NATIONAL TRANSPORTATION SAFETY BOARD
Meeting of November 18, 2025
(Information subject to editing)

Contact of Containership *Dali* with Francis Scott Key Bridge and Subsequent Bridge Collapse
Patapsco River
Baltimore, Maryland
March 26, 2024
DCA24MM031

This is a synopsis from the NTSB's report and does not include the Board's rationale for the findings, probable cause, and safety recommendations. NTSB staff is currently making final revisions to the report from which the attached findings and safety recommendations have been extracted. The final report and pertinent safety recommendation letters will be distributed to recommendation recipients as soon as possible. The attached information is subject to further review and editing to reflect changes adopted during the Board meeting.

Executive Summary

What Happened

On March 26, 2024, about 0129 local time, the 984-foot-long Singapore-flagged cargo vessel (containership) *Dali* was transiting out of Baltimore Harbor in Baltimore, Maryland, when it experienced losses of electrical power, propulsion, and steering and struck Pier 17, the southern pier that supported the central span of the Francis Scott Key Bridge (Key Bridge). A substantial portion of the bridge subsequently collapsed into the river, and portions of the pier, deck, and truss spans collapsed onto the vessel's bow and forwardmost container bays.

A seven-person road maintenance crew and one inspector were on the bridge when the vessel struck it. Six of the highway workers died as a result of the bridge collapse. One highway worker survived the collapse with serious injuries, and the inspector escaped unharmed. One of the 23 persons aboard the *Dali* sustained a minor injury. Damage to the *Dali* exceeded $18 million. Cargo damages were undetermined.

At the time of this report, replacement costs for the bridge are estimated at $4.3 billion to $5.2 billion and is anticipated to open to traffic in late 2030.. Over 34,000 vehicles, 10% of which are trucks, that formerly traveled over the Key Bridge every day must now take alternate routes around and through the Port of Baltimore, increasing congestion and travel times. The Key Bridge was also the primary route for vehicles carrying hazardous materials. These vehicles, which are prohibited from using the tunnels under the Baltimore waterways, must now make extended detours around the port.

What We Found

On March 26, after getting underway from Seagirt Marine Terminal in the Port of Baltimore, Maryland the *Dali* experienced two electrical power outages (blackouts). We found that the initial underway blackout was caused by a series of electrical-related events that began when a signal wire (Wire 1), one of many in the main switchboard, electrically disconnected from its terminal block. The terminal block, a small, insulated plastic block, connected Wire 1 to another wire within the vessel's high-voltage switchboard. When Wire 1 electrically disconnected, one of the high-voltage breakers connecting the high-voltage bus to its step-down transformer—a mechanism that lowered voltage carried from the main, high-voltage, electrical bus before transferring it to the low-voltage bus—opened. The breaker opening interrupted power to the step-down transformer between the high-voltage electrical bus and the low-voltage electrical bus, which resulted in a low-voltage blackout.

Installed on each signal wire were labeling bands (wire-label banding), which were small silicone sheaths made of thermoplastic material that was heat-shrunk around the wire and had its associated terminal block printed on it. We found that Wire 1's label band (wire-label banding) covered all of the ferrule's blue insulated collar, increasing the ferrule's overall circumference, preventing the wire from being fully inserted into its terminal block—leaving Wire 1 vulnerable to becoming electrically disconnected.

We found that if infrared thermal imaging, an inspection technique that allows inspectors to identify possible points of failure in electrical components not visible to the human eye, had been used to inspect the *Dali*'s high-voltage switchboard connections as part of the vessel's preventative maintenance program, the loose Wire 1 may have been identified.

The low-voltage bus powered the low-voltage switchboard, which supplied power to vessel lighting and other equipment, including steering gear pumps, the fuel oil flushing pump and the main engine cooling water pumps. We found that the loss of power to the low-voltage bus led to a loss of lighting and machinery (the initial underway blackout), including the main engine cooling water pump and the steering gear pumps, resulting in a loss of propulsion and steering.

As a result of our investigation, we identified four safety concerns that, while not causal to the initial underway blackout, were related to preventing a loss of propulsion and recovering steering and vessel electrical power following a blackout.

- The configuration of the main engine to shut down due to low cooling water pressure.

- The use of the flushing pump as a fuel service pump for the electrical diesel generators.
- The operation of the vessel's low-voltage step-down transformer high-voltage breakers in Manual mode rather than Automatic.
- The effect of emergency diesel generator radiator damper positions on the generator's ability to start.

The first of these safety concerns was the configuration of the main engine to shut down due to low cooling water pressure. We found that this as-built configuration, which met classification standards at the time the vessel was constructed, endangered the vessel because the engine shut down when its cooling pump lost power following the initial underway blackout. Without the main engine running, the vessel's maneuverability was reduced.

