the initial conditions, where the vessel was already in a turning motion in close proximity to the buoys, as well as the prevailing current and wind conditions.
- However, in the opinion of the BSU, the root cause of the accident was not merely the decision to attempt this manoeuvre. The real issue was that an experienced bridge team found itself in a situation where such a decision had to be made at all.
- There was no discussion about aborting the manoeuvre due to the uncertain time frame. In situations in which safe passage appears at risk, it should be considered to forgo the entry and wait for the next tidal window.

5.2.3 Bridge Resource Management (BRM)

- The accident demonstrated the value of discussing navigation-related matters at an early stage, such as during the MPX. On MUMBAI MAERSK, there were no manoeuvre plans for potential alternative or emergency manoeuvres due to a lack of preparation. As a result, the decisions to initiate opposite-course manoeuvres were made ad hoc on two occasions.
- On the day of the accident, the high volume of communication made it impossible for the pilot alone to ensure safe navigational advice. He did not have sufficient resources to diligently perform all his duties as a member of both the shore-based and the bridge team.
- Internal communication (content, topics), language barriers and a lack of technical resources (no dedicated MFD) meant that the third officer could not perform his duties as co-navigator and “safety barrier” effectively. Effective use of bridge resources (both technical and human) and focused team communication, however, are essential for maintaining situational awareness.

- Information processing on the bridge, including the (necessary) additional radio communication heard over the radio, was overloaded. In the case of a significantly increased volume of communication and/or unforeseen changes to the passage plan, it must be ensured that safe navigation and voyage monitoring remain the top priority for the bridge team.

5.3 Approach planning

- Changes in ship sequence and approach planning could not be shared in real time with all involved parties. The absence of a central information system caused delays in information transmission to all stakeholders and led to an increased volume of communication.
- As a central communication hub, the VTS centre was not always able to ensure timely sharing of information, particularly in situations involving multiple actors and deviations from the original arrival plan.

5.4 Pilot allocation

- The ship only had one pilot that evening. As a rule, this practice does not pose a problem in this pilotage area. However, in the opinion of the BSU, it would have been extremely beneficial on the evening in question if the pilot on board had been accompanied by a colleague solely responsible for communication, since this really did take up about half of his time (see above).

5.5 Communication

- Maintaining radio discipline between the involved pilots by correctly identifying radio stations and communicating using only the equipment on board would have better enabled the bridge team to develop complete situational awareness. Maintaining radio discipline between the involved pilots, correctly identifying radio stations, and using only the communication methods designated on board would have better enabled the bridge team to develop a complete situational awareness. Otherwise, other vessels without pilots (e.g., pilot exemption certificate holders, small craft) and bridge team members miss crucial information or cannot interpret it properly.

6 ACTIONS TAKEN

Discussions are currently ongoing for Bremen, Bremerhaven, and Wilhelmshaven regarding the development of a data-driven, centralised arrival planning system for the Rivers Weser and Jade.

In response to this accident, Maersk has revised the basis of its internal ECDIS training programmes. The trainings now explicitly incorporate lessons learned from cases such as the grounding of MUMBAI MAERSK to ensure cross-team knowledge sharing of the gained insights.

The Weser II / Jade Pilots’ Association regularly consults with the GDWS regarding potential changes to the requirements within the pilotage area. The topic of pilot allocation is also regularly discussed. Even after reviewing this accident, however, both parties see no reason to change the existing practice.

7 SAFETY RECOMMENDATIONS

The following safety recommendations do not constitute a presumption of blame or liability in respect of type, number or sequence.

The BSU recognises the conflict between a strong economic interest in maximising the use of existing tidal windows and the safety-related aspects that sometimes contradict this. With this in mind, the BSU endeavours to sufficiently account for both of the two realities in its safety recommendations.

7.1 WSA Weser-Jade-Nordsee

The BSU makes the following recommendations to WSA Weser-Jade-Nordsee:

The existing, historically evolved system of arrival planning for the rivers Jade and Weser should be revised to ensure that information on changes to arrival schedules reaches, or can be viewed by, all relevant parties in real time, as far as this is possible. This could be achieved by establishing a digital, centralised information platform.

Such a platform would not conflict with the responsibilities of the VTS centre or the current communication structure, but would rather serve as a complement to them.

