Statens haverikommission
Swedish Accident Investigation Authority

Final report RS 2019:02e

MIGNON – Cargo hold fire on 4 April 2018

File no. S-59/18

28 March 2019

SHK investigates accidents and incidents from a safety perspective. Its investigations are aimed at preventing a similar event from occurring in the future, or limiting the effects of such an event. The investigations do not deal with issues of guilt, blame or liability for damages.

The report is also available on SHK´s web site: www.havkom.se

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This document is a translation of the original Swedish report. In case of discrepancies between this translation and the Swedish original text, the Swedish text shall prevail in the interpretation of the report.

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General observations

The Swedish Accident Investigation Authority (Statens haverikommission – SHK) is a state authority with the task of investigating accidents and incidents with the aim of improving safety. SHK accident investigations are intended to clarify, as far as possible, the sequence of events and their causes, as well as damages and other consequences. The results of an investigation shall provide the basis for decisions aiming at preventing a similar event from occurring in the future, or limiting the effects of such an event. The investigation shall also provide a basis for assessment of the performance of rescue services and, when appropriate, for improvements to these rescue services.

SHK accident investigations thus aim at answering three questions: *What happened? Why did it happen? How can a similar event be avoided in the future?*

SHK does not have any supervisory role and its investigations do not deal with issues of guilt, blame or liability for damages. Therefore, accidents and incidents are neither investigated nor described in the report from any such perspective. These issues are, when appropriate, dealt with by judicial authorities or e.g. by insurance companies.

The task of SHK also does not include investigating how persons affected by an accident or incident have been cared for by hospital services, once an emergency operation has been concluded. Measures in support of such individuals by the social services, for example in the form of post crisis management, also are not the subject of the investigation.

The investigation

SHK was informed on 4 April 2018 that a marine casualty involving car and truck carrier MIGNON (call sign SJCD) had occurred the same day in the South China Sea.

The incident has been investigated by SHK represented by Ms Helene Arango Magnusson, Chairperson, Capt Dennis Dahlberg, Investigator in Charge until 28 February 2019, Capt Jörgen Zachau, Operations Investigator and from 1 March 2019 Investigator in Charge, and Mr Tomas Ojala, Investigator specializing in Fire and Rescue Services.

The investigation team of SHK was assisted by a fire expert from the Research Institutes of Sweden AB (RISE)

The investigation was followed by Capt Patrik Jönsson of the Swedish Transport Agency.

Investigation material
Interviews have been conducted with the crew on board, shipping company representatives and representatives of the Swedish Transport Agency. The fire has been investigated on-board the vessel.

A factfinding presentation meeting with the interested parties was held on 9 October 2018. At the meeting SHK presented the facts discovered during the investigation, available at that time.

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Ship particulars	
Flag/register	Sweden
Identification	MIGNON
IMO identification/call sign	9189251/SJCD
Vessel data	
Type of ship	PCTC[1]
New building shipyard/year	Daewoo Okpo Shipyard, South Korea/1999
Gross tonnage	67,264 gross
Length, over all	227.9 metres
Beam	32.26 metres
Draft, max	11.02 metres
Deadweight at max draft	28,126 tonnes
Main engine, output	Hyundai MAN B&W 8S60MC/14,700 kW
Propulsion arrangement	Single fixed-blade propeller
Lateral thruster	2 bow propellers, total 2,165 kW
Rudder arrangement	Spade rudder with bulb
Service speed	19.5 knots
Ownership	Wallenius Wilhelmsen Ocean ASA
Management	Wallenius Marine AB
Classification society	Lloyds
Minimum safe manning	16 crew

Voyage particulars	
Ports of call	Masan, South Korea – Akaba, Jordan
Type of voyage	International
Cargo information/passengers	New and used vehicles
Manning	22 crew

Marine casualty information	
Type of marine casualty or incident	Serious casualty
Date and time	4 April 2018, at 17:26 hrs ship's time[2].
Position and location of the marine casualty	016º28N 116º58E
Weather conditions	Wind around north-north-west 3–5 m/s, good visibility
Consequences	
Personal injuries	None
Environment	None identified
Vessels	Structural damage to cargo hold and cargo as well as damage to lighting, hydraulic system, pneumatics and fire alarm system

[1] Pure Car Truck Carrier.
[2] The time zone used on board

SUMMARY

On 4 April 2018, the fire alarm went off on deck 1, i.e. the lowest deck of the cargo hold on the car and truck carrier MIGNON. The vessel was sailing in the South China Sea off the Philippines, having departed ports in Japan and South Korea on the way towards Europe. The vessel was nearly fully loaded with different new vehicles and used passenger cars.

A search team led by the chief engineer was quickly able to identify a fire among the used cars on deck 1. The chief engineer made the decision to activate the CO_2 fire suppression system.

The investigation shows that the actual activation of the fire suppression system was delayed by approximately five minutes due to unclear instructions. Once the system had been activated, the fire could be extinguished. SHK has made the assessment that if the activation of the fire suppression system had been further delayed, there would have been a risk of the fire becoming uncontrollable and of the extinguishing operation failing. It cannot be ruled out that such a scenario could have entailed serious danger to the crew and a total loss of the vessel.

The fire caused fire or smoke damage to a large number of cars, as well as damage to decks 1, 2 and 3.

The investigation shows that the fire was probably caused by a short circuit in the starting motor of a used passenger car. The fire had then spread to combustible material in the car's engine compartment and then to the passenger compartment and on to other cars and parts of the ship's structure.

Contributing factors that allowed the fire to spread included the cars being loaded close together and the car windows on the driver's side being rolled down.

Safety recommendations

Following the incident, the shipping company has installed a new central fire alarm control panel. Furthermore, a new instruction for the fire suppression system is being developed in collaboration with the manufacturer. Work to review emergency checklists, including procedures to call for outside help, has also been initiated. In addition, procedures have been introduced to ensure that the negative pole of used car is always disconnected.

SHK therefore refrains from issuing any recommendations in these regards.

Wallenius Marine AB is recommended to:

- Reduce the risk of fire in vehicles being transported by taking fire prevention measures based on identified fire risks for each type of vehicle. See section 3.3.1. *(RS 2019:02 R1)*

- Develop procedures for loading of vehicles which allow the windows on the vehicles to be kept closed, in order to limit the spread of fire. See section 3.3.2. *(RS 2019:02 R2)*

- Complete the work that has been initiated to improve the search team routines, set limits for what risks the team members are allowed to take, and provide adequate training for the team, so that its members are able to identify risks and determine a suitable protection level before taking action. See section 3.2.2. *(RS 2019:03 R3)*

The Swedish Transport Agency is recommended to:

- Advocate internationally for inspections in conjunction with loading of used vehicles in all the world's ports. See section 3.3.1.
(RS 2019:04 R4)

1. FACTUAL INFORMATION

1.1 Sequence of events

On 4 April 2018 at 17:26 hrs, shortly after the crew had finished eating dinner, the fire alarm was triggered in the cargo compartment on deck 1, i.e. the lowest deck. At that time, the vessel was in the South China Sea off the Philippines (see figure 1) having called at ports in Japan and South Korea to load different vehicles, and was now heading to Europe via Aqaba in Jordan. The last port the vessel departed was Masan in South Korea, which it left on 1 April 2018.

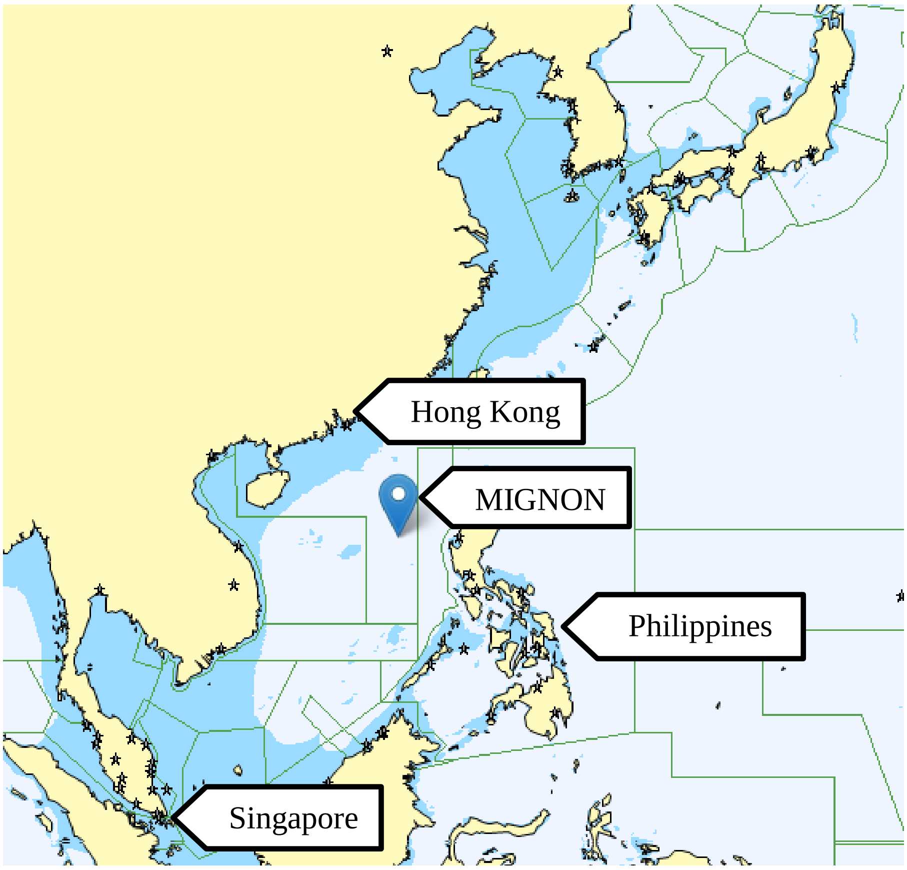


Figure 1. Position of the vessel MIGNON when the fire alarm went off. Image: Map Data copyright European Maritime Safety Agency (EMSA); Electronic Nautical Charts Data copyright Jeppesen C-Map Professional.

There were vehicles on all the decks and the vessel was almost fully loaded. There were new and used passenger cars as well as plant and construction machinery on board. The passenger cars on decks 1 and 2 were used.

The first fire alarm, which came from a detector in the aft part of the cargo compartment on deck 1, was followed shortly afterwards by fire alarms from several other detectors on deck 1, and then later from more detectors on the decks above.

Figure 2. The first fire alarm was sent by a detector on the bottom loading deck, deck 1, in the circled area.

The crew manned their stations in accordance with the muster list on board. At 17:29 hrs all hands were at their stations. One of the functions in the fire organisation was a search team of two, whose task was to carry out a preliminary check of the situation. The search group was ordered to go to deck 1, where the detectors had first been set off, in order to assess the situation and, if possible, confirm that there was a fire. The bridge also tried to assess the situation by means of a surveillance camera on deck 4, but nothing out of the ordinary could be observed from the images.

The search team noted that there was almost no smoke midship on deck 1. However, thick black smoke could be seen further astern, and after a continued search, the assessment was made that any source of the fire alarm other than a fire could be ruled out. This was communicated via radio to the chief engineer on board. The search team then exited the cargo hold.

The chief engineer, wanting to form his own opinion of the situation, had simultaneously gone down to the aft part of deck 1. He too was able to note that there was thick black smoke in the cargo hold. He ordered the search team to exit the cargo hold, in order to activate the CO_2[3] fire suppression system. The time was 17:37 hrs.

The chief engineer subsequently went to the engine room and the adjacent CO_2 room to activate the fire suppression system. The chief engineer asked the search team to notify him when they had exited the cargo hold, and when he received this confirmation, he initiated the activation of the extinguishing system. However, he found the instructions unclear, and a little over five minutes passed before the fire suppression system was activated. When it was, the time was 17:52 hrs. At that point, 26 minutes had passed since the fire alarm went off.