The second safety concern was the operation of the flushing pump as a service pump for supplying fuel to online diesel generators. The online diesel generators running before the initial underway blackout (diesel generators 3 and 4) depended on the vessel's flushing pump for pressurized fuel to keep running. The flushing pump, which relied on the low-voltage switchboard for power, was a pump designed for flushing fuel out of fuel piping for maintenance purposes; however, the pump was being utilized as the pump to supply pressurized fuel to diesel generators 3 and 4.

Unlike the supply and booster pumps, which were designed for the purpose of supplying fuel to diesel generators, the flushing pump lacked redundancy. Essentially, there was no secondary pump to take over if the flushing pump turned off or failed. Furthermore, unlike the supply and booster pumps, the flushing pump was not designed to restart automatically after a loss of power. As a result, the flushing pump did not restart after the initial underway blackout and stopped supplying pressurized fuel to the diesel generators 3 and 4, thus causing the second underway blackout (low-voltage and high-voltage).

The day before the accident, on March 25, the *Dali* had experienced two blackouts while in port. The second in-port blackout on March 25, was ultimately caused by the flushing pump, which lacked redundancy, not restarting after a loss of power, supplying insufficient fuel pressure to online diesel generators. This was also the cause of the second underway blackout on March 26.

Although not causal to the initial underway blackout, we found that the crew's operation of the flushing pump as the service pump for online diesel generators was inappropriate because the necessary fuel pressure for diesel generators 3 and 4 would not be automatically reestablished after a blackout. We found that operational oversight by Synergy, the *Dali*'s operator, was inadequate because it did not discontinue crews' ongoing use of the flushing pump as a service pump for the diesel generators aboard the *Dali* and at least one other vessel we identified.

The third safety concern we identified was the operation of the vessel's high-voltage breakers for the low-voltage step-down transformers in Manual mode rather than in Automatic mode. As discussed above, the step-down transformer lowered the voltage from the main, high-voltage bus to the low-voltage bus. In Manual mode, the high-voltage breakers had to be manually closed after a blackout. In Automatic mode, high-voltage breakers for the vessel's other step-down transformer would connect and automatically restore low-voltage power within 10 seconds (Automatic) after a blackout. Aboard the *Dali*, there was no regulation or vessel operational guidance to set the breaker control mode to Automatic or Manual. Because the breakers' control modes were set to Manual when the initial underway blackout occurred, one of the high-voltage breakers, along with its corresponding low-voltage breaker, opened, and a crewmember had to manually close these breakers to restore power. We found that keeping the high-voltage breakers' control modes set to Automatic rather than Manual would not have prevented either underway blackout, but it would have shortened the duration of the initial underway blackout from 58 seconds to 10 seconds, providing more time for the crew to attempt to recover critical systems, such as propulsion, as the vessel approached the Key Bridge. Despite the delay caused by the step-down transformer needing to be manually restarted, we found the engineering crew's response to restoring low-voltage power after the first underway blackout timely.

The fourth safety concern was the effect of the emergency diesel generator radiator damper positions on the generator's ability to start within 45 seconds, as required by international regulations. After a loss of LV power, the emergency diesel generator is designed to start and power essential onboard systems such as navigation and communication equipment and emergency lighting. After the initial underway blackout, the *Dali*'s emergency diesel generator took 70 seconds to connect. We found this was because the generator damper actuator's limit switch, which detected whether the damper was open or closed, did not indicate open in the required time due to unknown circumstances. Due to the system design, any delay in the opening of the radiator damper (or its limit switch indicating it as not open) would postpone the emergency generator starting.

Proactive safety management, when done correctly, is predictive, designed to anticipate and address safety issues before they occur, and utilizes continuous data analysis to improve policies and procedures. The NTSB has previously advocated for the benefits of, and made recommendations to implement and improve, safety management systems (SMS) across all modes of transportation, because an effective SMS can help organizations proactively identify risks to reduce and prevent accidents and accident-related loss of lives, time, and resources. The International Maritime Organization's (IMO) International Safety Management Code for the Safe Operation of Ships and for Pollution Prevention, commonly referred to as the International Safety

Management, or ISM, Code (International Safety Management [ISM] Code), establishes the standard for SMSs in the marine industry. The commercial aviation industry's SMS model provides a robust framework for achieving effective safety management that supports a systematic, top-down, proactive approach. The four components of the aviation SMS are safety policy, safety risk management, safety assurance, and safety promotion. While the requirements of the ISM Code include some elements of a comprehensive, proactive safety management system, we found that ISM code does not fully encompass the four critical components found in the aviation model.

After the initial underway blackout, the *Dali*'s heading began swinging to starboard toward Pier 17 which was only 200 feet from the edge of the channel. We found that the pilots and the bridge team attempted to change the vessel's trajectory, but the vessel's loss of propulsion so close to the Key Bridge rendered their actions ineffective. About a minute after the vessel first lost power, the pilot contacted a shoreside dispatcher to notify them of the emergency and instruct them to close the Key Bridge to traffic. Maryland Transportation Authority (MDTA) Police officers were stationed on both ends of the bridge conducting traffic control duties as part of the ongoing maintenance project. The officers immediately stopped all traffic from entering onto the bridge, and as a result, the bridge was cleared of traffic about 48 seconds before the vessel struck the bridge. We found that the quick actions of the pilots, the pilots' shoreside dispatchers, and the MDTA, to stop bridge traffic prevented a greater loss of life from the bridge collapse.