7.2 Weser II / Jade Pilots' Association

The BSU makes the following recommendations to the Weser II / Jade Pilots' Association:

.1 As far as this is possible, mobile phones should not be used for making calls or for any other purpose during pilotage.

.2 In the long term, the focus should instead be on supporting the development of the alternative centralised information platform described in 7.1 and integrating it into the PPU, for example.

.3 In cases where adhering to a time window poses a risk to safe passage, entry should be avoided, and the next tidal window should be awaited.

.4 Basic radio discipline, correctly identifying radio stations, should be maintained at all times. When communicating by radio in the pilotage area, all parties should bear in mind that a lack of radio discipline can deprive certain traffic participants (e.g., pilot exemption certificate holders, small craft) of crucial information or the ability to interpret it properly.

7.3 Federal Waterways and Shipping Administration (GDWS) and Weser II / Jade Pilots' Association

The BSU recommends the following to the Federal Waterways and Shipping Administration (GDWS) and the Weser II / Jade Pilots' Association:

The mandatory allocation of two sea pilots for large vessels in the Weser pilotage area should be reviewed. Many of the arguments put forward by the Federal Waterways and Shipping Agency (WSA) Elbe-Nordsee for implementing this measure on the Elbe (see Chapter 3.2.9.2) also apply to the Weser.

7.4 Mærsk Line A/S

The BSU makes the following recommendations to Mærsk Line A/S:

.1 Appropriate measures, such as training, must ensure that all nautical officers have a deep understanding of the functionality and principles of the ECDIS anti-grounding features.

.2 In the BRM courses for deck officers conducted or arranged by Mærsk Line A/S, special emphasis should be placed on always relaying information to:

- junior officers in the bridge team,
- members of the bridge team who do not speak the language of the pilotage area.

Similarly, special emphasis should be placed on a well-structured distribution of tasks within the bridge team.

.3 The procedural instructions for voyage planning should be revised, and the templates for the voyage passage plan should be updated.

8 QUELLENANGABEN

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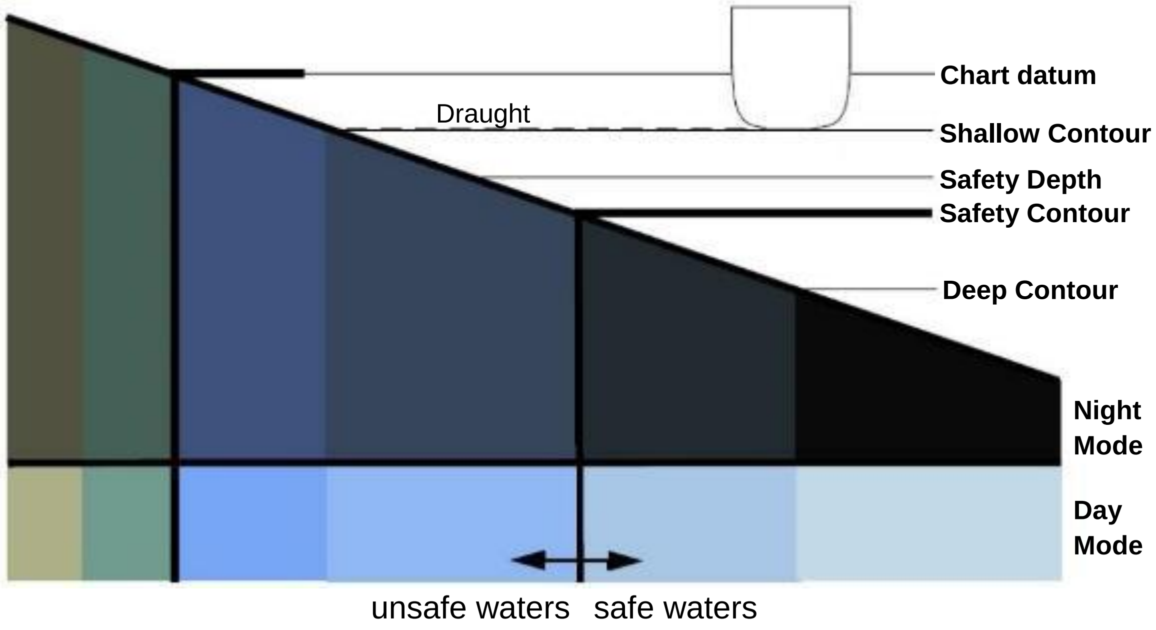
9 ANNEXES