During the time the fire suppression system was active and releasing CO_2, smoke was coming out of one of the ventilators on the upper deck. The fire dampers of the ventilators should have closed automatically when the fire alarm or the fire suppression system was activated, but

[3] CO_2 Carbon dioxide, also referred to as carbonic acid, is an invisible odourless gas that is heavier than air and which extinguishes fire by diluting the oxygen in the air. Extinguishing fire with carbonic acid requires a closed space in order to be effective. However, diluting the oxygen in a closed space entails serious risks. The lack of oxygen can lead to loss of consciousness and death if people enter such spaces without any breathing equipment.

one damper was left open. However, the damper could quickly be manually closed.

The master and some of the crew were monitoring the situation from the bridge by listening to the internal radio traffic. They also stayed updated on which ships were nearby, in case they needed outside assistance. However, this was never considered necessary. They did however contact the shipping company's Designated Person Ashore (DPA) at an early stage. The DPA ensured that the shipping company's crisis plan was activated.

The fire suppression system was automatically shut down after 15 minutes, and after another two hours, a couple of crew members checked that the extinguishing attempt had been successful. As the cargo compartment had not yet been ventilated, they were wearing breathing equipment. No fire was detected, but it was noted that there were fire-damaged cars on deck 1 and structural damage on deck 2. It was also noted that the fire had caused damage to cable runs and hydraulics.

After the check, the cargo compartment was kept closed until the following day, when another check was carried out. Following that check, it was decided that the cargo compartment would be ventilated in order to allow hydraulic pipes and electric cables to be temporarily repaired. These repairs were necessary since the ballast tanks could no longer be manoeuvred, and the ship had started to list slightly as the fuel in the tanks was used.

The fire alarm could not be repaired. It was therefore decided that a watch would be set up on the damaged decks in case there was another fire.

In order to assess the damage to the ship, carry out repairs and replenish the CO_2, a decision was made to go to Singapore, which was deemed to be the port in range with the best conditions to do so. However, the ship was not given permission to enter the port area due to the fire that had happened on board. The MIGNON instead anchored in international waters outside Singapore. Representatives from the classification society, the insurance company and the shipping company then arrived to the ship to investigate the casualty and determine what action to take. The classification society cleared the MIGNON temporarily for the journey to the final destination, from where she could continue to a shipyard for repairs. However, the conditions for this were, amongst others, that hydraulic lines, electrical installations and fire alarm was repaired and that the fire suppression system was refilled with CO_2 prior to departure. Another requirement was that all cars were moved from the area with structural damage on deck 2 in order to reduce the load there.

1.2 Injuries to persons

None.

1.3 Damage to ship

The fire resulted in structural damage to decks 2 and 3. Approximately 360 square metres of steel on deck 2 and approximately 300 square metres on deck 3 was replaced during the shipyard repairs. Deck 2 had been deformed both upwards and downwards roughly at the centre line, with a difference between the highest and lowest point of around 40 cm. Cables and pipes for hydraulics and pneumatics had also been burned off. The cut cables meant that lighting and fire alarm were not functional on decks 1 and 2. The damage to the hydraulic lines meant that the valves for the ballast and bunker tanks could not be actuated.

Figure 3. The underside of deck 2, above where the burning cars were standing. The plates and the beams of the deck have been deformed both upwards and downwards.

1.4 Other damage

According to information from the shipping company, more than 500 cars incurred fire or smoke damage. Some twenty of these had very extensive fire damage.

1.5 Place of occurrence

At the time of the occurrence, the MIGNON was in the South China Sea, a marginal sea of the Pacific Ocean and one of the most trafficked waters on Earth. The South China Sea is demarcated in the north by the south coast of China and Hong Kong, in the northeast and east by Taiwan and the Philippines, in the south by Borneo and in the west by Mainland Southeast Asia (see map in figure 1). These waters constitute a very important trade route in global shipping. It is also an area where piracy is known to occur.

The fire was detected when the closest land was the Philippines to the east, as the MIGNON was approximately 270 M[4] northwest of Manila.

[4] 1 M = 1 nautical mile, i.e. 1,852 metres.

However, the SAR area[5] involved belonged to China and Hong Kong, China, respectively. The vessel was just over 120 M west of the approximate border of the Philippine SAR area. The nearest Rescue Coordination Centre (RCC) was in Hong Kong, approx. 390 M essentially due north of the position.

1.6 Ship particulars

The MIGNON is a car and truck carrier with the capacity to carry 7,200 cars. The ship was built in South Korea in 1999, as part of a series of identical vessels, and was lengthened by 28 metres in 2005. The vessel was equipped and constructed for trade area A (unlimited trade) in order to enter global traffic. The MIGNON had thirteen cargo decks, of which decks 5, 7 and 9 were hoistable (adjustable height).

The cargo hold consisted of four sections, designated A to D, separated by firewalls. The fire started in section D, comprising decks 1 to 5, where deck 5 was a hoistable deck. There were openings between decks, for example, in the form of vehicle ramps and holes for securing cargo. The total cargo area on the fixed decks 1–4 was 10,575 m^2.

1.6.1 Cargo

The MIGNON was nearly fully loaded with new and used passenger cars and with plant and construction machinery. The used passenger cars had been loaded in Japan and South Korea. In Japan, unlike in South Korea, all used passenger cars were routinely inspected before being loaded onto a vessel.

1.6.2 Description of relevant parts or systems

The vessel's fire protection equipment

The fire protection equipment included fire alarm, a manually activated CO_2 fire suppression system in the cargo compartments and engine room, and portable fire extinguishers and fire hydrants with hoses in several locations on the vessel.

There was also a firefighting organisation manning two fire stations, which held extinguishing and smoke-diving equipment (see figure 4). According to the vessel's muster list (see figure 4), the firefighting organisation consisted of the chief engineer as the fire chief, responsible for leading the response in case of a fire, two firefighting teams with smoke divers, one medical group and one search team.

The search team consisted of two crew members without firefighting equipment. Their task was to quickly make their way to the location of the alarm in order to assess the situation. They were also to check doors and fire dampers around the alarm's point of origin.

[5] Search and Rescue area – the area where a certain nation is responsible for sea rescue.

The firefighting teams each consisted of five members: one smoke diver team leader, two smoke divers with breathing equipment and two assistants. In case of a fire alarm, the groups were to go to the fire stations to prepare for action. When the search team had assessed the situation, the chief engineer was to make a decision on how to carry out firefighting operations. Either the smoke diver teams could be dispatched to extinguish the fire or, if the fire was deemed to be too inaccessible, too widespread or too dangerous for the smoke divers, the fire suppression system could be used.

Position	Station	Fire
Master	Bridge	Takes over watch on bridge
Chief Officer	As appr.	Deputy Fire Chief
2nd Officer	Hospital	Medical Group Leader
3rd Officer	2	Team leader (TL)
3rd Officer	Bridge	Crew count / External radio comm.
Chief Engineer	As appr.	Fire Chief
1st Engineer	ECR	In charge of ECR
2nd Engineer	1	Team leader (TL)
2nd Engineer	1	Smokediver
El Engineer	Search	Close fire dampers
Bosun	Search	Close fire dampers
AB	1	Assisting team
AB	2	Smokediver
AB	2	Smokediver
AB	2	Assisting team
Repairman	1	Assisting team
Repairman	2	Assisting team
Motorman	1	Smokediver
Chief Cook	Hospital	Medical Group
Messman	Hospital	Medical Group
Extra crew	Bridge	Go to Bridge

Figure 4. The vessel fire muster list and fire station 1 on the vessel, with equipment for smoke divers and control unit to set off the CO_2 system.

The written procedure for bridge personnel of the watch contains a checklist with a number of actions to take (hereafter referred to as the “action checklist”). Item 5 on that list was to call the rescue services and the shipping company agent, provided the vessel was in port. Item 11 was to notify the shipping company. Otherwise, there are no more items on the list referring to contacts with the outside world, unless an evacuation was to be necessary. However, there is a note in the procedure that its contents should only be considered a guideline, and that not all possible and necessary measures were included in the description.

Fire alarm system

The fire alarm system consisted of heat or smoke detectors (see figure 5) in different parts of the vessel, the central fire alarm control panel on the bridge and fire alarm panels, for example, in the vessel reception (see figure 6). There were smoke detectors in each of the separated sections of the cargo hold (see figure 8), and the fire suppression system was distributed across the same sections. The fire detectors in question reacted to both smoke and heat, but the central fire alarm panel was not equipped to read temperature.

Figure 5. Smoke detector in the cargo hold.

Figure 6. Fire alarm panel indicating which detectors and sections are giving off an alarm. Such panels could be found on the bridge and in the reception.

The fire alarm log in the central control had a maximum capacity of 100 activities. In order to register another event, the system would automatically erase the oldest events. There is a printer connected to the fire alarm system that could print out each individual event as they occurred, but it stopped functioning at an early stage of this occurrence.

Section D, which comprises the cargo compartments on decks 1–5 where the fire started, had 114 smoke detectors placed in the deckhead (i.e. the ceiling). These were distributed as follows: 8 on deck 1, 52 on deck 3 and 54 on deck 5. There were no detectors on decks 2 and 4.[6] According to information received, practical tests including fire and smoke formation tests were conducted in the cargo compartments in conjunction with the vessel series being fitted with a fire alarm system, to see how smoke would spread between the decks.

[6] As mentioned, deck 5 was a hoistable deck, which could be in up-position. The underside of deck 6 was thus the fixed ceiling of deck 4.

Fixed fire suppression system with CO_2 (carbonic acid)

The vessel had a fixed fire suppression system with approximately 50.8 tonnes of CO_2. The system had a control unit and tanks of CO_2 in the "CO_2 room" (see figure 7), which was located near the engine room. Another control unit was found in fire station 1 on deck 14 (see figure 4).

Figure 7. The "CO_2 room" control unit, which was used to set off the fire suppression system.

The fire suppression system was divided into seven sections, covering all cargo compartments, the engine rooms and the engine control room (see figure 8). Release of CO_2 in the sections was controlled by a timer that regulated the release so that the right amount of extinguishing agent was released in relation to the volume of the space. In section D, which was activated in conjunction with the fire, it had been set to release around 33.5 tonnes of CO_2 during approx. 15 minutes (see figure 9). In each section, there was a pipe system with nozzles underneath the decks to achieve as good a dissemination of the CO_2 as possible.

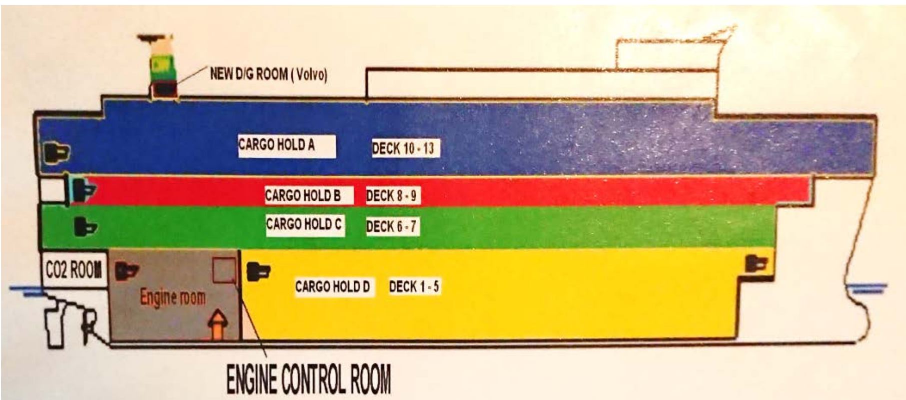
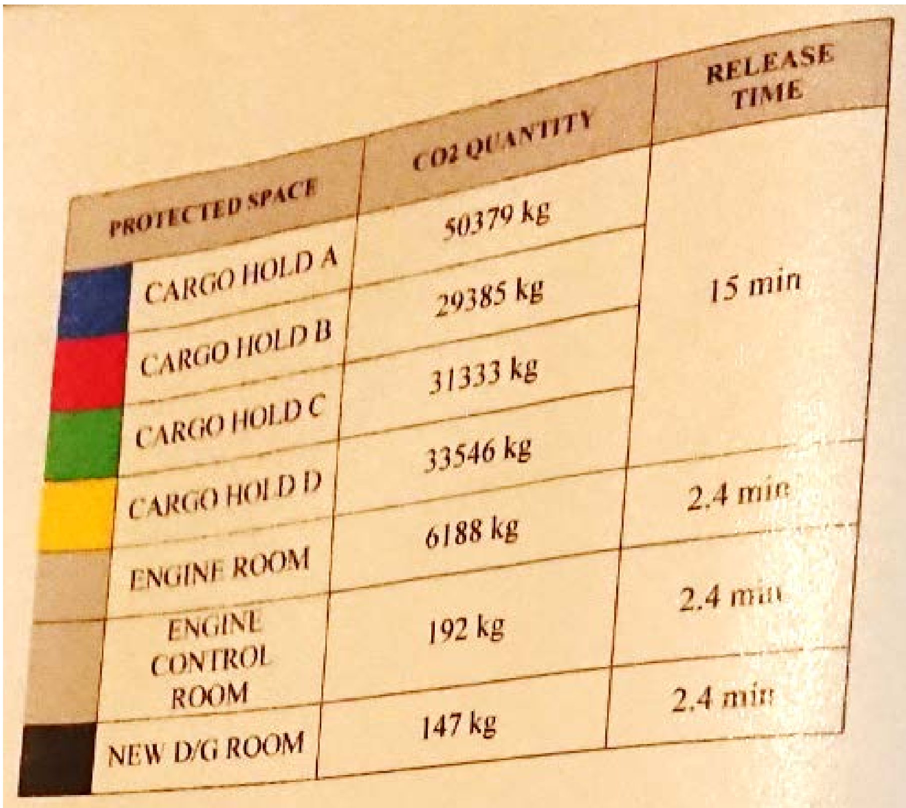


Figure 8. The fire alarm system sections in the cargo compartments and the fixed fire suppression system. It was the yellow section that was activated in conjunction with the incident.