The Key Bridge, like many other bridges, was not equipped with a warning system to prevent motorists from driving onto the bridge in the event of a hazard. We found that, in lieu of police officers or highway workers capable of quickly stopping traffic, motorist warning systems preventing motorists from entering onto a bridge are a critical countermeasure that can save lives and may be a component of an effective bridge protection strategy. Methods to prevent motorist deaths resulting from bridge collapses have been promoted since the 1970s. Since the 1980s, while working with American Association of State Highway and Transportation Officials (AASHTO), the Federal Highway Administration has promoted the use of various technologies to mitigate motorist deaths and injuries in various publications and guide specifications. We also found that owners of bridges over navigable waterways frequented by ocean-going vessels would benefit from updated guidance on motorist warning systems.

The seven highway workers and inspector on the Key Bridge at the time were not notified of the *Dali*'s emergency situation before the bridge collapsed. We found that, had they been notified about the same time the MDTA Police officers were told to block vehicular traffic, the highway workers may have had sufficient time to drive to a portion of the bridge that did not collapse. Further, we found that effective and immediate communication to evacuate the bridge during an emergency is critical to ensuring the safety of bridge workers.

As a result of our investigation and past investigations the NTSB has performed we identified as a safety issue the vulnerability of bridges over navigable waterways to strikes by large ocean-going vessels. On March 18, 2025, we issued a report, *Safeguarding Bridges from Vessel Strikes: Need for Vulnerability Assessment and Risk Reduction Strategies*, related to this safety issue. In our report, we found that, had the MDTA conducted a vulnerability assessment of the Key Bridge as recommended by the 1991 and 2009 American Association of State Highway and Transportation Officials *(AASHTO) Guide Specifications and Commentary for Vessel Collision Design of Highway Bridges*, the MDTA would have been aware that the bridge was almost 30 times greater than the AASHTO threshold of risk for catastrophic collapse from a vessel collision when the *Dali* collision occurred.[1] Further, had the MDTA conducted the vulnerability assessment using AASHTO's Method II vulnerability assessment calculation, the MDTA would have had information to proactively identify strategies to reduce the risk of a collapse and loss of lives associated with a vessel collision with the bridge. Finally, we found that owners of numerous bridges over navigable waterways frequented by ocean-going vessels are likely unaware of their bridges' risk of catastrophic collapse from a vessel collision and the potential need to implement countermeasures to reduce the bridges' vulnerability.

Recovery and analysis of the *Dali*'s voyage data recorder (VDR) data was integral to our investigation. However, our investigators encountered significant challenges that highlighted the need for robust standards for manufacturer-provided VDR software. We found that although the VDR model installed on board the *Dali* generally complied with IMO regulations and International Electrotechnical Commission (IEC) standards, significant deficiencies in data accessibility, audio usability, and playback software functionality revealed a critical disconnect between published technical standards and practical investigative and organizational needs to identify safety issues and solutions, and for operators and regulators to ensure safety. We found that the monoaural audio configuration of the *Dali*'s VDR system, which mixed multiple microphones into shared channels, significantly impaired the NTSB's ability to isolate and analyze critical bridge conversations, distinct voices, and sounds from the alarms and background noise. This configuration reduced the recording's intelligibility and limited the effectiveness of audio enhancement tools. Furthermore, audio information from both sides of the electric telephone was not recorded during the accident, which prevented the NTSB from hearing the engine room's responses to bridge communications during the accident. We found that the lack of recording of parametric information (such as speed, thrust, steering, GPS position, automatic identification system data, and chart plotter

[1] The Maryland Department of Transportation State Highway Administration was a member of the development committee the 2009 AASHTO *Guide Specifications and Commentary for Vessel Collision Design of Highway Bridges*. MDTA was a member of the Bridges and Structures Subcommittee for the AASHTO *Load Resistance Factor Design (LRFD) Bridge Design Specifications*, which references the 2009 *Guide Specifications*.

information) by the VDR during a vessel power loss can inhibit proactive monitoring of these data by organization and adversely impact the investigation into an accident and make it more difficult for operators to use the data to improve safety of operations.

We investigated the wider issue of large containerized cargo ships, which have grown significantly in size and capacity in recent decades, calling more often at ports such as Baltimore. The increased size of vessels and increased cargo volumes presents challenges for existing port infrastructure that may not have been built. We found that increasingly larger containerized cargo vessels, such as the *Dali*, pose increased risks and challenges to maritime safety due to their reduced maneuverability in proximity to existing port and waterway infrastructure that was not designed to accommodate vessels of such size. Finally, we found that, as cargo vessel designs continue to evolve with the latest available standards and technology, increased redundancy to maintain critical systems, such as the main engine and steering, can mitigate risks in restricted waters.

