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Research Article

LeakMatrix Port

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Abstract: *It is extremely expensive and lengthy to inspect a ship while in the harbor, especially considering that leaking water or oil causes great problems. Oil and water damage harbors and also endanger workers by covering surfaces and releasing strong, noxious odors. Thus, the authors built LeakMatrix Port in order to receive a risk rating, ships send in their arrival data 24 to 72 hours beforehand. During this time, the decks are scanned using overhead and thermal imaging and LiDAR, and underwater sensors examine the hull for cracks and staining. An artificial intelligence is used to rate a ship's level of risk. In this case, green is considered a good rating and the spill crew is called for red. A ship can be released once the required repairs are finished and another scan is completed.*

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1. INTRODUCTION

It is extremely expensive and lengthy to inspect a ship while in the harbor, especially considering that leaking water or oil causes great problems. Oil and water damage harbors and also endanger workers by covering surfaces and releasing strong, noxious odors. Thus, LeakMatrix Port is built to obtain a risk rating, ships send in their arrival data 24 to 72 hours beforehand. LeakMatrix Port represent a system that has several components which are connected.

1.1 Hydraulic System

Hydraulic system-uses pumps to pressurize and transport fluid from the reservoir around the network. It converts mechanical energy into fluid power. The flow direction is managed by valves. In case of a spill, they let out the excess pressure (Joyce, 2023). The flow and pressure are generated by a pump driven by an electric motor or engine. The energy is then converted into smooth, linear motion using a hydraulic cylinder (Joyce, 2023, Magister Hydraulics, n.d.). The hydraulic cylinder is a simple device with a barrel, piston with a rod and seals that prevent fluid from leaking. The movement of the

rod is done by pressurized fluid acting on the piston (Hydraulic Megastore, n.d.). A relatively small cylinder can produce a significant force compared to pure electrical actuators. (Joyce, 2023) In LeakMatrix, this system is used for raising and lowering the sensor platform to match the height of different-sized ships. The pump provides the pressure. The cylinder smoothly moves the platform. The platform stays stable while the vessel is being scanned.

1.2 Sensors

In Aijazi et al. (2016), common commercial 3D laser scanners could be used to collect complete data of ship hulls. This method combines data collected from different angels through many times scanning to generate full 3D points. Automatic analysis could be implemented to detect the defect like the corrosion to reduce the time of inspection. Moreover, according to the research of Chereysky et al. (2021), laser scanning (LiDAR) is more practical of two 3D methods in large vessels. A compact coast sensor developed by Hou et al. (2022) can detect the UV induced fluorescence of oil on the water surface for oil detection. This could be an early warning with the change of its detection. A long-term experiment in Dalian ports showed that this system works well for a rapid surface detection. In LeakMatrix, the unit of LiDAR would generate the shape of the vessel and indicate the abnormal for the surface. Besides, the oil leakage sensor, which would locate at the water level beside the lane. It would detect the oil leakage when the ship goes through.

1.3 Cameras

Infrared cameras are the cheapest and most popular type of remote sensor. It is proven that thermal infrared camera can detect the oil products on water. Oil layers with greater thickness have higher temperature in comparison to surrounding surface (Pilžis&Vaišis, 2017). De Kerf et al., (2020) developed drone-based oil spill detection system inside ports. They also emphasized the importance of having infrared camera for nighttime operations. Below water surface, there are applications of underwater robots with cameras or lasers used by Fitzgerald et al. (2022) for inspection of the damaged hull. 3D models allow planning of the repairs without the need for dry dock. LeakMatrix system uses thermal camera to show unusual temperature patterns on and around the hull which can signal about the leakage. Underwater camera is used to inspect submerged parts of the hull for rust, cracks or stains which cannot be seen from above, but might lead to leaking.

1.4 AI Analysis System

De Kerf et al. (2020) proposed a two-step framework including a training step that automatically annotated the RGB images and paired with the infrared images to train a dataset. A test step that a pretrained network runs on a low-power device for real-time detection. For example, Aijazi et al. (2016) automated the process of locating and analyzing corrosion from LiDAR scans of hulls. The AI system in LeakMatrix integrates information from the LiDAR, thermal camera, underwater camera and oil leak sensor, and identifies any boat with signs of leakage. This is fed to human inspectors to confirm and take further action.