PROTECTED SPACE	CO2 QUANTITY	RELEASE TIME
CARGO HOLD A	50379 kg	15 min
CARGO HOLD B	29385 kg	
CARGO HOLD C	31333 kg	
CARGO HOLD D	33546 kg	
ENGINE ROOM	6188 kg	2.4 min
ENGINE CONTROL ROOM	192 kg	2.4 min
NEW D/G ROOM	147 kg	2.4 min

Figure 9. Release times and quantities of extinguishing agent in the seven sections of the fire suppression system.

1.6.3 Voyage data recorder

SHK has had access to the vessel's VDR[7].

1.6.4 Crew

The crew of the MIGNON consisted of 22 crew members from Sweden, the Philippines and Finland.

At the time of the incident, the master had been employed by the Wallenius shipping company since 1979, and as ship's master for the last 15 years. The master had completed Advanced Firefighting training in 2015.

At the time of the incident, the first officer had been at sea for 30 years, 18 of which as first officer. He had been employed by the shipping company since 2001. The first officer had also completed Advanced Firefighting training in 2015.

At the time of the incident, the chief engineer had been at sea since 1980, with 18 years as chief engineer. He had been employed by the Wallenius shipping company since 2010 and on the MIGNON since 2013. He had completed Advanced Firefighting training in 2014.

[7] VDR – Voyage Data Recorder.

The electrical engineer had been at sea since 1992, the last eleven years working for the Wallenius shipping company. He had completed Advanced Firefighting training in 2016.

The bosun[8] had been employed by the Wallenius shipping company for eleven years and had completed Basic Safety training in 2016.

1.7 Meteorological information

At the time of the accident, the wind was around north-north-westerly 3–5 m/s. The weather was clear with good visibility. The air temperature was 26 degrees and the water temperature was 29 degrees.

1.8 Emergency response

1.8.1 Vessel conditions

Deck 1 was fully loaded with used passenger cars, while deck 2 was only partially loaded with cars (see figures 10 and 11). The cars were parked very close together, with lashings on all wheels. Often, the spaces between the cars were so narrow that it was not possible to pass through at all, but in some cases it was possible to pass sideways. The lashings were fastened to the deck and to the top half of the wheel, stretching out a bit from the cars (see figure 12). For this reason, it was difficult to move around among the cars, as there was a risk of tripping over the lashings. A firefighting operation where smoke divers would have to pass the cars would thus entail a very great risk for the crew.

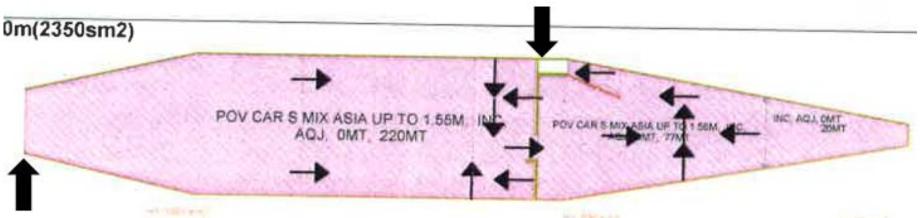


Figure 10. Cargo on deck 1: used passengers on the whole deck. The passages down to the deck that were used by the search team and the chief engineer respectively have been marked with bold arrows.

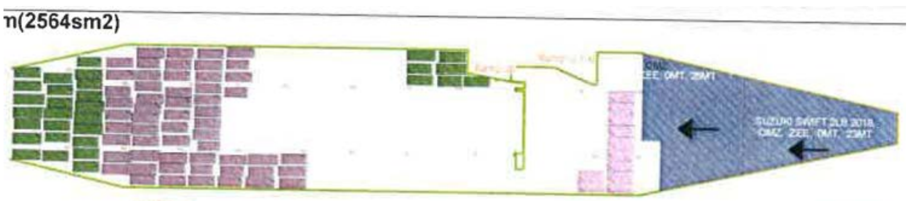


Figure 11. Cargo on deck 2: The filled boxes indicate the positions of the used cars.

[8] Boatswain, foreman for the deck ratings.

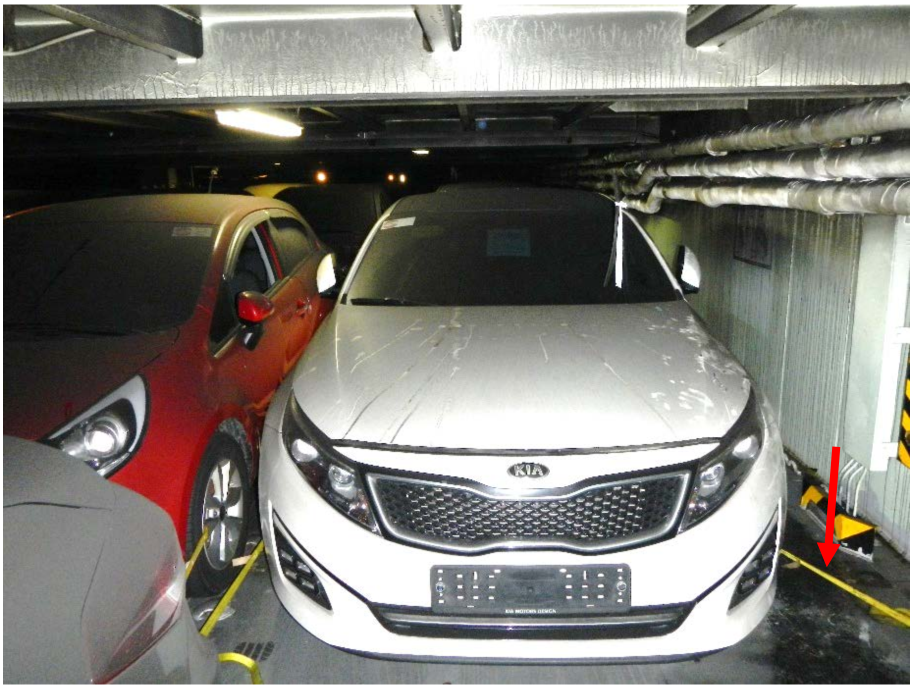


Figure 12. The cars were parked very close together. Also visible in the photo are the yellow lashings between the deck and the wheels, see arrow on the right.

1.8.2 *The fire*

The fire started on deck 1. It then spread to cars on the deck above. Some twenty passenger cars were completely burned out and, according to the shipping company, more than 500 cars incurred fire and smoke damage (see figure 13). Hydraulic oil from a fire-damaged pipe in the vessel had also ignited. There was substantial smoke development with significantly reduced visibility.

Figure 13. Fire-damaged car on deck 1. Note how the deckhead is bulging downwards.

1.8.3 Firefighting operation

When the fire alarm sounded at 17:26 hrs, all stations on board were manned according to the vessel muster list. The master, the chief officer, the second officer and one cadet gathered on the bridge. The chief engineer collected a communication radio from the office and then checked the fire alarm panel in the adjacent reception. He noted that the alarm was coming from deck 1, near frame 64, i.e. from an area astern (see figure 14). More alarms were set off by other detectors in the same area directly afterwards. The chief engineer announced over the radio that the situation was serious, and that the smoke divers should start gearing up. He then made his way to the bridge. Shortly thereafter, the different groups reported that they were in position, with five crew members in each firefighting team and three crew members in a medical team.

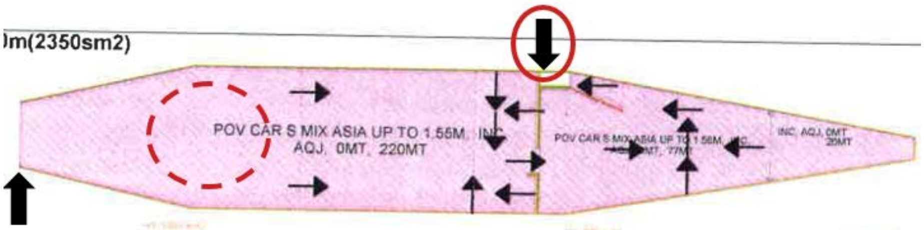


Figure 14. The first fire alarm came from deck 1, in the area circled with a broken line. The search team entered by the circled arrow.

The search team consisted of the electrical engineer and the bosun. The electrical engineer was notified that a fire alarm had been triggered in deck 1. He collected a radio and a torch, changed into heavier work clothes and was quickly on his way. The bosun was in the shower when the fire alarm sounded and therefore left slightly later than the electrical engineer.

The electrical engineer took the port midship stairwell down towards deck 1 at 17:31 hrs. When he entered deck 1 from the stairwell, there was no smoke. The decks he had passed on the way down were also smoke-free.

As he entered deck 1, there was a bulkhead separating him from the section of the deck where the fire detector had been triggered. He continued his search along the bulkhead, and when he arrived at the opening towards the aft part of the deck, where he had relatively good visibility, he noticed thick black smoke astern. He proceeded aft through thinner smoke and smelled burning plastic. When he arrived at the cars, the smoke turned thick and black, and he had to go down on all fours underneath the smoke to be able to breathe. He crawled a bit further aft next to the cars along the wall of the cargo compartment, and when he looked underneath the cars, he could see an orange-white glow in the distance. Above the cars, he had only observed the thick black smoke and no visible flames.

At this point, the electrical engineer deemed it established that the fire alarm had been triggered by an actual fire. He called out over the radio that there was a car fire, and then made his way back alternately crawling and walking towards the point where he had entered. When he reached the bulkhead, the bosun had also arrived on deck 1 using the same stairwell as the electrical engineer. At the same moment, the chief engineer called the search group on the radio and ordered them to leave the cargo hold, as the CO_2 fire suppression system was about to be activated. The time was 17:37 hrs.

Before the electrical engineer had announced that the fire alarm had been triggered by a car fire, and while the crew on the bridge was waiting for the search team to report back, there were more fire alarms from deck 1. The chief engineer deemed the situation to be serious. However, he wanted to see the situation for himself and so made his way towards deck 1 via a combined air duct and emergency exit on the starboard side. This entry point was further aft on the vessel than the stairwell used by the search team to descend to the same deck (see figure 15).

There was no smoke on the way down the air duct, but when he opened a door to deck 1, he was met by thick black smoke coming out of the cargo hold. The chief engineer immediately closed the door and made the assessment that this was not a situation that could be handled by the firefighting teams on the vessel. He ordered the search group to exit the cargo hold and close it, so that he could activate the fire suppression system. This occurred roughly at the same time as the electric engineer and the bosun met up on deck 1.