What We Recommended

We recommended that Synergy, the vessel manager that provided the crew and operated the vessel, work with its classification society to obtain approval to implement the use of infrared thermal imaging for routine monitoring of electrical components, including to detect inadequate signal wire connections. We recommended WAGO, the manufacturer of the terminal block, add a warning in its product data sheet accompanying WAGO terminal block 280-681 (the model of the terminal block Wire 1 connected to), as well as any other terminal block models or similar products that incorporate wire-label banding it manufactures, to explain that improperly placed wire-label banding can impede proper insertion of wire into a terminal block. We also made a recommendation to HD Hyundai Heavy Industries Co., Ltd. (HHI), the vessel's builder to incorporate proper wire-label banding installation methods into its electrical department's standard operating procedures to ensure that wire-label banding installed on a wire does not impede the proper insertion of wire into a terminal block.

In addition, we recommended that Nippon Kaiji Kyokai (ClassNK), the *Dali*'s classification society, share the circumstances of the accident with the International Association of Classification Societies and urge them to distribute this report to their members, highlighting:

a. the importance of avoiding placement of wire-label banding such that it impedes proper insertion of the wire in a terminal block
b. the benefits of using infrared thermal imaging as part of a preventative maintenance program for routine monitoring of electrical components to detect inadequate signal wire connections
c. the potential risks that partially open radiator dampers can pose to emergency generators starting

d. the need for members to review their rules on acceptable emergency generator start design.

As seen with the *Dali*, the loss of steering pumps and auxiliary systems supporting the main engine can result in the loss of steering and propulsion, which is critical to maintaining the ship's position while operating within narrow channels and close to port infrastructure. We recommended that the Coast Guard conduct and publish the results of a study that examines the availability, feasibility, and safety benefits of redundant means to ensure that large single-propulsion-engine cargo vessels maintain propulsion and steering when maneuvering in restricted waters.

We issued several recommendations related to recovery following a blackout. To eliminate vessel crews' use of the flushing pump as a fuel oil service pump and reduce the risk of subsequent blackouts, we recommended that Synergy develop, implement, and monitor for compliance an SMS policy and procedure to ensure that vessel crews are using the fuel oil service pumps as designed for the diesel generator fuel supply systems installed on board its vessels. To avoid unnecessary main engine shutdowns during blackouts, we recommended that Synergy identify ships it operates that are equipped with an engine like the *Dali*'s and ensure they are not configured to automatically shut down due to low cooling water pressure. We also recommended that HD Hyundai Heavy Industries, identify all active HD Hyundai Heavy Industries-constructed vessels with Hyundai-MAN B&W 9S90ME C9.2 engines installed, which are configured to Germanischer Lloyd rules and are designed to shut down on low cooling water pressure, and alert the current vessel owners of this configuration and the circumstances of this accident. Additionally, to improve crews' ability to recover from blackouts, we recommended that Synergy develop, implement, and monitor for compliance and effectiveness a safety management system policy and procedure to ensure that vessel crews are setting high-voltage breakers' control mode to Automatic while operating, unless the transformer breakers are being manually operated or maintenance is being performed and incorporate this policy and procedure within its safety management system. Finally, we recommended that Synergy identify ships it operates with similar arrangements to the *Dali* and notify crews of those vessels that partially open radiator dampers can delay or prevent the emergency diesel generator from starting automatically.

To address the need to enhance the IMO's ISM Code that establishes SMS standards for the marine industry and make it more similar to the commercial aviation industry SMS model, we recommended the Coast Guard, which is the US representative to the IMO, propose to the IMO that it revise the International Management Code for the Safe Operation of Ships and for Pollution Prevention and associated guidelines to fully incorporate safety policy, safety risk management, safety assurance, and safety promotion into its safety management system requirements. We issued two recommendations to increase the safety of workers on bridges over navigable waterways. First, we recommended that the American National Standards Institute's

(ANSI) Accredited Standards Committee on Safety in Construction and Demolitions Operations A10 revise *ANSI/ASSP A10.47, Work Zone Safety for Roadway Construction*, to include an effective and immediate means of emergency communications to alert workers performing roadway work on bridges over navigable waterways, which should consider the presence of law enforcement for traffic control. We also recommended that the Harbor Safety Committee National Steering Team share with harbor safety committees nationwide the importance of having a procedure, including immediately available emergency contact information, for pilots to initiate contact with shoreside support in an emergency requiring shoreside action to ensure timely and efficient action by first responders and port stakeholders.

In our March 18, 2025, report related to this investigation, we issued four urgent recommendations to safeguard bridges from contact by large ocean-going vessels. We recommended that the Federal Highway Administration, in coordination with the US Coast Guard and US Army Corps of Engineers, establish an interdisciplinary team and provide guidance and assistance to bridge owners on evaluating and reducing the risk of a bridge collapse from a vessel collision. We also identified 68 bridges that were:

(1) over navigable waterways that are frequented by ocean-going vessels,

(2) built before 1996 (bridges under design or initial construction in 1991 were likely not built to AASHTO's *Guide Specifications*), and

(3) may not have undergone a vulnerability assessment based on recent vessel traffic.

