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GUIDELINES FOR UNMANNED AUTONOMOUS VESSELS FOR SEAWORTHINESS

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Abstract

This study demonstrated the advantages of applying the Deming cycle methodology to establish a standard for unmanned autonomous vessels in Taiwan. This study used Taiwan's marine engine room statistics to analyze factors related to marine engine room accidents. The Deming cycle was then repeated to make practical decisions. The statistics indicated that most engine room accidents are concentrated in administrative task performance, maintenance work, and complex systems and are mostly caused by human error. Furthermore, these results indicate that the appropriate establishment of the Deming cycle methodology can enhance decision making for the marine engine room through introduction of a standard for unmanned autonomous vessels.

Key words: Unmanned Autonomous Vessel, Deming Cycle, Marine accident, Taiwan.

Introduction

Maritime safety is a crucial concern in numerous countries. In Taiwan, 90% of import and export trade is transported by maritime transportation, and such trade will likely increase in the future. To improve safety and reduce casualties in maritime transportation, the shipping industry has focused on improving factors such as ship systems [1], structures [2], and seaworthiness [3]. To ensure the safety of international maritime traffic, many studies, including by the International Maritime Organization

(IMO), have proposed various guidelines for ship management [4-5]. The International Safety Management (ISM) Code of the IMO framework has been crucial in the field of maritime safety for many years [6]. However, improvement in safety management methods in these times may be difficult. In relation to the ISM Code or other management methods, double checking the most crucial concerns is difficult, particularly in an era in which manned, remote, automated, and autonomous ships are being developed [7]. Therefore, a methodology was adopted as a primary measure in which repeated checking is performed to make practical decisions. To maximize the effectiveness of management, W. Edwards Deming presented a four-step management method in 1950 that can be used for the control and continuous improvement of business processes called the Deming cycle (Plan, Do, Check, Act; PDCA) [8]. In this study, the Deming cycle (PDCA) was used as a risk assessment method for the prevention and analysis of a standard for unmanned autonomous vessels. The most important feature of the PDCA methodology is that it provides guidelines for a confirmation target, execution, and repeated checks to achieve safety [9-10]. Furthermore, this method can help identify problems that should be addressed to avoid wrong decisions. Therefore, this study provides insights into maritime safety management methodologies to reduce the number of maritime casualties and improve safety.

Deming Cycle (PDCA) Methodology

This paper aimed to utilize PDCA for analyzing the characteristics of accidents in the engine rooms of Taiwanese vessels in terms of maritime safety, thus providing pertinent information related to maritime safety management performance.

The flowchart of PDCA is displayed in Figure 1. PDCA includes Plan, Do, Check, and Act procedures that can be described as follows:

Plan: Plan the activities that need to performed. Identify the problems and propose solutions.

Do: Test everything that has been considered in the previous step.

Check: Clarify the results, avoid recurring mistakes, and decide whether the hypothesis is successfully supported or not.

Act: Finish the plan. Repeat the standardized plan, check the plan by carefully going through all the steps again, and attempt to further improve.

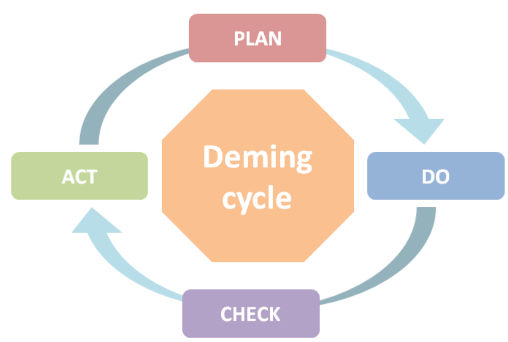

Figure 1: Flowchart of Deming cycle.

In previous studies [11-12], PDCA was considered a prominent method for improving products, people,

Table 1: Marine accidents statistical data (2013-2017) .