For his part, the chief engineer needed to get to the CO_2 room by the engine room, which was one of the locations on the vessel from where the fire suppression system could be activated. On his way up from deck 1, he heard several explosions. His theory was that the airbags and tyres on the cars had exploded.

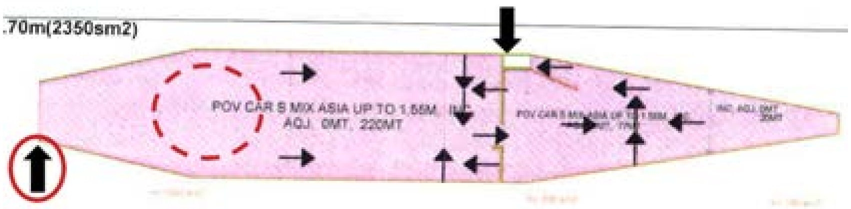


Figure 15. The chief engineer arrived on deck 1 at the circled arrow in the image. The first fire alarm was triggered by a detector circled with a broken line.

As the chief engineer headed towards the engine room, he heard over the radio that the search team was exiting the cargo hold. He asked them to notify him when they were out. The search team exited the same way they entered, and closed all doors behind them. When the chief engineer arrived in the control room by the engine room, he could see the search team leaving deck 6 on the monitors. When checking the camera on deck 4, there was still no detectable smoke. The chief engineer called one of the firefighting teams and instructed them to come down to the engine room just in case. He then went to the CO_2 room to activate the fire suppression system.

In the CO_2 room, there were two instructions for activating the system (see figure 16), one instruction from the manufacturer and one that had been produced aboard the vessel. The chief engineer started following the manufacturer's instructions. There were two valves in a control cabinet for the system. The chief engineer understood the instruction to mean that the main valve should open 90 seconds after the first valve (valve 1) had been opened.

However, he forgot to check his watch. He waited for what he deemed to be slightly longer than 90 seconds, but the system was not activated. He then read through the instruction again and came to the understanding, under the stressful circumstances, that it may be necessary to wait for as long as four minutes. When he had waited for what he thought was longer than four minutes, he chose to open the second valve too, at which point the fire suppression system was immediately activated. The time was now 17:52 hrs, and section D of the cargo hold, which comprised decks 1–5, was filled with CO_2. This occurred 26 minutes after the first fire alarm.

Figure 16. The image above shows the two instructions in the CO_2 room by the engine room. The instruction at the front, with the photographs, is the one produced aboard the vessel. The instruction on the white pane behind it, without photographs, was the one used by the chief engineer.

On and off during the operation, it was difficult to establish contact via the radio, or to hear and understand what was being said. The bridge for example called the chief engineer when he was in the CO_2 room. They had to call several times before establishing contact, and it was then difficult to understand what was said. The radio communication from deck 1 was also inadequate at times.

A valve was left partly open in the CO_2 room, leaking gas, which caused the alarm indicating excessive CO_2 levels to go off. The chief engineer closed the valve, but a small leakage remained. However, the remaining leakage was so small that the gas was vented out and the alarm stopped. There was also a leaking flange in the joint of a CO_2 line in the engine room. However, the leakage was small enough that it was deemed not to affect the function of the system or entail any danger, so no action was taken in this regard.

While the fire suppression system was active, the crew on the bridge noticed that there was smoke coming out of one of the air ducts on the starboard side. The air ducts have fire dampers that are intended to close automatically in the event of a fire alarm and when the fire suppression system is activated, since a closed space is of essential importance when using CO_2 to extinguish a fire. When a smoke diver from one of the firefighting teams went to check, it was discovered that one damper was completely open and another one was partially open. However, the dampers could be closed manually. After this, the fire dampers of all the other air ducts were also checked and proved to be closed. The time at this point was 18:10.

Approx. 15 minutes after the fire suppression system had been activated, a timer automatically turned off the flow of CO_2. According to the fire suppression system meter, approx. 40 tonnes of carbonic acid had been used. However, according to the instructions, only around 33.5 tonnes should have been consumed after that time. There were still twelve tonnes left in the system, so a certain extinguishing capacity remained. Suppressing a fire in the engine room, for example, would have required approx. six tonnes CO_2.

Around two hours later, the chief engineer and the first engineer entered the cargo hold wearing breathing equipment, in order to check whether the extinguishing operation had been successful. They could find no remaining fire and, in the area with the greatest fire damage, it was warm but not hot. A description used was that it was “warm, but too cold for a sauna”. Visibility was somewhat limited by thin smoke.

1.9 Regulations and inspections

1.9.1 Fire protection

Basic principles

Applicable fire protection regulations are found in the Swedish Transport Agency's Regulations and General Advice (TSFS 2009:97) on fire protection, fire detection and fire suppression on SOLAS[9] ships built before 1 July 2002.

The above regulations stipulate, among other things, that:

- living quarters must be separated from other parts of the vessel through built-in, heat-insulated barriers,
- the use of combustible materials must be limited,
- it must be possible to detect any fire in the zone where it has started,
- it must be possible to limit and extinguish any fire in the area where it has started,
- escape and access routes used for firefighting must be protected, and
- firefighting equipment must be easily accessible.

Carbon dioxide systems

In regard to cargo holds, the above regulations furthermore state that, unless otherwise stipulated, the available quantity of gas must be at least sufficient to provide a minimum volume of released gas equal to 45 per cent of the gross volume of the largest sealable Ro-Ro cargo hold. The system must be such that at least two thirds of the gas required for the relevant space can be released over the course of 10 minutes.

For carbon dioxide systems installed on 1 October 1994 or later, the following also applies:

- in a protected space, there must be two separate actuators set up to release the carbon dioxide and to safeguard the alarm functions. One of the actuators is to release the gas from the canisters. The second actuator is to open the valve of the lines that transfer the gas to the protected space.
- the two actuators must be placed in a release cabinet marked in a way that clearly shows what space they serve. If the release cabinet with the actuators has to be locked, a key for the cabinet

[9] SOLAS – International Convention for the Safety of Life at Sea. The convention regulates how vessels are to be constructed and equipped, especially in regard to life-saving operations, fire suppression and radio equipment, and how cargo is to be handled.

must be placed in a key box with breakable glass in a clearly visible location near the cabinet.

The delivery of a carbon dioxide system must include an instruction for the system, along with a maintenance checklist. This instruction must be available in Swedish and in English. The installation must be inspected and tested in the first seaworthiness inspection and subsequently at least every two years. Certificates of such inspection must be issued and kept in the inspection log. The carbon dioxide quantity must be checked at least once per year. Completed checks must be documented.

Fixed fire detection and fire alarm systems

The regulations furthermore stipulate that detectors and manual actuators must be grouped into sections. The activation of a detector or manual actuator must trigger an optical and acoustic fire alarm by the central controller and the indication units.

Detectors must also be placed where they will be of optimal use. Placements near beams and ventilation ducts, or other locations where the air flow may influence their function and locations where shocks and physical damage can be expected, must be avoided. In general, detectors placed underneath the deckhead must be placed at least 0.5 metres from bulkheads.

Detectors must be distributed and placed in accordance with the table below:

Detector type	Maximum deck surface per detector	Maximum centre distance	Maximum distance from bulkhead
Heat	37 m²	9 m	4.5 m
Smoke	74 m²	11 m	5.5 m

The regulation also states that “the administration may require or allow a different distribution based on test data accounting for the detector properties”.

1.9.2 *Loading*

In accordance with the IMDG Code[10], vehicles are generally considered dangerous goods. Most cars are classified as goods category UN3166. However, vehicles classified under this UN number[11] are subject to special regulations set out in part 3, Chapter 3.3 of the IMDG Code. In accordance with a special provision (961) of the Code, vehicles are not subject to the provisions of the IMDG Code if the following conditions, amongst others, are met:

1) Vehicles are stowed on the vehicle and ro-ro spaces or on the weather deck of a ro-ro ship or a cargo space designated by the

[10] IMDG – International Maritime Dangerous Goods.
[11] Number identifying hazardous substances and products, which is assigned by a UN body.

Administration (flag State) and approved for the carriage of vehicles, and there are no signs of leakage from the battery, engine, fuel cell, compressed gas cylinder or accumulator, or fuel tank.

For vehicles powered solely by lithium batteries and hybrid electric vehicles powered by both an internal combustion engine and lithium metal or ion batteries, as a main rule, some further demands are required. Where a lithium battery is damaged or defective, the battery shall be removed.

2) For vehicles powered by a flammable liquid fuel with a flashpoint of 38°C or above (e.g. diesel), there are no leaks in any portion of the fuel system, the fuel tank(s) contains 450 L of fuel or less and installed batteries are protected from short-circuit.

3) For vehicles powered by a flammable liquid fuel with a flashpoint less than 38°C (e.g. petrol), the fuel tank(s) are empty and installed batteries are protected from short circuit.

4) For vehicles powered by a flammable gas (liquefied or compressed), the fuel tank(s) are empty and the positive pressure in the tank does not exceed 2 bar, the fuel shut-off or isolation valve is closed and secured, and installed batteries are protected from short circuit.

5) For vehicles solely powered by a wet or dry electric storage battery or a sodium battery, and the battery is protected from short circuit.

Vehicles that do not fulfil the above conditions set out in the special provision must be assigned to category 9, in accordance with the IMDG Code, and fulfil the code requirements for that category (see special provision 962). The following requirements also apply:

1) The vehicles shall not show signs of leakage from batteries, engines, fuel cells, compressed gas cylinders or accumulators, or fuel tank(s).

2) For flammable liquid powered vehicles the fuel tank(s) containing the flammable liquid shall not be more than one fourth full and in any case the flammable liquid shall not exceed 250 L unless otherwise approved by the competent authority.

3) For flammable gas powered vehicles, the fuel shut-off valve of the fuel tank(s) shall be securely closed.

4) Any installed batteries shall be protected from damage, short circuit, and accidental activation during transport. Lithium batteries shall meet special requirements. Where a lithium battery installed in a vehicle is damaged or defective, the battery

shall be removed and transported according to SP 376, unless otherwise approved by the competent Authority.

1.10 Tests and research

1.10.1 Fire investigation

A fire investigation has been conducted in order to determine the probable cause of the fire and to assess the fire spread.

The examination of the cars took place firstly when the vessel was anchored outside of Singapore and secondly at the Remontowa shipyard in Gdansk. All examinations have been conducted on board the vessel. The initial examination outside of Singapore was conducted by SHK's investigator. In Gdansk, the examination was carried out by an expert from RISE[12] with assistance from the SHK investigator.

2. ACTIONS TAKEN

Since the incident occurred, the shipping company has, for example, installed a new central fire alarm control panel on the vessel. The control panel has a greater memory capacity for reading activated fire detectors. It also allows the temperature to be read for each individual detector.

New procedures have been introduced for the loading of used cars in South Korea. The negative pole of the car battery is always disconnected now. In addition, it is noted what propulsion system the vehicle is using and where it is placed.

All checklists intended to be used in an emergency are being revised, and in conjunction with this work, the shipping company will consider the matter of whether the checklists should be supplemented with procedures to call for outside help. The shipping company is also developing better procedures for search group operations.

A new, clearer instruction for the fire suppression system is being produced. This work is carried out in collaboration with the manufacturer. However, a procedure has already been introduced for senior officers to practice the operation of the CO_2 system every two months.

[12] RISE (Research Institutes of Sweden) is an independent government research institute with experts and testing and demonstration environments.

3. ANALYSIS

In this investigation, SHK has attempted to clarify the sequence of events, determine the cause of the fire and map its spread. SHK has also investigated how the crew handled the situation as it unfolded, especially the actual firefighting operation. Finally, SHK has also found grounds to discuss possible actions to reduce the risk of this type of fire starting and to minimise the risks of the fire spreading if one was to occur.

3.1 Cause of fire and fire spread

3.1.1 Conditions before the fire started

The cargo compartments affected by the fire were loaded with used passenger cars. Deck 1, where the fire began, was fully loaded. Deck 2, directly above deck 1, was only partially loaded, but fully loaded in the area right above the area of the fire. The cars were parked tightly side by side, and it was not always possible to pass between them. The lengthwise distance between the cars was somewhat greater. All the cars had the driver's window rolled down, and the keys had been placed inside. The reason for leaving the windows rolled down was to be able to reach the keys if the car door was to lock for some reason. The batteries of all cars were connected but the ignitions were turned off. The new cars had a few litres of fuel remaining in the tank to be able to drive them in conjunction with loading and unloading. However, the amount of fuel remaining in the used cars was unknown.