We recommended that 30 bridge owners identified in the report as managing bridges over navigable waterways frequented by ocean-going vessels whose bridges were likely not designed and built to the AASHTO *Guide Specifications* determine their bridges' AASHTO Method II annual frequency of collapse and inform the NTSB whether the probability of collapse is above the AASHTO threshold. We recommended that these bridge owners develop and implement a comprehensive risk reduction plan if this annual frequency exceeded the AASHTO threshold. We have received responses from all of the bridge owners, and this report includes the classifications for each response.

We issued three recommendations to address motorist warning systems on bridges. We recommended that 20 bridge owners who, in response to the March 2025 NTSB Urgent Safety Recommendation H-25-2, found their bridges above the AASHTO threshold or who indicated that they have not yet completed their Method II calculations should, as part of their short-term bridge risk reduction and mitigation strategy to protect the traveling public, evaluate and, if appropriate, incorporate a motorist warning system capable of activating when a threat is identified and immediately warn and stop motorists from entering onto the bridge.

We recommended that AASHTO lead the efforts to update their *Guide Specifications and Commentary for Vessel Collision Design of Highway Bridges* to include guidance in the selection of motorist warning systems with consideration of cost and other asset management principles. Evaluated changes should include hazard alert and sensing technologies capable of detecting errant vessels and bridge movements that would indicate a need for bridge closure and would both warn and prevent motorists from entering a bridge once a threat is detected.

We also recommended that the Federal Highway Administration (FHWA) work with AASHTO to research and implement hazard alert and sensing technologies capable of detecting errant vessels and bridge movements that would indicate a need for bridge closure and would both warn and prevent motorists from entering a bridge once a threat is detected.

Finally, as a result of this investigation, we issued two recommendations related to improving VDR systems' functionality and ease of use during investigations. First, we recommended that the Coast Guard notify the IMO of the VDR technical issues encountered during our investigation into the contact of containership *Dali* with the Francis Scott Key Bridge and subsequent bridge collapse, and submit to the IMO a concrete proposal to require:

1. the recording of mandatory data inputs from systems that remain powered during a blackout,
2. the recording of engine room communications to the bridge
3. the recording of multiple bridge microphone inputs such that the audio channels can be isolated or recorded independently, and
4. performance requirements for playback software that facilitates real world use, including enhanced criteria for exporting proprietary VDR data into open industry standard formats.

Second, we recommended that the ANSI propose to the IEC Technical Committee 80 to revise *IEC 61996-1 ed. 2* to require:

1. the recording of mandatory data inputs from systems that remain powered during a blackout,
2. the recording of engine room communications to the bridge,
3. the recording of multiple bridge microphone inputs such that the audio channels can be isolated or recorded independently, and
4. updating the performance requirements for playback software that facilitates real world use, including enhanced criteria for exporting proprietary VDR data into open industry standard formats.

We determined that the probable cause of the contact of the containership *Dali* with the Francis Scott Key Bridge was a loss of electrical power (blackout), due to a loose signal wire connection to a terminal block stemming from the improper installation of wire-label banding, resulting in the vessel's loss of propulsion and steering close to the bridge. Contributing to the collapse of the Key Bridge and the loss of life was the lack of countermeasures to reduce its vulnerability to collapse due to impact by ocean-going vessels, which could have been implemented if a vulnerability assessment had been conducted by the MDTA as recommended by AASHTO. Also contributing to the loss of life was the lack of effective and immediate communications to notify the highway workers to evacuate the bridge.

Conclusions

Findings

1. None of the following were factors in this accident: (1) environmental or waterway conditions; (2) vessel complement and mariner credentialing; (3) impairment of the *Dali* crew or pilots due to alcohol or other tested for drugs; (4) fuel quality or switchover of fuels; (5) vessel's ability to get underway after in-port blackouts; or (6) the presence of non-redundant steel tension members in the Key Bridge's continuous steel through-truss.
2. The initial March 26 low-voltage blackout was caused by Wire 1 electrically disconnecting from Terminal Block 381 within the HV switchboard, which resulted in high-voltage breaker HR1 opening, interrupting power to step-down transformer TR1 and the LV bus.
3. The position of the wire-label banding on the ferrule of Terminal Block 381's Wire 1 prevented Wire 1 from being fully inserted into the terminal block spring-clamp gate, causing an inadequate connection and leaving Wire 1 loose and vulnerable to becoming electrically disconnected.
4. If infrared thermal imaging had been used to inspect wire connections within the HV switchboard before the accident as part of the *Dali*'s preventative maintenance program, the loose signal wire may have been identified.
5. The loss of power to the low-voltage bus led to a loss of lighting and machinery, including the main engine cooling water pump and the steering gear pumps, which resulted in a loss of propulsion and steering.
6. The as-built configuration of the *Dali*'s main engine to automatically shut down due to low cooling water pressure met classification standards at the time the vessel was constructed; however, it endangered the vessel because it prevented the main engine from being available following the initial underway blackout, thus reducing the vessel's maneuverability.