2. LITERATURE REVIEW

Ports are important connecting points between ships, cargo and coastal communities which make the impact of a single leaking ship a potential threat to the entire harbour. The International Tanker Owners Pollution Federation (ITOPF, 2026) reports that there were 6 tanker spills 7 tonnes in 2025. This corresponded to a total release of around 4000 tonnes of oil. Smaller spills are much more common. When examining the long-term record with ITOPF, it is shown that small and medium sized

spills make up 95% of all reported incidents. Of these 40% occur during loading, and 29% occur during discharge. These operations commonly take place in ports/terminals (ITOPF, n.d.). Take for example the recent ones in April 2026, while the container ship MSC Denmark VI was being refueled at the Port of Antwerp, there was a leak of oil. Local news reported a crack in the hull probably on the spot of rust but was not detected until the next morning. (Maritime Executive 2026). They had to close a part of the river Scheldt, and had to turn a cruise ship back (Cruise Hive 2026).

In 2017 in Malaysia at Pasir Gudang, there was a collision that made a hole in the hull of the ship, and about 300 tonnes of heavy fuel oil were spilled into the Johor Strait. The owners had to spend about RM5 million to clean up the mess (The Star 2017). In 2025, there was a leaking pipe in the Tanjong Langsat port terminal, with fuel oil flowing as far as Changi Beach, Singapore (Free Malaysia Today 2025). What is common in all of them is that they only noticed the leak after things were already damaged. This shows that there is a need to detect earlier. LeakMatrix means that a ship inspection system shall detect early stage of oil leaks and damaged hull to avoid pollution incidents. It is a system with one scan line at the port entrance. When a vessel passes by a sensor mast, it is inspected by this system.

3. METHODOLOGY

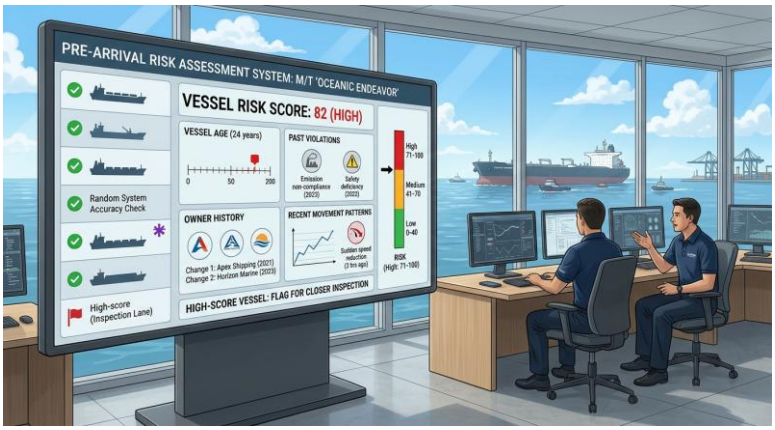


Figure 1. Step 1: Pre-Arrival Notice and Risk Score (24 to 72 hours before arrival)

Before the ship reaches the port, the ship will have notified the estimated time of arrival, and any known issues that may affect the vessel such as leaks, damage, or engine problems. The port system will then give the vessel a risk score. The risk score will be based on the vessel's age, violations, owner history and recent movement for example any sudden drops in speed. If a vessel has a risk score, then it is just moved to the normal lane. If the vessel scores as a risk, it will be flagged for further investigation. A few vessels with a risk score are still chosen at random to be pulled aside just to check the accuracy of the system. I believe this targeting has been growing more significant as the number of vessels of this class coming into ports has increased, and the risk of oil spillage associated with them (The Malaysian Insight, n.d.).



Figure 2. Step 2: Arrival and Gantry Setup

The ship is then identified and directed by the port side to the LeakMatrix berth. They enter the dimensions of the vessel in the control room and the hydraulic system moves the sensor platform up and down, matching the hull. No one is required to be on board for the scan. That matters because workers in tanks may be exposed to dangerous gases that have no odor (MFE Inspection Solutions, n.d.).