The vessel's cargo hold had 170 cm of headroom to the load-carrying beams of decks 1 and 2. Running roughly along the centre line, above the headroom between the load-carrying structure under the plate of deck 2, there were electrical cables on cable racks, hydraulic oil lines and pipes for the fixed fire suppression CO_2 system. Deck 1 was a fixed deck above the bottom ballast tanks. In addition to the hull side mountings, deck 2 was also supported by pillars in two longitudinal rows. All over the surface of deck 2, there were through holes of approx. 5 cm in diameter for securing cargo at just under one-metre intervals.

3.1.2 Cause of the fire

As stated, a fire investigation has been conducted in order to determine the probable cause of the fire and to map its spread. The investigation started with an assessment of the fire's external impact on the cars in the cargo compartment where the fire started. The fire and smoke damage to the car bodies and to the vessel were assessed from the smallest and inwards to the most extensive damage. This was done in order to gain an idea of the spread of the fire and to identify the likely starting point. During this work, the most fire-damaged cars were also marked with number combinations to facilitate the continued efforts. Both deck 1 and deck 2 were examined.

The fire damage to the cars on deck 2 was not as extensive as on the cars on deck 1, and the damages clearly indicated that the fire had impacted the cars from below. It could therefore be ruled out that the fire would have started on deck 2.

Figure 17. The likely starting point of the fire is in the area circled with a broken line on the deck drawing. Also shown in the image is the marking, the numbers on the hood, that was done on the cars in order to identify the different cars more easily.

As there were no fire-damaged areas underneath or next to the fire-damaged cars on deck 1, this was assessed as the likely starting point of the fire (see figure 17). The investigation continued with an examination of the vessel fixtures and fittings. No signs of short-circuiting in the electrical fittings could be detected, nor any heat-generating installations near combustible material. It was therefore ruled out that the fire could have started in the vessel fixtures and fittings. No signs were found around the cars that would indicate arson.

Eleven cars had very extensive damage, and some cars were completely burned out. Focus was placed on determining whether the cause of the fire was in one of these cars. After a more detailed examination of the eleven cars, the efforts could finally be directed to one car. The car in question had fire damage further down in the front section than the other cars, and the fire damage to the other cars was inclined towards that car. The passenger and engine compartments of this car were examined in detail, which, along with an investigation of the outside fire damage, led to the conclusion that the fire had likely started in the engine compartment (see images 18 and 19).

Figure 18. The fire pattern on the car where the fire likely started. In this image, the cars have been moved from deck 1 to an undamaged deck higher up in the vessel for further investigation.

Figure 19. The engine room of the car where the fire likely started.

No indications of arson could be found in the car, and it was deemed most likely that the fire was started by an electrical fault. Electrical components were therefore examined in more detail. The ignition switch was found on the floor of the passenger compartment in the remnants of the interior that had burned. There was no key in the ignition, nor was any trace of a key found. Focus was therefore shifted to the electronic components that could have been powered by the battery without the ignition being turned on.

After several components had been examined, it was assessed to be less likely that the fire had started in the battery or in the cables, as there were no clear indications of this. Instead, three other components were identified which could possibly have caused the fire, namely the generator, the circuit breaker and relay box, and the starting motor. The three components were disassembled and a melted copper plate was found in the solenoid[13] of the starting motor (see figures 20–23). The other components showed no clear signs of the fire potentially starting there.

Figure 20. The solenoid of the starting motor where the fire most likely started.

Figure 21. The starting motor with the solenoid to the right.

[13] A solenoid is a type of magnetic coil which, in this case, activates the starting motor by supplying a strong electric current to propel it.

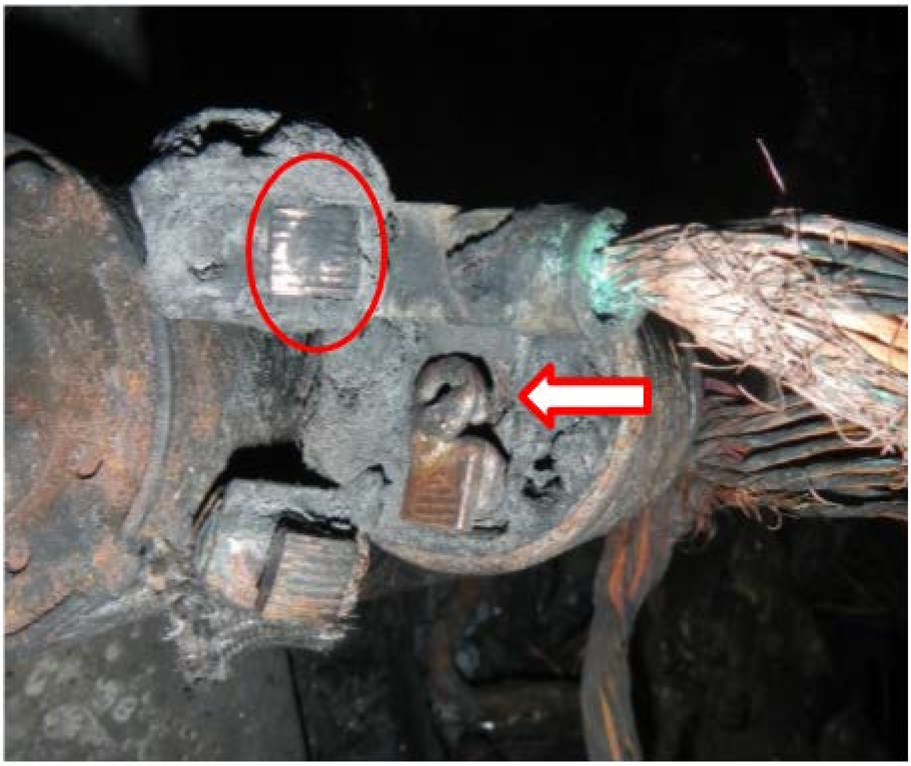


Figure 22. The contacts of the solenoid where the short circuit occurred. The position of the starting motor in the image corresponds roughly to its placement in the car. It can be seen in this image how the copper plate has melted and spilled downwards (arrow). Also note the soot on the upper contact surface (circled), which indicates poor contact between that surface and the copper plate.

Figure 23. The short-circuited copper plate removed from the solenoid on the left and a copper plate from an undamaged starting motor of the same type on the right.

The investigation then proceeded to assess how the copper plate could have melted and whether this could have caused the fire. Copper has a melting point of 1,085 °C, which means that this is the minimum temperature reached. SHK's assessment is that a very strong short circuit caused the copper plate to melt.

The current for the starting engine was led directly from the battery via a heavy cable to the solenoid, without any circuit breakers or other safety devices, which is the normal construction for a passenger car. Since the copper plate was part of the system to conduct electricity directly from the battery to the starting motor, the short circuit could likely continue until the battery was empty.

The solenoid short circuit could have been caused by several different factors, anything from a manufacturing error to causes relating to the use of the car in question. Determining these causal factors with any greater degree of certainty would likely require very extensive and resource-consuming examinations, if it were even possible. SHK therefore chose not to proceed with the investigation in this respect.

The investigation was then focused on assessing the effect of the short circuit on the plastic fitting of the copper plate. There was another vehicle (hereafter referred to as the reference vehicle) on board the vessel with the same type, but undamaged, starting motor and otherwise identical plastic fittings in the engine compartment as the vehicle where the fire originated.

Using a disposable lighter, a simple test was conducted to set fire to the undamaged plastic fitting from the reference vehicle. The flame from a disposable lighter is capable of reaching the temperature that must have been reached to melt the copper plate (approx. 1,085 ^{o}C). In the test, the plastic fitting caught fire when exposed to the flame, but went out when the flame was removed (the plastic fitting was in other words self-extinguishing). Based on this, the conclusion was drawn that the short circuit in the solenoid could have ignited the plastic fitting and that the latter could not have self-extinguished as long as the short circuit lasted.

The plastic details of the generator and the circuit breaker and relay box from the reference vehicle were also tested using the disposable lighter. The generator cover was self-extinguishing, but the circuit breaker and relay box continued to burn after the flame was removed (see figure 24).

Recalls from the manufacturer of the car type have been checked to see if any fire hazards have been described. The car where the starting motor caught fire was a 2015 Hyundai Sonata. However, none of the recalls from Hyundai Motor Company published by the NHTSA[14] appear to have been linked to any fire hazards.

[14] The National Highway Traffic Safety Administration, an agency under the U.S. Department of Transportation.

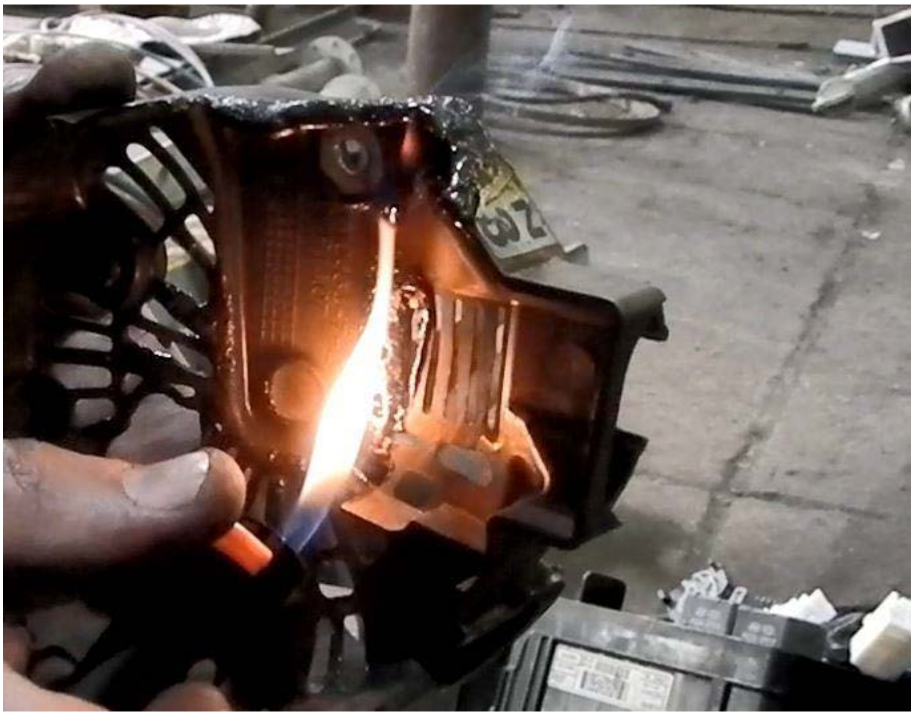


Figure 24. Example of one of the simple fire tests performed. The image shows the generator cover being tested. The cover could be ignited, but self-extinguished when the flame was removed.

3.1.3 *Fire spread*

There was a large quantity of plastic details in the engine compartment, and a few centimetres above the solenoid of the reference vehicle, there was a plastic inlet manifold (see figure 25). This was removed and tested with the disposable lighter in the same manner as the other plastic details (see above). The inlet manifold burned without self-extinguishing and also started dripping burning plastic. Once the inlet manifold was ignited, it was thus possible for the fire to spread to the other flammable parts of the engine compartment. Even if certain plastic details of the engine compartment were self-extinguishing, this property did not limit the spread of the fire, as fire in other parts kept supplying flames and heat. As the inlet manifold released droplets of burning plastic, it is likely that the fire could also spread downwards at an early stage.

Figure 25. The engine compartment of the reference car. The arrow marks the plastic inlet pipe and the approximate positions of the solenoid and the starting motor below it.

The metal “firewall” between the engine and passenger compartments had cavities that were covered in plastic. After the plastic had melted or burned off, the fire has thus been able to spread to the passenger compartment through these openings (see figure 26).

Figure 26. Openings between the engine and passenger compartments, where the plastic has melted.