7. The engineering crew's initial response to restoring low voltage (LV) power after the first underway blackout was timely.

8. The second underway blackout on March 26 and the second in-port blackout on March 25, during which both the high- and low-voltage buses lost power, were caused by insufficient fuel pressure to online diesel generators, resulting from the inability of the flushing pump to automatically restart following a loss of power.

9. The crew's operation of the flushing pump as the service pump for online diesel generators was inappropriate because the necessary fuel pressure for diesel generator 3 and diesel generator 4 would not be automatically reestablished after a blackout per the fuel system's design.

10. Synergy's operational oversight was inadequate because it did not discontinue crews' ongoing use of the flushing pump as a service pump for the diesel generators aboard the *Dali* and at least one other vessel.

11. Keeping the high voltage (HV) breakers' control modes set to Automatic rather than Manual would not have prevented either underway blackout, but it would have shortened the duration of the initial underway blackout from 58 seconds to 10 seconds, providing more time for the crew to attempt to recover critical systems, such as propulsion, as the vessel approached the Key Bridge.

12. It is likely that the emergency diesel generator's failure to connect and power the emergency switchboard within 45 seconds, as required by International Maritime Organization regulations, was due to the emergency diesel generator radiator damper actuator's limit switch not indicating open in the required time due to unknown circumstances.

13. The actions of the pilots and the bridge team in response to the emergency were executed in a timely manner, but the vessel's loss of propulsion close to the Key Bridge rendered their actions ineffective.

14. The pilots', the pilot dispatcher's, and the Maryland Transportation Authority's quick actions to stop bridge traffic prevented a greater loss of life from the bridge collapse.

15. In lieu of police officers or highway workers charged with traffic control and capable of quickly stopping traffic, a motorist warning system designed to warn and stop motorists from entering onto a bridge is a possible countermeasure that can be quickly implemented to save lives and may be a component of an effective bridge protection strategy.

16. Owners of bridges over navigable waterways frequented by ocean-going vessels would benefit from updated guidance on motorist warning systems including incorporation of hazard alert and sensing technologies capable of detecting errant vessels and bridge movements that would indicate a need for

bridge closure and systems that would both warn and prevent motorists from entering a bridge once a threat is detected.

17. Had the inspector and highway workers been notified of the *Dali*'s emergency situation about the same time the Maryland Transportation Authority police officers at each end of the bridge were told to block vehicular traffic, the highway workers may have had sufficient time to drive to a portion of the bridge that did not collapse.
18. Effective and immediate communication to evacuate the bridge during an emergency is critical to ensuring the safety of bridge workers.
19. While the requirements of the International Safety Management Code include some elements of a comprehensive, proactive safety management system, the code does not fully encompass all four critical components of safety policy, safety risk management, safety assurance, and safety promotion.
20. The lack of recording of parametric information by the voyage data recorder during a power loss can inhibit proactive monitoring of these data by organizations and adversely impact an accident investigation.
21. Audio information from both sides of the *Dali*'s electric telephone was not recorded during the accident, which prevented the National Transportation Safety Board from hearing the engine room's responses to the accident.
22. The monoaural audio configuration of the *Dali*'s Japan Radio Co., Ltd-brand JCY-1900 voyage data recorder system, which mixed multiple microphones into shared channels, significantly impaired the National Transportation Safety Board's ability to isolate and analyze critical bridge conversations, distinct voices, and sounds from the alarms and background noise, thereby reducing the recording's intelligibility and limiting the effectiveness of audio enhancement tools.
23. Although the *Dali*'s Japan Radio Co., Ltd-brand JCY-1900 voyage data recorder complied with International Maritime Organization and International Electrotechnical Commission standards, significant deficiencies in data accessibility, audio usability, and playback software functionality revealed a critical disconnect between published technical standards and practical investigative and organizational needs to identify safety issues and solutions, and for operators and regulators to ensure safety.
24. Increasingly larger cargo vessels, such as the *Dali*, pose increased risks and challenges to maritime safety due to their reduced maneuverability in proximity to existing port and waterway infrastructure that was not designed to accommodate vessels of such size.
25. As cargo vessel design continue to evolve with the latest available standards and technology, increased redundancy to maintain critical systems, such as the main engine and steering and mitigate risks in restricted water.

Probable Cause

The National Transportation Safety Board determines that the probable cause of the contact of the containership *Dali* with the Francis Scott Key Bridge was a loss of electrical power (blackout), due to a loose signal wire connection to a terminal block stemming from the improper installation of wire-label banding, resulting in the vessel's loss of propulsion and steering close to the bridge. Contributing to the crew's inability to recover propulsion from the loss of electrical power was the limited time available due to the Dali's proximity to the bridge. Contributing to the collapse of the Key Bridge and the loss of life was the lack of countermeasures to reduce the bridge's vulnerability to collapse due to impact by ocean-going vessels, which could have been implemented if a vulnerability assessment had been conducted by the Maryland Transportation Authority as recommended by the American Association of State Highway and Transportation Officials. Also contributing to the loss of life was the lack of effective and immediate communications to notify the highway workers to evacuate the bridge.