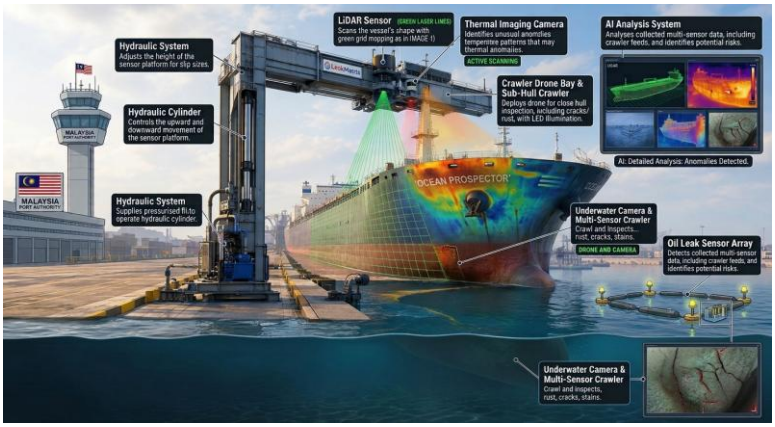


Figure 3. Step 3: Scanning

A LiDAR sweeps the outline of the vessel and any unusual protrusions on its hull. A thermal camera detects changes in temperature. The underwater camera inspects the portion of the hull underwater for rust, cracks and stains. There is an oil-leak sensor that keeps an eye on the water around that area. Such a hull inspection is already utilized in the industry. There are underwater drones which allow the authorities to inspect a ship without a diver, in the water or taking the ship to a dry dock (MFE Inspection Solutions, n.d.).

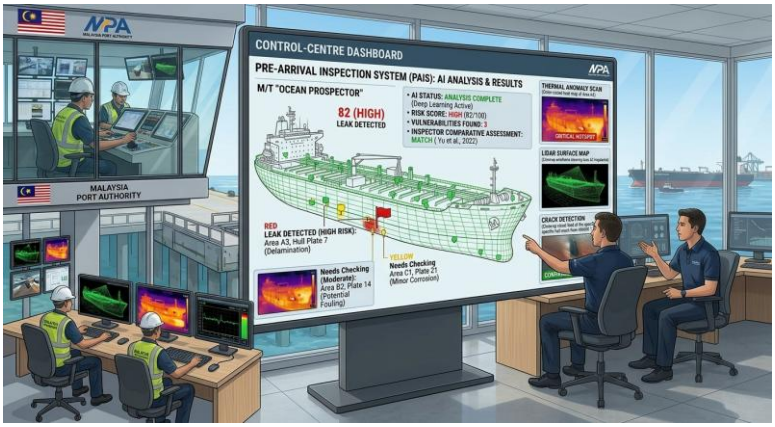


Figure 4. Step 4: AI Analysis and Results

The AI combines all of the sensor data, creates a map of the ship's shape and ranks each suspicious location based on the information. A yellow indicates a spot that requires further inspection, and a red means a leak has actually been found where and how is shown on a clear drawing of the ship. Previous research has demonstrated that deep learning systems are able to detect corrosion, fouling and delamination on ship surfaces and accurately assess its severity, similar to a trained human inspector.



Figure 5. Step 5: Decision and Spill Response

If the scan is clear, the vessel is immediately taken to the green lane for unloading and loading and the full inspection report is automatically recorded. This type of remote inspection has been reported to save over 50% of the total cycle time (ShipUniverse, n.d.). If a leak is detected, the system will alert the control centre and the spill-response centre at the same time. Cargo is stopped or the ship is moved to a specific holding area. In Malaysia, the alert is passed to the Department of Environment, which has overall responsibility for the response to an oil spill, and to the Marine Department, which has the primary operational responsibility. Next, the spill-response team places booms and absorbent materials in the hull area. This is good news because the whereabouts of the leak have already been determined and the team does not need to search the entire vessel to find the leak.