Once the fire had spread to the passenger compartment, the rolled-down window had provided sufficient air supply for the fire to grow freely. The heat from the fire has then led to all the windows melting or cracking. The fire has then gradually been able to spread between the cars, as they were placed closed together and the driver’s windows were all rolled down.

Figure 27. Rolled-down driver’s window. Note the deployed airbag and the short distance between the cars.

Directly above the burned cars on deck 1, there were electric cables and hydraulic lines mounted on the deckhead (see figure 28). These have been damaged by the fire and leaking hydraulic fluid has thereby further contributed to the spread of the fire. The assessment is that the rate of heat release increased markedly when approximately 100 litres of hydraulic fluid was dispersed over the vehicles and the deck. A car that was standing directly below the electric cables and hydraulic lines also had a sunroof, which meant that the fire had a substantial impact in that location (see figure 29).

Figure 28. Lines for hydraulic oil and cable ducts above the cars, which were affected by the fire.

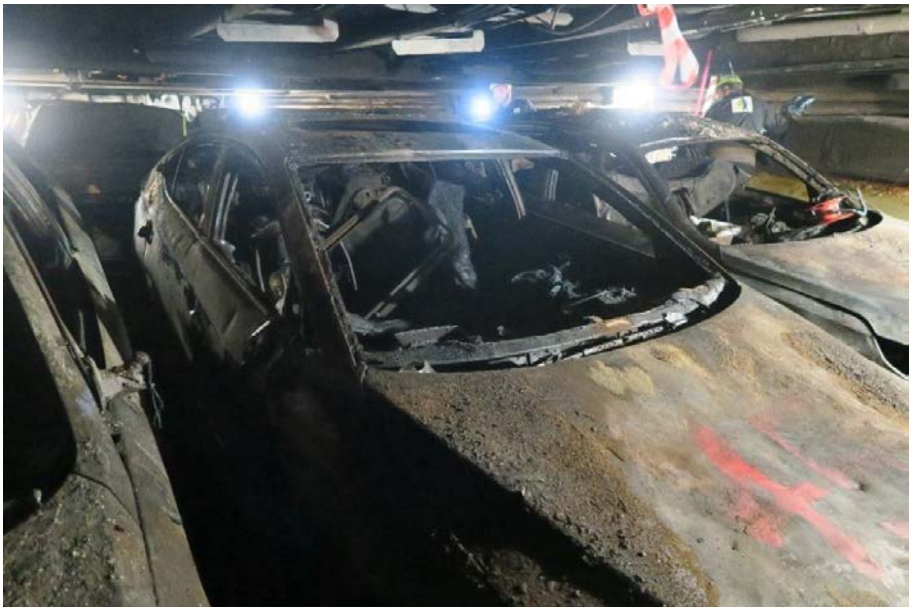


Figure 29. The car with the sunroof, where the fire inside the car affected the hydraulic lines and cables in the deckhead above.

The fire also spread to cars on deck 2, above the deck where the fire started. The entire deck had holes for securing cargo at around one-metre intervals (see figure 30). The fire could thus spread through the cargo securing holes. The deck was furthermore made entirely of steel, with no fire or heat insulation. The fire has therefore likely spread to the tyres of the cars above due to heat transfer through the vessel's steel construction. The heat from the fire has also affected the integrity of the vessel's decks all the way up to deck 3. However, the heat transfer has not ignited any cars or other parts of the vessel anywhere other than in decks 1 and 2.

Figure 30. The holes for securing cargo in the deckhead to deck 2.

3.1.4 Summary of conclusions

To sum up, the conducted investigation into the origin of the fire has led SHK to draw the conclusion that a very strong short circuit has in all likelihood occurred in the starting motor. The high temperature that occurred in the short circuit has melted a copper plate in the starting motor solenoid, which ignited the plastic fittings of the plate. Since the solenoid was located very close to a plastic inlet pipe, this too was ignited and the fire has then spread to other flammable parts of the engine compartment.

The fire has then spread to the passenger compartment and on to the surrounding cars. The fact that the cars were placed close together and that the driver's window was rolled down on all the cars facilitated the spread of the fire.

3.2 Firefighting operation

The investigation cannot rule out the possibility that the occurrence could have led to a very extensive fire resulting in critical damage to the vessel and danger to the crew, had the firefighting operation been further delayed or not occurred at all. Although the firefighting operation could be successfully completed, some critical parts of the operation should be mentioned.

3.2.1 Limitations of the fire alarm system

The cargo hold had smoke detectors, sensors able to detect smoke or particles in the air passing through the device. Smoke detectors can essentially react to smoke as well as steam or dust. The smoke detectors also had temperature sensors, but that signal could not be registered by the central fire control panel. At the time of the incident, the fire alarm system was thus indicating the presence of smoke or particles in the cargo compartment, but it was not possible to discern whether, and if so where, there was a temperature increase.

If the temperature could have been read on the fire control panel when the fire alarm was activated, it could have given an early indication that there was a fire. There was a detector directly above the fire area, and it would probably have been possible to register a very rapid increase to high temperatures of several hundred degrees Celsius. It would then have been possible to rule out any causes other than fire for the fire alarm being activated. This would have facilitated the deliberations on what measures to take and the search team would not have needed to enter the dangerous area on deck 1 to investigate whether there was a fire. However, there were not detectors on every deck of section D; only decks 1, 3 and 5 were equipped with detectors. This means that for a fire on deck 2, for example, it is possible that a temperature reading would not have provided a basis for a quicker decision.

A review of the requirements set out for the number of detectors when the vessel was built in 1999 may lead to the conclusion that the number of detectors in section D is too low. The provisions for vessels built before 1 July 2002 (see section 1.9.1) state that the maximum deck surface per smoke detector is 74 m^2. The fact that the MIGNON was rebuilt in 2005 has not entailed altered requirements in this regard. The total deck surface in Section D was 10,575 m^2, and the number of smoke detectors was 114, which gives approx. 93 m^2 per detector. Based on this calculation, the section should be short of 29 smoke detectors.

The cargo compartments comprised by decks 1–5 are however not separated, as there is a large number of openings of varying size. According to information to the investigation, testing was conducted when the vessel series was built in the form of live tests with fire and smoke development. Even if no documented results of this testing have been presented to SHK, it may be that such results have provided the basis of dimensioning and placement of the detectors. In this context, it can be noted that the administration (in this case, the former Maritime Inspectorate) may permit a different distribution in accordance with the applicable provisions, if this is supported by test data. Regardless, SHK makes the assessment that the lower number of detectors in relation to the table in the regulation has had no impact on the sequence of events in this case, as there was a detector right above the area where the fire started. It must therefore be up to the inspectorate to follow-up on this matter if deemed needed.

From both an investigation and a learning point of view, it was unfortunate that the fire alarm system log had a registering capacity limited to 100 activities. Registration of additional events meant that the system gradually erased older events. In other words, it has not been possible to obtain information from the system after the incident regarding which detectors were triggered and in what order. Since the device printing logged data was not working at the time, no printed data has been available either.

However, the shipping company has now installed a new central fire alarm control panel with a greater capacity to register activated detectors and to read the temperature from each individual detector. This measure increases the chances of a quicker and safer firefighting operation and improves the possibility of analysis following an activation of the alarm. In view of this, SHK finds no grounds to give a recommendation to the shipping company in regard to actions relating to the fire alarm.

3.2.2 Risks in the search team operation

As stated in section 1.8.3, the search team consisted of the electrical engineer and the bosun. The electrical engineer could respond immediately whereas it took a little longer for the bosun, who was in the shower when the fire alarm sounded. However, this entailed no consequences for the search team’s capacity to complete its task of assessing what had triggered the fire alarm. That being said, to approach the fire alone, like the electrical engineer did in this case, constitute a very large risk.

The investigation shows that the electrical engineer quickly arrived on deck 1 via a midship stairwell, and that he entered the deck immediately. At his entry point, there was hardly any smoke, but he could see thick dense smoke astern through the opening in the bulkhead. Even so, he continued the search alone, first through thin smoke that smelled of burned plastic and later crawling on all fours under thick black smoke. The bosun had not yet arrived on deck 1.

In SHK's view, the electrical engineer subjected himself to a very great risk by moving towards and underneath the thick black smoke from the fire. In order to move around the deck, he also had to go through a number of narrow passages where he had to walk sideways and step over lashings, which he could have tripped over. If the smoke had suddenly thickened, it could have become very difficult for him to find his way out from the deck. The more a fire grows in a closed space, the lower the underside of the smoke from the fire. The conditions were such that the underside of the smoke could have suddenly and rapidly dropped due to the development of the fire or changes in the airflow.

In addition to the risk of no longer being able to find his bearings, the electrical engineer was also at risk of being exposed to toxic substances and elevated heat. If the smoke had become denser, it could have caused the electrical engineer to quickly lose consciousness, with a high risk of a fatal outcome.

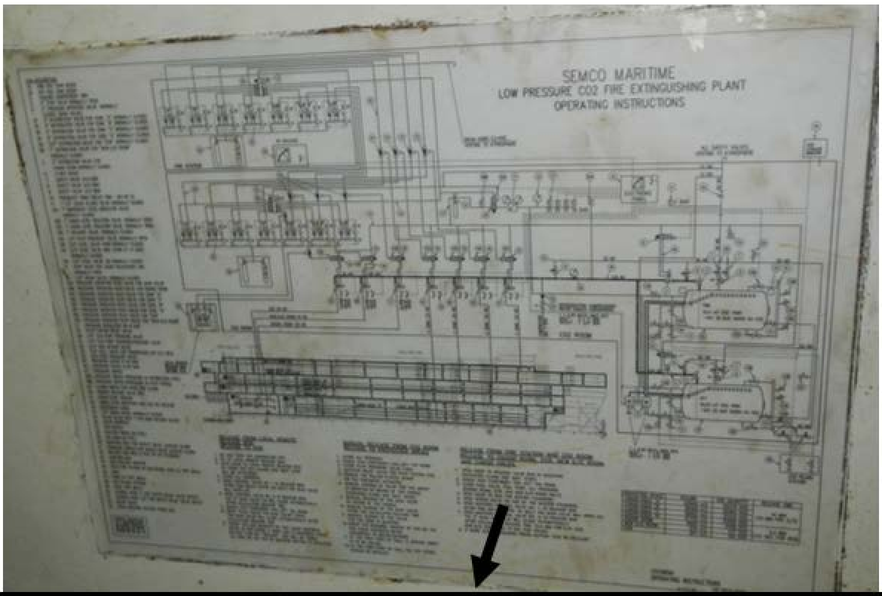
Using a search team can be an effective way of quickly assessing a situation and identifying the need for action. At the same time, such a scheme entails risks. Knowledge and training are required to identify and assess these risks. If a search team is to be used, the procedures should set limits for what risks the team members are allowed to take and a suitable level of protection should be determined. During an ongoing assignment, the search team must also continuously assess the risks and adapt the search based on this risk assessment. According to the shipping company, work is under way to produce a better search team procedure. SHK finds it to be of the utmost importance that this work is completed.

3.2.3 Delayed activation of the fire suppression system

As the report has indicated, there were two instructions for activating the fire suppression system: one from the manufacturer, which also included additional information regarding the system, and one instruction produced on the vessel, which only included the steps to take in an emergency. The chief engineer followed the manufacturer's instructions. However, these instructions proved to be difficult to interpret. The investigation shows that the ambiguous instruction delayed activation of the system by just over five minutes.

According to step 6 of the instruction, one of two valves (masters control valve no. 1) was to be opened, and after waiting around 90 seconds, the main valve for the CO_2 system would open automatically. In the next step, number 7, the second valve (masters control valve no.

2) was then to be opened and the system would then shut down automatically after approx. 15 minutes (see figure 31).



6. OPEN MASTERS CONTROL VALVE NO. 1, IN RELEASE BOX.
AFTER TIME DELAY (APPR. 90 SEC.) THE MAIN VALVE WILL OPEN (4).
7. OPEN MASTERS CONTROL VALVE NO. 2, IN RELEASE BOX.
THE 5" MAIN VALVE (4) WILL CLOSE AUTOMATICALLY
AFTER CALCULATED RELEASE TIME. (2,4 MIN FOR E/R AND
15 MIN. FOR HOLDS)

Figure 31. Excerpt from the instruction followed by the chief engineer to activate the CO_2 system. The delay occurred when the main valve was not opened in accordance with step 6. The figure four within parenthesis in step 6 was also understood to mean that there may be a four-minute delay.