Safety Recommendations

As a result of this investigation, the National Transportation Safety Board makes the following new safety recommendations.

To the US Coast Guard:

1. Conduct and publish the results of a study that examines the availability, feasibility, and safety benefits of redundant means to ensure that large single-propulsion-engine cargo vessels maintain propulsion and steering when maneuvering in restricted waters.

2. Propose to the International Maritime Organization that it revise the International Management Code for the Safe Operation of Ships and for Pollution Prevention and associated guidelines to fully incorporate safety policy, safety risk management, safety assurance, and safety promotion into its safety management system requirements.

3. Notify the International Maritime Organization (IMO) of the voyage data recorder (VDR) technical issues encountered during our investigation into the contact of containership *Dali* with the Francis Scott Key Bridge and subsequent bridge collapse and submit to the IMO a concrete proposal to require: (1) the recording of mandatory data inputs from systems that remain powered during a blackout, (2) the recording of engine room communications to the bridge, (3) the recording of multiple bridge microphone inputs such that the audio

channels can be isolated or recorded independently, and (4) performance requirements for playback software that facilitates real world use, including enhanced criteria for exporting proprietary VDR data into open industry standard formats.

To the Nippon Kaiji Kyokai (ClassNK):

4. Share the circumstances of the contact of the containership *Dali* with the Francis Scott Key Bridge and subsequent bridge collapse with the International Association of Classification Societies and urge them to distribute report [MIR-25-XX] to their members, highlighting:

    a. the importance of avoiding placement of wire-label banding such that it impedes the proper insertion of a wire in a terminal block

    b. the benefits of using infrared thermal imaging as part of a preventative maintenance program for routine monitoring of electrical components to detect inadequate signal wire connections

    c. the potential risks that partially open radiator dampers can pose to emergency generators starting

    d. the need for members to review their rules on acceptable emergency generator start design.

To the American National Standards Institute:

5. Propose to the International Electrotechnical Commission Technical Committee 80 to revise *IEC 61996-1 ed. 2* to require: (1) the recording of mandatory data inputs from systems that remain powered during a blackout, (2) the recording of engine room communications to the bridge, (3) the recording of multiple bridge microphone inputs such that the audio channels can be isolated or recorded independently, and (4) the updating of performance requirements for playback software that facilitates real world use, including enhanced criteria for exporting proprietary voyage data recorder data into open industry standard formats.

To the American National Standards Institute Accredited Standards Committee on Safety in Construction and Demolitions Operations A10:

6. Revise *ANSI/ASSP A10.47, Work Zone Safety for Roadway Construction* to include an effective and immediate means of emergency communications to

alert workers performing roadway work on bridges over navigable waterways, which should consider the presence of law enforcement for traffic control.

To the Harbor Safety Committee National Steering Team:

7. Share with harbor safety committees nationwide the circumstances of the contact of the containership *Dali* with the Francis Scott Key Bridge and subsequent bridge collapse, highlighting the importance of having a procedure, including immediately available emergency contact information, for pilots to initiate contact with shoreside support in an emergency requiring shoreside action to ensure timely and efficient action by first responders and port stakeholders.

To HD Hyundai Heavy Industries:

8. Incorporate proper wire-label banding installation methods into your electrical department's standard operating procedures to ensure that wire-label banding installed on a wire does not impede the proper insertion of the wire into a terminal block.

9. Identify all active HD Hyundai Heavy Industries constructed vessels with Hyundai-MAN B&W 9S90ME C9.2 engines installed, which are configured to Germanischer Lloyd rules and are designed to shut down on low cooling water pressure, and alert the current vessel owners of this configuration and the circumstances of this accident.

To Synergy Marine Group Pte. Ltd:

10. With classification society approval, implement into your preventative maintenance program and safety management system the use of infrared thermal imaging for routine monitoring of electrical components, including the means to detect inadequate signal wire connections.

11. Identify ships you operate that are equipped with a Hyundai-MAN B&W 9S90ME C9.2 engine and ensure that they are not configured to automatically shut down due to low cooling water pressure.

12. Develop, implement, and monitor for compliance and effectiveness a safety management system policy and procedure to ensure that vessel crews are using the fuel oil service pumps as designed for the diesel generator fuel supply systems installed on board your vessels.

13. Develop, implement, and monitor for compliance and effectiveness a safety management system policy and procedure to ensure that vessel crews are setting high-voltage breakers' control mode to Automatic while operating, unless the transformer breakers are being manually operated or maintenance is being performed.

14. Identify ships you operate with similar arrangements to the *Dali* and notify crews of those vessels that partially open radiator dampers can delay or prevent the emergency diesel generator from starting automatically.