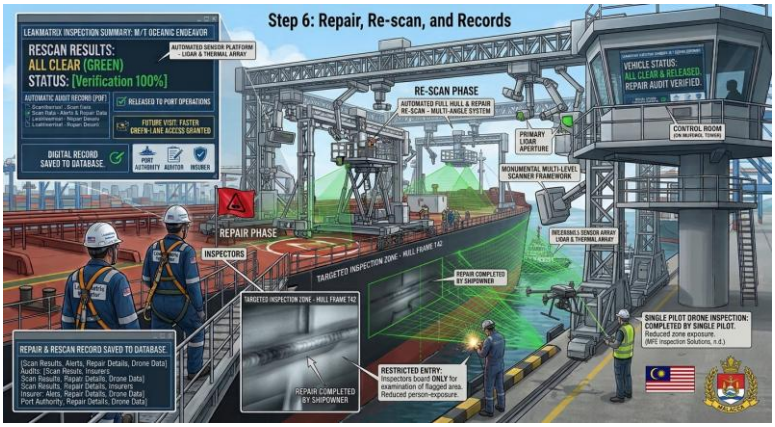


Figure 6. Step 6: Repair, Re-scan and Records

Inspectors only board a vessel in full PPE to inspect the repair area. The ship owner then performs the repair. Limiting access to a specified area, instead of the entire vessel, reduces the number of personnel exposed. In one example, an inspection that would normally require three to four personnel working on rope was done by a pilot who flew a drone (MFE Inspection Solutions, n.d.). Following repair, the vessel is scanned. Once the clearance is confirmed, the vessel is released to resume port operations. The system maintains a set of scan results, alerts and repair records for auditors, insurers and the port authority. Vessels whose inspections are later, enjoy accelerated green-lane access on future port calls.



Figure 7. LeakMatrix Port's Components and Functions

4. FINDINGS

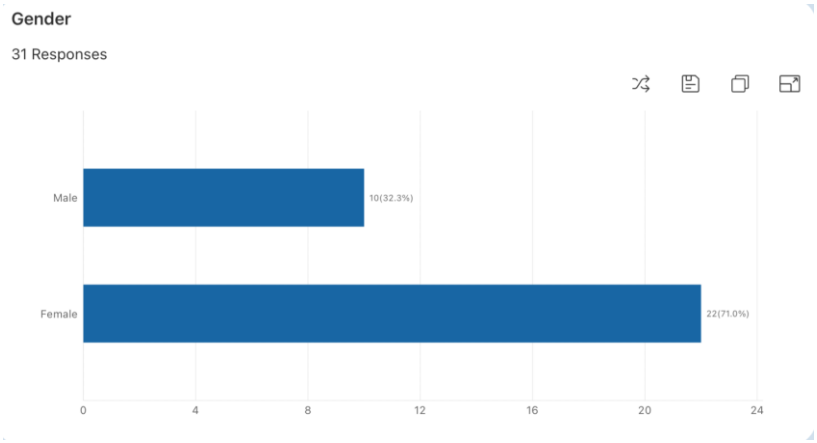


Figure 8. Respondents' Feedback 1

Based on a survey of 31 respondents, 71% were female and 32.3% were male. The result show that respondents provided positive feedback regarding the innovation of the LeakMatrix Port.

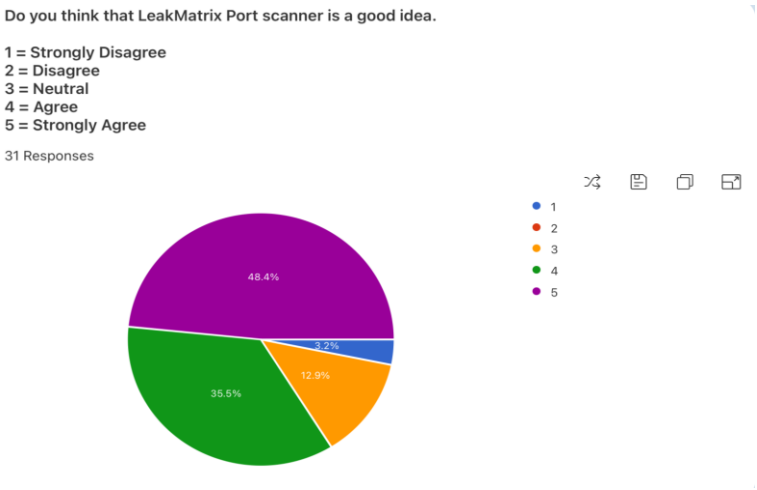


Figure 9. Respondents' Feedback 2

Next, 48.4% of the respondents strongly agree and 35.5% of the respondents agree that the LeakMatrix Port is a good idea. Meanwhile, 12.9% of the respondents are neutral and 3.2% of the respondents strongly disagree. This result shows that majority of the respondents accept the idea of scanning the vessel which can detect leaks.