When the main valve had not opened after what the chief engineer deemed to be around 90 seconds, he read the instruction again. Step 6 of the instruction includes the figure four within parenthesis, and the chief engineer understood this to mean that the time of delay could be as much as four minutes. However, the figure in parenthesis actually refers to the number on the main valve in the instruction drawing of the system. When, after waiting four minutes, the main valve still did not open, he opened the second valve (according to step 7) and the main valve immediately opened.

The instruction incorrectly indicated in step 6 that the main valve would open 90 seconds after valve 1 (masters control valve no 1) had been opened. The timer did delay the opening of the main valve for 90 seconds, but valve 2 (masters control valve no 2) also had to be opened in order for the main valve to open in the first place.

According to the manufacturer of the fire suppression system, the timer and the delay are intended to allow any people remaining in the area where the system will be activated to evacuate. However, this function is questionable, partly because it has been added in the middle of activating the system, and partly because it is not possible to determine the time it may take for one or more people to evacuate a space. On the other hand, it is of course important to have a procedure in place to ensure that no-one is left in the space where the fire suppression system is to be activated.

The vessel’s own instruction was more concise and only focused on the manoeuvres required to activate the fire suppression system, which ought to make it easier for the person doing it to quickly activate the system.

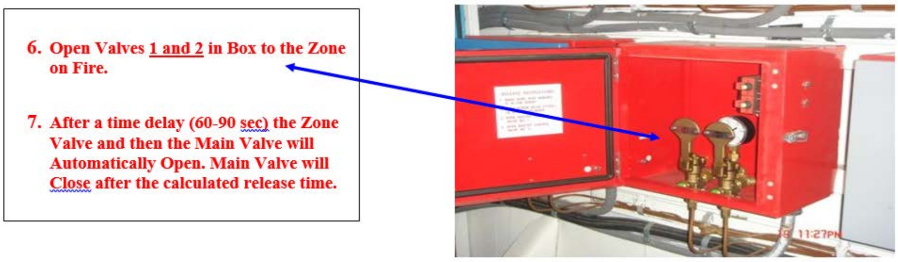


Figure 32. Instruction produced on the vessel.

It cannot be ruled out that the fire could have seriously endangered the lives of the crew and caused a total loss of the vessel if the firefighting operation had not taken place or had been further delayed. There were nearly 42,000 cubic metres of air in the cargo compartment, which was not hermetically sealed, despite fire dampers and doors. Even more air could have been added if the fire had damaged the dampers or doors. The fire thus had access to a lot of oxygen and the chances of it dying down on its own are considered to be very small. On the contrary, it would have more likely started to spread faster. Very high temperatures in large parts of the cargo compartment could have weakened critical parts of the vessel and could also have increased the risk of reigniting following a late attempt to extinguish the fire.

Initiating firefighting operations as soon as possible can thus be the determining factor in the outcome of a fire. This may be a matter of the activation having to be executed within a few minutes in order to avoid serious consequences from a fire. The procedures as well as the instructions to activate the fire suppression system should therefore be reviewed so that they are clear and easy to follow, especially since fires that are serious enough to require activation of the system are very rare. However, as the shipping company is already working on developing a new instruction for the fire suppression system, SHK will not issue any recommendation in this respect.

3.2.4 Radio communication

Everyone who participated in the operation had a radio to communicate with other crew members and to report to the bridge. However, the radio contact between certain locations on the vessel, especially between the bridge and the lower parts of the ships, was inadequate at times. It was for example difficult at times for the bridge to interpret the reports from the CO_2 room and, for short periods of time, there was no radio contact whatsoever.

If radio communication does not work, it can lead to serious situations. The basis for making decisions can be so inadequate that insufficient or incorrect actions are taken. With this in mind, the communication facilities should be reviewed and improved.

In addition, SHK has noted that some of the radio communication was in Swedish, which is not optimal for an international crew. However, in this case, this is not assessed to have had any impact on the firefighting operation or the outcome of the occurrence.

3.3 Actions to reduce the risks of fire and fire spread

3.3.1 Actions to reduce the risk of fire in electrical components in vehicles

In order to minimise the risk of fire in electrical components in different types of vehicle, the negative poles of the batteries can be disconnected in order to render the car's electrical system powerless, which prevents the occurrence of short circuits in electrical components.

A problem in newer vehicles may be that the battery is concealed, and that there may be multiple batteries. Newer vehicles with a start/stop function may for example have two batteries. The extra batteries can be installed in a location other than the engine compartment. Nor is it easy to determine whether the vehicle is equipped with more than one battery.

In regard to electric and hybrid vehicles, there is currently no equally simple way to reduce the risk of fire as a result of short-circuiting. SHK has not had the possibility nor reason, within the scope of this investigation, to more closely investigate which measures could reduce the risk of fire due to short-circuiting in such vehicles.

There is a large number of different battery solutions, but in summary, no general preventive measures to eliminate the risk of fire in all types of vehicle. It may thus be necessary to take several different types of action in order to minimise the risk of electrical vehicle fires on board a vessel. For this reason, it is important to identify the fire risks for each type of vehicle in preparation for maritime transport, in order to take the correct fire prevention measures for each vehicle category.

Special observations regarding loading

According to the IMDG Code, the main rule is that vehicles are to be considered dangerous goods. However, there are exceptions for vehicles that are free of leakages and loaded in spaces that fulfil the requirements of SOLAS Chapter II-2, regulation 20. The risks are thus considered to be managed if the vehicles fulfil certain requirements, and if the cargo holds have been specifically constructed and equipped for this type of cargo. In order to ensure that the vehicles fulfil the requirements of the special regulations, they must, in SHK's view, also be checked in conjunction with loading. However, the investigation shows that checks of used vehicles are only conducted in certain ports. SHK therefore deems it suitable to issue a recommendation to the Swedish Transport Agency to advocate such checks in suitable international contexts for the loading of used vehicles in all the world's ports.

3.3.2 Reducing the risk of fire spread

As it is not possible to completely eliminate the risk of fire, measures should also be taken to limit the consequences of a possible outbreak of a fire. In this case, the spread of the fire between cars was aided by the cars being parked close together, by the side windows being open and by hydraulic oil leaking out into the fire area.

Closing the windows of a vehicle significantly reduces the risk of fire spread (see statement from RISE in regard to fire development in a passenger car, annex 1 to this report). A fire can still arise in the passenger compartment of a vehicle, but it will be more difficult for the fire to develop if the windows and doors are closed. The oxygen is then insufficient to produce the maximum heat release rate and the heat of the fire cannot reach the levels that would cause the windows to crack and break.

The reason why the driver's windows on the cars were open was to have access to the key or remote control, should the doors of the car lock for some reason. However, when asking around different car manufacturers, it has emerged that it should not be possible for new vehicles to lock while the key is in the ignition or the remote control is still inside the vehicle. Since the risk of fire spread can be significantly reduced by keeping the doors and windows of the car closed, SHK is of the opinion that the shipping company should be recommended to produce a loading procedure that enables doors and windows to be kept closed during transport.

The placement of the hydraulic lines directly above the vehicles caused the pipes to burst due to the fire, and approx. 100 litres of hydraulic oil leaked out. This added fuel to the fire, which likely expedited the fire spread. However, changing the pipelines of the vessel is deemed to entail relatively large reconstruction measures, and this action must therefore be considered in relation to the risks and other, alternative, preventative measures.

3.4 Distress call

According to information, the master of the MIGNON stayed updated on which ships were nearby, in case the vessel needed outside assistance. However, the assessment was made that no such assistance was necessary. For this reason, no distress call was made and the MIGNON did not contact any of the nearby vessels.

In the present case, the crew proved capable of managing the situation on their own. However, there is cause to mention in this context that there are a number of investigations relating to occurrences where the crew has refrained from calling for outside help, which has sometimes led to devastating consequences.[15] A decision not to call for outside help must thus be thoroughly considered and evaluated.

The decision on whether or not to call for outside help is made on board, and the master is responsible for this decision. Such a decision naturally involves an assessment of the vessel's and the crew's capacity to manage the occurrence, but it may also be necessary to evaluate other circumstances, such as the conditions for sea rescue in the area the vessel is in and the distance to available help. SHK is well aware that the conditions to receive outside assistance in the event of a fire vary greatly with geographical location in the world. In this case, the vessel was in the South China Sea and the nearest Rescue Coordination Centre was located approx. 390 M away, which in practice meant that the vessel likely would have had to rely on nearby vessels and their resources if the need arose.

As SHK has noted in section 3.2.3, the fire could have rapidly become uncontrollable, which would have entailed serious risks to both crew and vessel. However, the investigation has shown that it was only the day after the incident that the crew fully realised the extent of the fire. It can therefore be assumed that at the time of the event, the crew was not fully aware of the severity of the situation.

There is no rule stipulating that a vessel must send out a distress call during an occurrence which the crew deems themselves capable of handling on their own. Nonetheless, it is important to have favourable conditions to call for outside help if necessary, for example by including and correctly prioritising such an action in the relevant checklists. In the emergency checklist in the event of fire that was applied on board the MIGNON, there was no point in reference to calling for help, if you disregard contacting the shipping company. In SHK's opinion, the shipping company should review the checklist and consider supplementing it in this regard.

[15] See, e.g., SHK's investigation report RS 2016:05 STENA JUTLANDICA/TERNVIND or the Accident Investigation Board Norway's report Sjö 2012/08 LANGELAND (both are available at www.havkom.se). Also refer to the report on the loss of the COSTA CONCORDIA.

4. CONCLUSIONS

4.1 Findings

a) The vessel was nearly fully loaded with new and used vehicles.
b) Deck 1 was fully loaded.
c) Deck 2 was only partially loaded, but there was cargo in the fire area.
d) Decks 1 and 2 were loaded only with used passenger cars.
e) All the used cars had the windows rolled down.
f) The fire most likely started in a used car on deck 1.
g) The fire was most likely caused by a short circuit in the starting motor of the used passenger car.
h) The short circuit could probably continue until the car battery was depleted.
i) The fire spread to several other cars on deck 1, and proceeded up to deck 2.
j) No distress call was made and no nearby vessels were contacted.
k) All functions of the firefighting organisation were activated in accordance with the vessel muster list.
l) One person in the search team tasked with investigating the incoming fire alarm approached the fire area alone and without protective equipment and crawled in underneath the fire smoke.
m) A decision was made to activate the fixed CO_2 fire suppression system.
n) There were two different instructions for activating the fire suppression system.
o) The instruction chosen to activate the system was unclear, which delayed the activation by approximately five minutes.
p) The fire was completely extinguished by the CO_2 fire suppression system.
q) A large number of cars incurred fire or smoke damage.
r) The damage to the vessel was limited to parts of decks 1, 2 and 3.
s) If the activation of the fire suppression system had been further delayed, or if the firefighting operation had failed or not been carried out, it cannot be ruled out that this could have entailed a danger to the crew and a risk of total loss of the vessel.
t) There were shortcomings in the internal radio communication.

4.2 Causes and contributing factors

The fire was likely caused by a short circuit in the starting motor of a passenger car and then spread to combustible material in the car’s engine and passenger compartments and then on to other cars and parts of the ship’s structure.

Contributing factors that allowed the fire to spread to other cars included the cars standing close together and the car windows on the driver’s side being rolled down.

5. SAFETY RECOMMENDATIONS

Following the occurrence, the shipping company has installed a new central fire alarm control panel. Furthermore, a new instruction for the fire suppression system is being developed in collaboration with the manufacturer. Work to review emergency checklists, including procedures to call for outside help, has also been initiated. In addition, procedures have been introduced to ensure that the negative pole of used car is always disconnected. (See section 2.)

SHK therefore refrains from issuing any recommendations in these regards.