2013-2017	Total	Deck Department		Engine Department		Others	
Accidents	163	95		23		45	
Percentage	%	58.3		14.1		27.6	
		Human Errors(%)	Others(%)	Human Errors(%)	Others(%)	Human Errors(%)	Others(%)
		86.5	13.5	96.3	3.7	46.8	53.2

and services. Therefore, we utilized the first step of the PDCA guidelines to identify the plan for the maritime industry, accounting for various types of human factors [13, 14], ship collision events [15, 16], hull/ machinery damage events [17], and management methods [18]. The ISM Code and PDCA methodology are both applicable management methods for devising maritime safety management systems. Both methods outline the risks and hazards to be addressed by safety management to prevent the occurrence of incidents. Dissimilarities are observed between the two methodologies; that is, only PDCA provides guidelines for a confirmation target, execution, repeat checking, and then achieving safety. Double checking the ISM Code is difficult because frequently entails only guidelines lack management-efficient systems. Therefore, PDCA was analyzed as a set of guidelines that can be widely applied in maritime safety to complement the use of the ISM Code as a maritime safety management method. In this study, a correlation was observed between the PDCA methodology and ISM Code for establishing the marine engine room standard for unmanned autonomous vessels. The PDCA or ISM Code cannot be applied in the absence of both these key factors.

Analysis

The previous section detailed the characteristics of applying PDCA methodology to maritime management. To develop the target of the marine engine room standard for unmanned autonomous vessels, this study improved maritime safety and reduced marine engine room accidents by enhancing the PDCA methodology based on human factors as the first step. The second step of the PDCA guidelines was applied to conduct a safety assessment for marine engine room safety. This study utilized data obtained from the Ministry of Transportation and Communication of Taiwan for the time period of 2013–2017 to analyze marine accidents in the vicinity of Taiwan [19]. The data indicated the occurrence of 163 marine incidents, namely collision/ contact, grounding/ stranding, leaking, hull/ machinery damage, and fire/ explosion accidents. In these data, 28 of the cases were leaking, hull/ machinery damage, and fire/ explosion (14.1%) in the Engine department, 95 cases were in the Deck department (58.3%) , and 45 cases were in other departments (27.6%) . Accidents that occurred because of human error were mostly concentrated in the Engine department (96.3%) . These occurrences were worse than those that occurred in the Deck department (86.5%) and other departments (46.8%) . Therefore, the analysis indicated that marine accidents predominantly occurred either by 95 cases in Deck department, however, 96.3% of accidents in the Engine department were caused by human error. Table 1 provides an overview of marine accident statistics.

Discussion and Results

The accident statistics were thoroughly examined, and they indicated that human error caused most engine room accidents; these accidents were concentrated in administrative, maintenance, and complex systems. The third step of the PDCA method was utilized to address the results, avoid recurring mistakes, and determine whether the hypothesis was successfully supported. Table 1 presents the statistical data that indicate that marine engine room accidents are typically caused by human errors. Numerous useful findings were discerned through this process, and we identified 8 options that can be employed as preferred characteristics: 1. basic requirements, 2. equipment requirements, 3. auxiliary equipment/ system requirements, 4. engine room control system requirements, 5. surveillance/ measurement/ analysis requirements, 6. inspection requirements, 7. appendix description, and 8. noun definition. After analyzing the aforementioned options, the final (i.e., fourth) step in the PDCA guidelines showed a striking effect from implementing the 8 options in the marine engine room standards for unmanned autonomous vessels. The results recommended a reasonable, sensible, and systematic outcome. Table 2 provides the list of 47 strategies that were used for classifying the data in this study, which were grouped into 8 categories. Because of space limitations, the following discussion focuses on findings that are specifically related to the PDCA method and 8 options for the marine engine room standard for unmanned autonomous vessels. Taking "basic requirements" as an example, 7 items of characteristics were analyzed. According to the PDCA method indicators, 4-step statements were then repeatedly checked, and administrative work, maintenance work, and complex engine room systems of distinction may be explicated using the PDCA method. Moreover, considering that 7 items of "basic requirements" were analyzed under PDCA cycle conditions, the results were reasonably reliable. The results showed a clear and strong relationship with the marine engine room standard for unmanned autonomous vessels and 8 options of characteristics. Although this relationship was significant, it was moderate in strength and consistent with assumptions of previous studies; however, no previous studies have thoroughly examined this question. This PDCA method of investigation exhibited some limitations when establishing the marine engine room standard for unmanned autonomous vessels. Moreover, methodological problems in this study design limited our interpretations; for instance, the creativity of humans. Thus, numerous questions regarding management-effective solutions remain unanswered using PDCA methods. Future studies should consider the limitations of this study. Despite the limitations of this study, the findings are crucial and thus warrant further research on the PDCA method; moreover, further research can include the established standard for unmanned autonomous vessels that will use eye tracking.