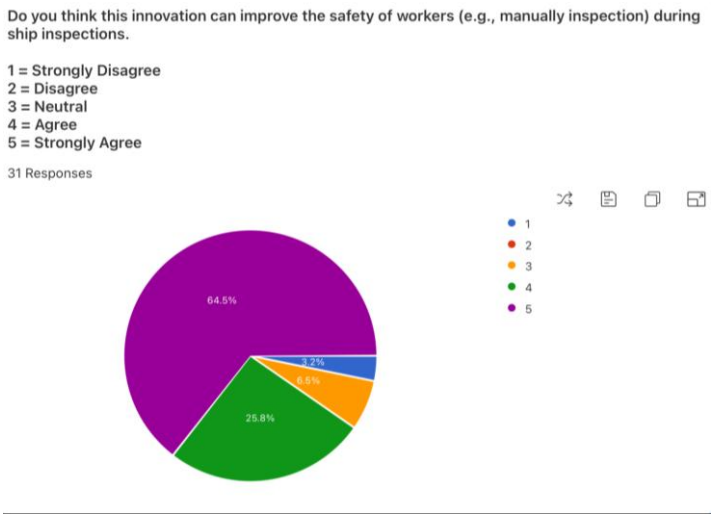


Figure 10. Respondents' Feedback 3

Furthermore, 64.5% of respondents strongly agree and 25.8% of the respondents agree that the innovation can ensure safety of workers during ship inspections; while 6.5% of the respondents were neutral. This result indicates that the respondents see the benefit of scanning during inspections since no one needs to board the ship or enter the ship will reveal danger towards workers.

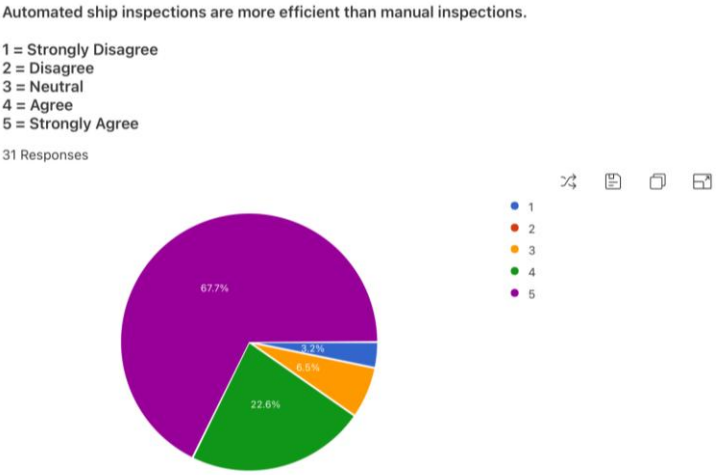


Figure 11. Respondents' Feedback 4

Moreover, 67.7% of the respondents strongly agree and 22.6% of the respondents agree that automated ships can be more efficient than manual inspections. This question received the highest 'strongly agree' rate than other question. This result shows that the respondents believe automation can reduce cost and time during inspections.

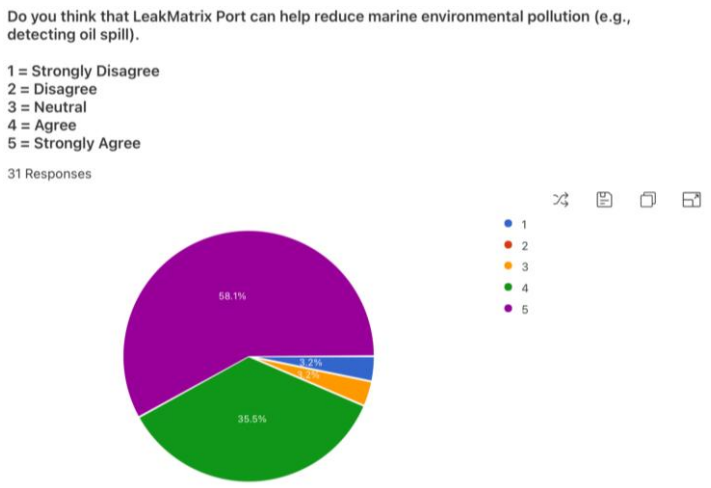


Figure 12. Respondents' Feedback 5

In addition, 58.1% strongly agreed and 35.5% agreed that LeakMatrix Port can help to decrease marine environmental problems such as detecting oil spills. While the authors combined the result strongly agreed and agreed, it shows that this innovation serves as early leak detection and it is valuable to the marine ecosystem.