Wallenius Marine AB is recommended to:

- Reduce the risk of fire in vehicles being transported by taking fire prevention measures based on identified fire risks for each type of vehicle. See section 3.3.1. *(RS 2019:02 R1)*

- Develop procedures for loading of vehicles which allow the windows on the vehicles to be kept closed, in order to limit the spread of fire. See section 3.3.2. *(RS 2019:02 R2)*

- Complete the work that has been initiated to improve the search team routines, set limits for what risks the team members are allowed to take, and provide adequate training for the team, so that its members are able to identify risks and determine a suitable protection level before taking action. See section 3.2.2. *(RS 2019:02 R3)*

The Swedish Transport Agency is recommended to:

- Advocate internationally for inspections in conjunction with loading of used vehicles in all the world's ports. See section 3.3.1. *(RS 2019:02 R4)*

The Swedish Accident Investigation Authority respectfully requests to receive, **by 28 June 2019** at the latest, information regarding measures taken in response to the recommendations included in this report.

On behalf of the Swedish Accident Investigation Authority,

Helene Arango Magnusson Jörgen Zachau

Appendix 1

Statement from RISE regarding fire development inside a passenger car, 01/03/2019

Fire size inside a car

By calculating the oxygen supply in an enclosed and sealed space, the amount of potential released energy from combustion before the oxygen content becomes too low to maintain a fire can be calculated.

Numerical studies were conducted using a two-zone model software – CFAST. A compartment of 3.5 m (length) × 2.0 m (width) × 1.5 m (height) was built to represent a car. The material of the car was steel, with conductivity 45.8 W/(m ℃), specific heat 0.46 kJ/(kg ℃), density 7850 kg/m^3 and emissivity 0.95. The steel was 0.03 m thick. The lower oxygen limit is 15% (in volume).

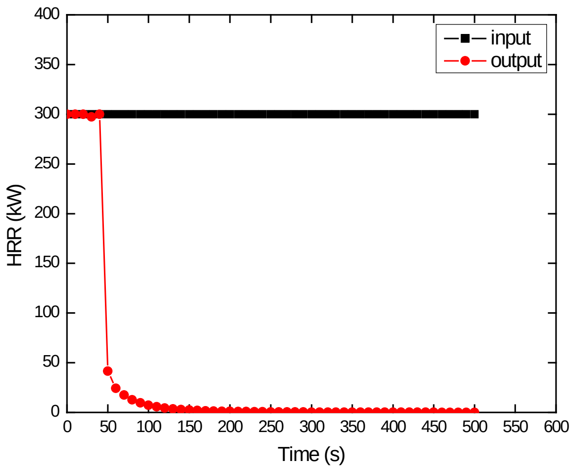
The fire source was made up of Polyester (C1H1.4O0.22) and Nylon (C1H1.8O0.17N0.17). The chemical formula of the fuel specie was simplified as C1H1.6O0.2N0.09, assuming a 50% Polyester and 50% Nylon. The soot yield was 0.075 and the CO yield was 0.038. The heat of combustion was 30 MJ/kg. The radiative fraction was 0.35. The fire was placed at the floor center of the compartment, with an area of 1 m^2. Two fire curves were studied: one constant curve at 300 kW (0.3 MW/m^2, a typical value for a car fire) and one fast growing curve to 1054 kW. A large value was set for the fast growing curve, to study the maximum heat release rate (HRR) the fire can reach before it self-extinguishes.

Sealed space

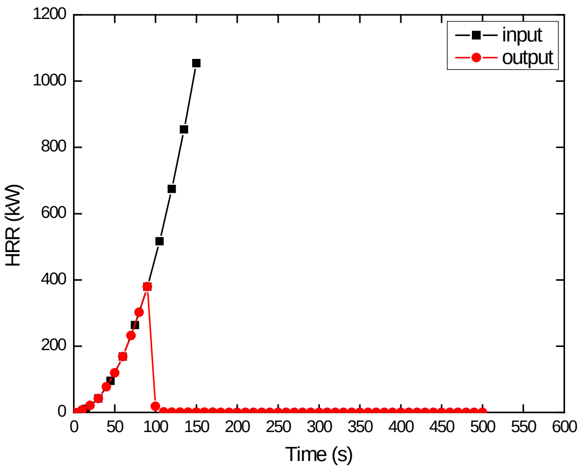
In a sealed enclosure, a preliminary estimation of HRR can be made by considering the consumption of oxygen. The amount of energy released per unit mass of oxygen consumed is 13.1 MJ/kg, which is considered to be accurate to ± 5% for most fuels. The total air volume inside the compartment is 3.5×2×1.5=10.5 m^3. In the fresh air, the oxygen has a volume fraction of 21% (23.2% in mass fraction). The air density is 1.2 kg/m^3. The mass of oxygen inside the compartment is 0.232×1.2×10.5=2.9 kg. The oxygen limit for self-extinguishing is 15% in volume fraction (16.6% in mass fraction). The oxygen can be consumed by combustion is: 2.9-0.166×1.2×10.5=0.81 kg. The energy released by combustion is 0.81×13.1=10.6 MJ, which corresponds to the fuel of 10.6/30=0.35 kg.

In the CFAST simulation, the predefined and output HRR is shown in Fig. 1. For the constant curve, the HRR drops from predefined 300 kW to 41 kW at 50 s, and then takes another 50 s to reach 7 kW. For the fast curve, the HRR drops from predefined 380 kW to 18 kW at 100 s, and then quickly self-extinguishes. The maximum HRR the fire can reach is 380 kW at 90 s.

The total energy released an be obtained by integrating the HRR over time. For constant curve, the total energy is 11.87 MJ, which requires the combustion of 11.87/30=0.40 kg fuel. For fast curve, the total energy is 13.69 MJ, which requires the combustion of 13.69 /30=0.45 kg fuel. The total energy released by a fast curve is larger than that from a constant curve. Compared with the preliminary estimation of 0.35 kg fuel, a larger value is obtained with CFAST.



(a) constant curve



(b) fast curve

Fig. 1. HRR of constant curve (a) and fast curve (b) in a sealed space.

Space with opening

To study the fire development in case of people breaking one window to escape, an opening was added at the front of the compartment (see Fig. 2). The opening size was 0.5 m × 0.5 m, which was placed 0.2 m from the left end and 0.8 m from the floor.

In the later stage of the fire, the oxygen needed for combustion is provided by the natural ventilation of the window. The possible maximum HRR inside a compartment during the ventilation-controlled stage can be estimated using:

$$\dot{Q}_{max} = 1500 A_0 \sqrt{h_0}$$

where A_0 is the area of the opening and h_0 is the height of the opening. In current case, $\dot{Q}_{max}$ =1500×0.25×$\sqrt{0.5}$=265 kW.

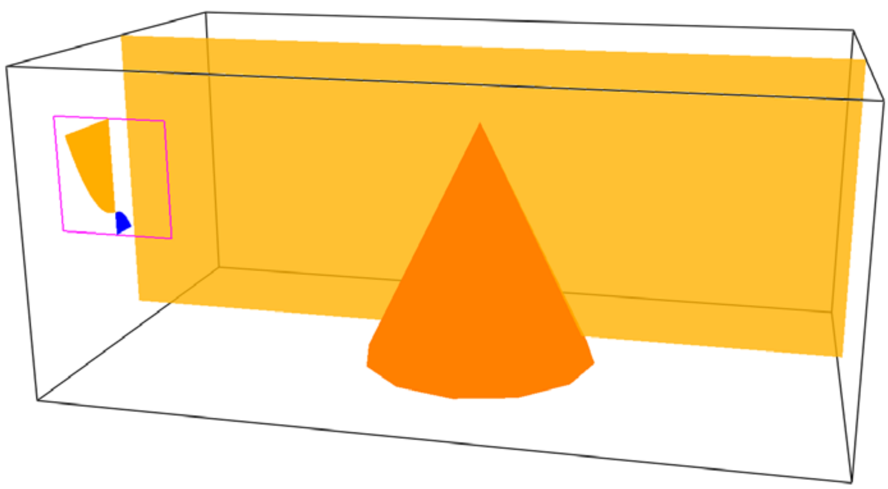
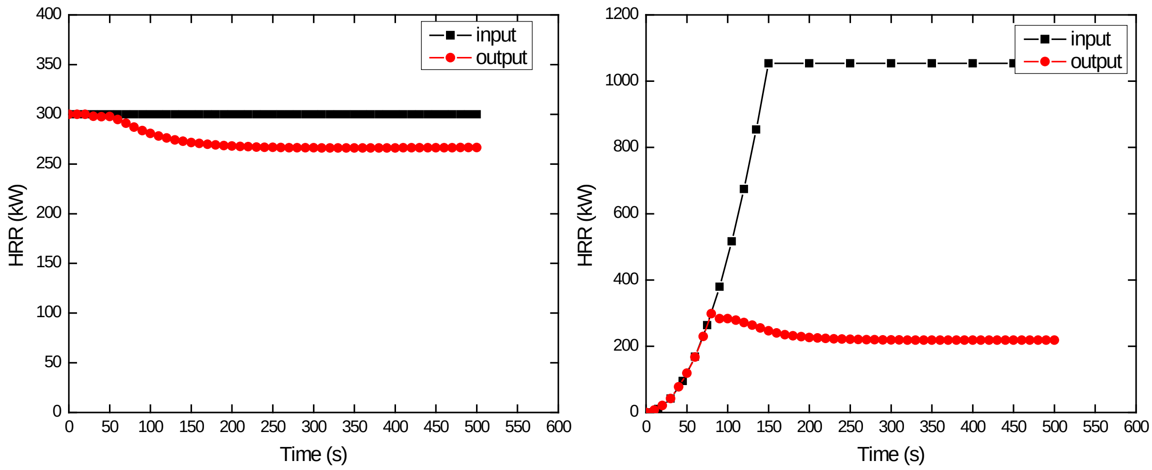


Fig. 2. Space with 0.5 m × 0.5 m window at the front.

Fig. 3 shows the HRR of the constant curve and the fast curve in presence of a window. For the constant curve, the fire drops from 300 kW to 295 kW at 60 s. Due to the oxygen supplied by the natural ventilation, a steady HRR of 266 kW is reached at 170 s. For the fast curve, the maximum HRR the fire can reach is 298 kW at 80 s. The final steady HRR is about 220 kW, reached at 250 s. For both curves, the final steady state HRR is close the estimated value 265 kW. One finding is that although the geometry is the same for the constant and fast curve, the final steady state HRR is different. The reason is unclear, but one may suspect that the pressure difference induced by different combustion process may have influenced the natural ventilation in the final steady stage.



(a) constant curve (b) fast curve

Fig. 3. HRR of constant curve (a) and fast curve (b) in a space with window.

The upper layer temperature of constant and fast curve is shown in Fig. 4. In the final steady stage, the upper layer temperature is about 250 °C. At this high temperature, the window may break down, and creates larger openings than expected.

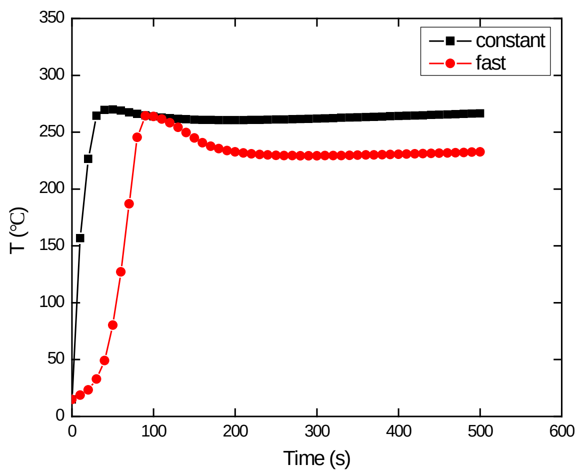


Fig. 4. Upper layer temperature of constant and fast curve inside the compartment.

Summary

To summarize, the time to reach a maximum HRR, the maximum HRR and the final steady state HRR in the four cases studied are listed in Table 1.

Table 1. HRR and time in the simulation.

	Time (s)	Maximum HRR (kW)	Final HRR (kW)
sealed			
constant curve	first 40	300	0
fast curve	90	380	0
with opening			
constant curve	first 50	300	266
fast curve	80	298	250