To WAGO Corporation:

15. Add a warning in your product data sheet accompanying WAGO terminal block 280-681 (model), as well as any other terminal block models or similar products that incorporate wire-label banding you manufacture, to explain that improperly placed wire-label banding can impede the proper insertion of a wire into a terminal block.

To California Department of Transportation, the Golden Gate Bridge Highway and Transportation District, the US Army Corps of Engineers, the Skyway Concession Company LLC, the Louisiana Department of Transportation and Development, the Maryland Transportation Authority, the Mackinac Bridge Authority, the New Hampshire Department of Transportation, the Delaware River Port Authority, the New Jersey Turnpike Authority, the New York State Bridge Authority, the Ogdensburg Bridge and Port Authority, the Seaway International Bridge Corporation, the Thousand Islands Bridge Authority, the Ohio Department of Transportation, the Oregon Department of Transportation, the Rhode Island Turnpike and Bridge Authority, the Texas Department of Transportation, the Washington State Department of Transportation, and the Wisconsin Department of Transportation:

16. As part of your short-term bridge risk reduction and mitigation strategies to protect the traveling public, evaluate the need for and, if appropriate, incorporate motorist warning systems capable of activating when a threat is identified and immediately warn and stop motorists from entering onto the bridge.

To the American Association of State Highway and Transportation Officials:

17. Update your *Guide Specifications and Commentary for Vessel Collision Design of Highway Bridges* to include guidance in the selection of motorist warning systems. Evaluated changes should include Federal Highway Administration research on hazard alert and sensing technologies capable of detecting errant vessels and bridge movements that would indicate a need for bridge closure,

and would both warn and prevent motorists from entering a bridge once a threat is detected.

To the Federal Highway Administration:

18. Research hazard alert and sensing technologies capable of detecting errant vessels and bridge movements that would indicate a need for bridge closure, and would both warn and prevent motorists from entering a bridge once a threat is detected. Provide the results of your research to the American Association of State Highway and Transportation Officials.

Previously Issued Recommendations

In March 2025, the NTSB issued a safety recommendation report titled *Safeguarding Bridges from Vessel Strikes: Need for Vulnerability Assessment and Risk Reduction Strategies*, which issued the following safety recommendations addressing the vulnerability of bridges over navigable waterways to strikes by large ocean-going vessels, identified during the *Dali* investigation (NTSB 2025):

To the Federal Highway Administration:

In coordination with the US Coast Guard and US Army Corps of Engineers, establish an interdisciplinary team—including representatives from the Federal Highway Administration, US Coast Guard, and US Army Corps of Engineers—and provide guidance and assistance to bridge owners on evaluating and reducing the risk of a bridge collapse from a vessel collision. (H-25-1) (Urgent)

To the US Coast Guard and the US Army Corps of Engineers:

Support the Federal Highway Administration in establishing an interdisciplinary team—including representatives from the Federal Highway Administration, US Coast Guard, and US Army Corps of Engineers—and provide guidance and assistance to bridge owners on evaluating and reducing the risk of a bridge collapse from a vessel collision. (H-25-2) (Urgent)

To the Bay Area Toll Authority, the California Department of Transportation, the Golden Gate Bridge Highway and Transportation District, the US Army Corps of Engineers, the Florida Department of Transportation, the Georgia Department of Transportation, Skyway Concession Company LLC, the Louisiana Department of Transportation and Development, the New Orleans Public Belt Railroad, the Maryland Transportation Authority, the Massachusetts Department of Transportation, the Mackinac Bridge Authority, the New Hampshire Department

of Transportation, the Delaware River Port Authority, the New Jersey Turnpike Authority, Metropolitan Transportation Authority Bridges and Tunnels, the New York City Department of Transportation, the New York State Bridge Authority, the Ogdensburg Bridge and Port Authority, the Port Authority of New York and New Jersey, the Seaway International Bridge Corporation, the Thousand Islands Bridge Authority, the Ohio Department of Transportation, the Oregon Department of Transportation, the Pennsylvania Turnpike Commission, the Rhode Island Turnpike and Bridge Authority, the Harris County Toll Road Authority, the Texas Department of Transportation, the Washington State Department of Transportation, and the Wisconsin Department of Transportation:

Calculate the American Association of State Highway and Transportation Officials (AASHTO) Method II annual frequency of collapse for the bridge(s) identified in Error! Reference source not found. of this report for which you are responsible and inform the National Transportation Safety Board whether the probability of collapse is above the AASHTO threshold. (H-25-3) (Urgent)

If the calculations that you performed in response to Safety Recommendation H-25-3 indicate that a bridge has an annual frequency of collapse greater than the American Association of State Highway and Transportation Officials threshold, develop and implement a comprehensive risk reduction plan that includes, at a minimum:

- guidance and assistance from the Federal Highway Administration, US Coast Guard, and US Army Corps of Engineers Interdisciplinary Team identified in Safety Recommendations H-25-1 and H-25-2, and short- and long-term strategies to reduce the probability of a potential bridge collapse from a vessel collision. (H-25-4) (Urgent)