9.1 Explanations and overview of the investigated ECDIS settings

Contour lines	Lines on a navigational chart that separate areas with different minimum water depths, e.g., a 10 m contour line separates waters with depths of less than or greater than 10 m on either side. Depending on the survey of the sea area, such lines are provided for 2 m, 5 m, 10 m, 20 m and 30 m, for example. In the ECDIS, different types of contour line can be adapted for the UKC calculation, allowing areas of varying water depth to be displayed visually.
Shallow contour	The ship's minimum navigable water depth, below which she will run aground. The setting for the shallow contour must be equal to or greater than her draught. If a setting is between existing contour lines, the ECDIS will round down to the next shallower contour – for example, a setting of 8 m will result in 10 m being used.
Safety contour	Distinguishes safe from unsafe water depths or waters, and triggers an audible and visual alarm to warn of potential grounding.
Safety depth	Entered value that affects the visual representation of depth information and – similar to the safety contour – highlights safe and unsafe areas. Equal or lower depths are black (white in night mode), indicating shallow waters, while greater depths are grey, indicating deep waters.
Deep contour	Distinguishes waters where shallow water effects are expected from deeper areas, where such effects are not expected. For a ship with a draught of 10 m, the deep contour can be set at 30 m, for example.



User symbols

In addition to the chart information from the ENCs[126], users can insert additional symbols into the chart manually, such as lines, areas, or text annotations. Text annotations are often used to display important information for the passage, such as which coastal radio station to contact at specific locations and the channel to be used.

Lines or areas are drawn to plot no-go areas in addition to the safety contour, for example. The 'own safety line' in NACOS Platinum is one of the few user icons that triggers an alarm when in close proximity, making it the preferred method for marking no-go areas. The line's hatching points toward the unsafe sea area:

126 ENC: Electronic navigational chart.

Safety corridor	In NACOS Platinum, a safe corridor with a variable width of up to 2 nm can be defined on the right, left, and as part of the planned route when planning the voyage. In addition to the route (one-dimensional), the safety corridor (two-dimensional) is checked for hazards during the automated route check. There should be no hazards such as shallow-water areas or buoys within the safety corridor so that a deviation from the route up to the edge of the defined corridor is possible without an additional check, if necessary, e.g., for collision avoidance.
Scale and SCAMIN	Depending on the zoom level of the navigational chart in the ECDIS (display scale), different amounts of chart information are displayed in the various ENC cells. Similar to paper charts, the cells are created at a certain scale (compilation scale). When the user zooms in, cells of a larger scale with more details are automatically displayed. The compilation to displayed scale ratio is the magnification ratio. The SCAMIN attribute defines the smallest scale at which objects are displayed. The display of various items of chart information based on the zoom level can be disabled, ensuring all objects/chart information are always shown, regardless of the scale used.
Representation of isolated dangers	Isolated dangers and shallow-water areas, e.g., due to wrecks or large boulders, are highlighted using the isolated danger symbol. Depending on the setting, such dangers are displayed both outside and inside the safety contour. 
Display categories, chart information	The user can define the amount of chart information shown in the ECDIS. The display categories 'Base' and 'Standard' are defined in IMO Resolutions A.817(19) and MSC.232(82) for this purpose. Base: Chart information that is essential at all times and cannot be removed from the display → not sufficient for safe navigation Standard: Chart information that should be shown when a chart is first displayed on the ECDIS. → minimum for voyage planning and monitoring

Depending on requirements, the amount of content defined in the standard category can be reduced (Standard '– or Base '+') or increased (Standard '+' or All '–') on the ECDIS display.

In NACOS Platinum, the selected display category is shown at the top of the screen.

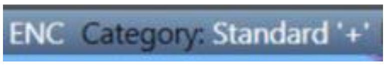
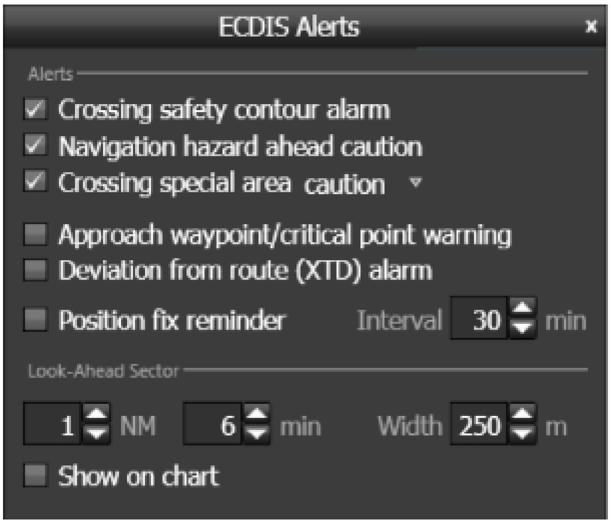


Chart symbols

Setting that determines whether chart symbols (e.g., buoys or lines) are displayed as symbols, similar to a paper chart, or in simplified form.