Conclusions

The Deming cycle methodology was adopted for establishing a standard for unmanned autonomous vessels in Taiwan. In this study, most engine room accidents cases were concentrated in administrative, maintenance, and complex systems and were caused by human error. The real case indicated that the repeated PDCA cycle can be used to establish standards for decision making applicable to marine engine rooms in the standard for unmanned autonomous vessels. The established standard for unmanned autonomous vessels should be considered as not only the most widely employed method for improving maritime safety but also a potentially beneficial approach for marine engine room safety. Furthermore, the standard for the marine engine room in unmanned autonomous vessels was presented. Finally, we believe the PDCA methodology can yield more complete results applicable to the marine engine room in the standard for unmanned autonomous vessel optimization in a future work.

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Table 2. Taiwan Standard for Marine Engine Room in Unmanned Autonomous Vessels

TSMERUAV.01: Basic Requirements

Source: authors

Guideline	Applicability
TSMERUAV.01.01:	-Projects that meet the requirements of this code may be referred to as the Taiwan Standard for Marine Engine Room in Unmanned Autonomous Vessels: TSMERUAV.
TSMERUAV.01.02:	-In Unmanned Autonomous Marine Engine Rooms, the system and attached equipment of the Engine Room can store and sense changes in the external environment and can perform logical analyses, comparisons and evaluations of learning behaviors, and provide suitable suggestions for improvement and decision making.
TSMERUAV.01.03:	-The scope of the Engine Room should include the marine primary engine (motor) system (e.g., the device) , generator system (including the device) , propulsion system (e.g., devices) , auxiliary equipment/ system requirements, engine room control system requirements, monitoring/ measurement/ analysis requirements, inspection requirements, and appendix instructions.
TSMERUAV.01.04:	-The specification of the content reference terms and definitions shall be described with reference to the appendix of this specification.
TSMERUAV.01.05:	-For the contents of the aforementioned norms, suggestions for improvement and results of the decision as well as the case may be asked to propose supplementary projects as a part of the supplementary content specification.
TSMERUAV.01.06:	-Requirements related to the norms of local or international regulations can also be covered in the supplementary project.
TSMERUAV.01.07:	-The Unmanned Autonomous Marine Engine room standard schedule should be from the initial shipbuilding to ship decommissioning. The operation status of the nacelle in the process of standardization must meet all the requirements of this standard in addition to the inspection requirements.

TSMERUAV.02: Equipment Requirements

TSMERUAV.02.01: Selected Field of Main Engine

Source: authors

Guideline	Applicability
TSMERUAV.02:	-The items meeting the equipment specifications should include the primary marine engine (motor) system (including the device) , generator system (including the device) , and propulsion system (including the device) .
TSMERUAV.02.01:	-The primary marine engine (motor) system (including the device) should take into account at least the reference conditions and make the diagnosis accordingly. The assessment scope includes the following:
TSMERUAV.02.01.01:	-The prime mover and performance: speed, applied voltage, armature current, armature resistance, and magnetic field density.