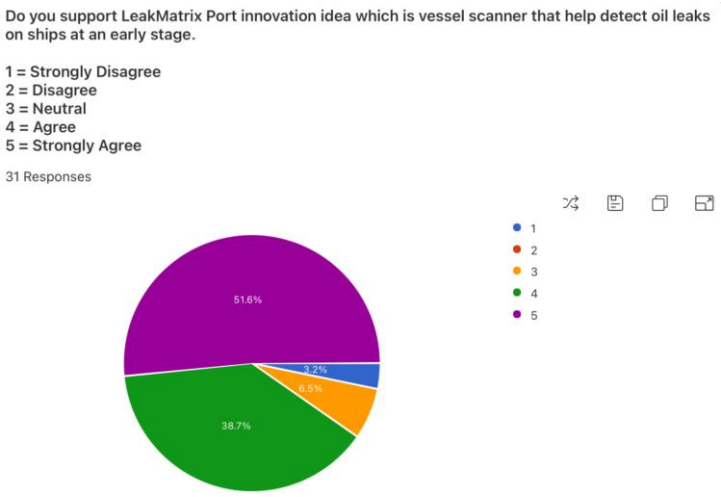


Figure 13. Respondents' Feedback 6

Lastly, 51.6% strongly agreed and 38.7% agreed that they support the innovation of LeakMatrix Port vessel scanner for detecting oil leaks at an early stage, while 6.5% were neutral. Overall findings show that Leakmatrix port is well received and has potential to make inspection more efficiently while reducing cost and time.

5. DISCUSSION

LeakMatrix Port guarantees the well-being of personnel in the maritime industry by reducing on-board personnel inspections. Inspection procedures in the past often dictated that personnel physically visit in the vessel and operate in various high-risk areas that posed threats to their life and

health, including poisoning by toxic gases, confined spaces and slippery floors. New technologies can apply remote inspections using LiDAR sensors, thermal cameras, underwater cameras and artificial intelligence analysis instead, thus eliminating human contact risky situations. These remote inspections techniques allow performing good inspections while minimizing personnel penetration to dangerous compartments (MFE Inspections Solutions, 2023).

Next, the introduction of LeakMatrix Port plays a significant role in environmental sustainability as it aids in the early detection of leaks and the quick response to spills. Oil leaking and hull damage can cause great pollution of water leading to difficulties for marine organisms and coastal areas. The system operates on a continuous monitoring process as the vessels are under constant observation by means of sensor networks and alerts the relevant authorities once the leakage is noticed, thus making it possible to take containment measures in advance and prevent the disastrous effects of the spill. As per research of De Kerf et al. (2020), automated monitoring and thermal imaging can be used to improve the efficiency of oil spill detection thus providing timely responses and minimizing the damage to the environment. For this reason, LeakMatrix Port contributes to the sustainable operations of the port.

Other than that, LeakMatrix Port increases operational efficiency via the automation of vessel inspections and reducing turnaround times. Unlike traditional inspection, which includes extensive manpower and long processing in others, the system will not require boarding to assess the vessel and allows a quick vessel assessment. With AI-powered analysis, suspicious areas are identified quickly, facilitating timely decisions in order to avoid delays in the cargo handling process. According to ShipUniverse (2024), the modern remote ship inspection technologies drastically reduce survey durations and operational costs while increasing inspection coverage. As a result, LeakMatrix Port will enhance port throughout, improve resource utilization and aid more efficient maritime operations.

6. CONCLUSION

In conclusion, LeakMatrix Port is a solution to the challenges associated with expensive and time-consuming parked ship inspections. Unaddressed water and oil leaks at ports can be extremely costly and dangerous. Additionally, leaks impact port operations, pollute the surrounding marine environment, and leave workers with slippery and foul-smelling port areas. The design goals for LeakMatrix Port were focused on increasing the efficiency and security of inspections while improving reliability.

No one has to board a vessel because scanning systems on the ship capture the image from outside the ship. The deck is scanned for potential oil spills and other objects using various types of systems, including thermal imaging and overhead sensors that use LiDAR, while other systems examine the underwater portion of the ship for signs of cracks and rust. The technology is also designed to distinguish stains from spills. Big ships entering the port are a large concern and systems can track the status of these ships by assessing a risk-score. For these ships, arrival information must be sent to the port from 24 to 72 hours in advance of the ship's scheduled arrival. Once sent, port employees can see all vessel status information.

AI colors ships red, yellow, or green based on the findings from its analysis. If the spill control center and spill team are notified of a potential leak, the AI sends a clear ship to the green lane. LeakMatrix Port allows Malaysia to significantly improve its port safety and operations with substantial savings, protection for port workers, and conservation of the environment.

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