ECDIS alerts

Various alarms can be enabled and disabled in NACOS Platinum's ECDIS alerts menu:



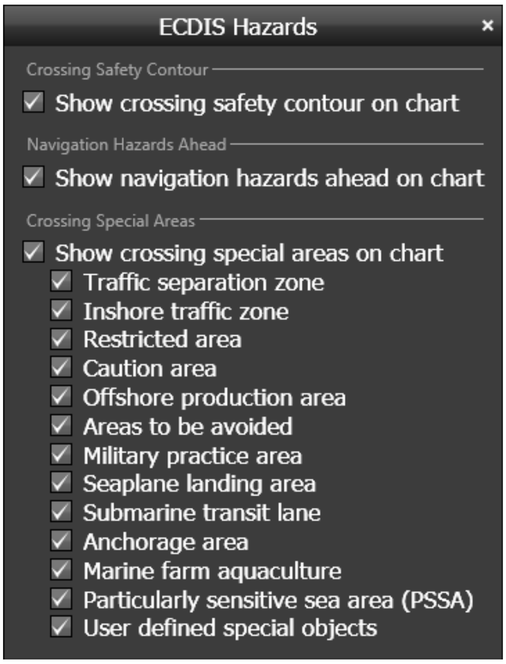
The top three options concern alarms issued when nearing or crossing the safety contour, certain selected navigational risks (ECDIS hazards, see below), and other specific areas (including the own safety line, see above).

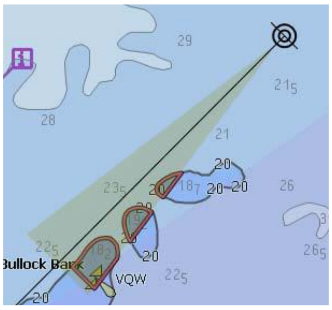
Additional notifications/alarms can also be set for nearing a waypoint on the planned route, deviation from the planned route beyond a pre-defined distance (cross-track distance, XTD), and as a reminder for determining the next position.

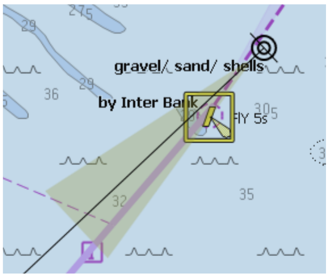
The range of the look-ahead sector, optionally displayed as a transparent yellow triangle ahead of the ship on the chart, determines when selected alarms are enabled.

ECDIS hazards

NACOS Platinum's ECDIS hazards menu is used to define which potential navigational risks should be additionally highlighted within the pre-defined look-ahead sector or planned safety corridor (see below):



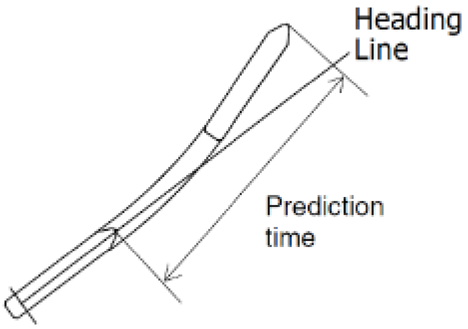




Prediction/ curved head[ing] line

The prediction or curved head[ing] line can be displayed in large scales (range of 1.5 nm and less) via an option in the ‘vector and trails’ menu. It shows the predicted track with the ship's outline and is based on the current rate of turn (ROT) and speed over ground (SOG). Unlike the true vector over ground, which is calculated using the course over ground (COG) and SOG, the prediction can also define a curve.

A prediction time of 0 to 360 s can be set in newer versions of NACOS Platinum.



Figures:

Sources: ECDIS system laboratory at BSH and Wärtsilä MULTIPILOT Platinum operating instructions (Revision 26).