TSMERUAV.02.01.02:	-The prime mover related components: armature windings and field windings, brush, chassis, and pole insulation characteristics.
TSMERUAV.02.01.03:	-Transformers and their components: voltage, current, phase number, rated current, power, copper loss, and iron loss.
TSMERUAV.02.01.04:	- Battery: Plates, partitions, containers, electrolyte proportion, voltage, current, and capacitance.
TSMERUAV.02.01.05:	-Ship switchboard related components: the primary switchboard, emergency switchboard, charging and discharging disk, and shore power disk.

TSMERUAV.02.02: Selected Field of Generator (including battery)

Source: authors

Guideline	Applicability
TSMERUAV.02.02:	-The generator system (including the device) should take into account at least consider the reference conditions and perform the diagnosis. The assessment scope includes the following:
TSMERUAV.02.02.01:	-Diesel fixed parts: base, rack, crankcase, cylinder and cylinder head, bearings, and bearings.
TSMERUAV.02.02.02:	-Diesel engine parts: piston, crank (and connecting rod) , valve, turbocharger, gear, spindle, and camshaft.
TSMERUAV.02.02.03:	-Diesel generator operating system: ventilation system, lubrication system, cooling system, fuel and injection system, start/ brake, and control system.
TSMERUAV.02.02.04:	-Diesel generator and its characteristics: speed, horsepower, torque, efficiency, load, and fuel consumption rate.

TSMERUAV.02.03: Selected Field of Propulsion System

Source: authors

Guideline	Applicability
TSMERUAV.02.03:	-Propulsion system (including the device) should consider at least reference conditions and diagnostic evaluation include the following:
TSMERUAV.02.03.01:	-Propulsion system components: blades, bosses, and propellers.
TSMERUAV.02.03.02:	-Propulsion system: propulsion shaft (spindle) , bearings, bearings, intermediate bearings, countershaft, and coupling.
TSMERUAV.02.03.03:	-Propulsion shaft operation system: hydraulic system, oil distribution system, remote control system, lubrication system, and oil seal device.
TSMERUAV.02.03.04:	- Propulsion Shaft Features: scratch, fatigue, galvanic, and cracked.

TSMERUAV.03: Auxiliary Equipment/ System Requirements

Source: authors

Guideline	Applicability
TSMERUAV.03:	-Items that meet the requirements of the auxiliary equipment/ system standard should include a system of all associated equipment and facilities in the ship apart from the mainframe equipment.
TSMERUAV.03.01:	-Relevant auxiliary systems should be based on the marine main engine (motor) system (including devices) , generator system (including devices) , and propulsion system (including devices) specifica-

	tion requirements. Other related ancillary equipment should be monitored/ measured/ analyzed according to requirements, inspection requirements, and regulatory requirements.
TSMERUAV.03.02:	-Piping and its associated (pump and valve) devices should be clearly marked with the purpose of use, use of media, methods of use, and the relevant system diagram.
TSMERUAV.03.03:	-Ballast water and its ancillary equipment should clearly indicate the purpose of use, use of media, methods of use, and the relevant system diagram.
TSMERUAV.03.04:	-Fire extinguishing and its ancillary equipment should clearly indicate the purpose of use, use of media, methods of use, and relevant system diagram.
TSMERUAV.03.05:	-Deck machinery and its ancillary equipment should clearly indicate the purpose of use, use of media, methods of use, and the relevant system diagram.

TSMERUAV.04: Engine Room Control System Requirements

Source: authors

Guideline	Applicability
TSMERUAV.04:	-Items that comply with the requirements of the standard of the engine room control system must include the normal operating conditions and emergency operating conditions.
TSMERUAV.04.01:	-Normal operation: In the normal operation, all equipment of the engine room should comply with the available unmanned duty standard of the engine room and unmanned duty value should be higher than or equal to 24 hours and meet the standards of night navigation. For special needs, such situations must be handled in through self-reliant operations of the ship or remotely.
TSMERUAV.04.02:	-Emergency operations: Under an alarm signal, unexpected situations, and related situations, the relevant system should be able to solve the problem according to the inherent processing flow or start the relevant device or method to solve it. In case of unmanageable status, it should be restarted according to the related operation process, or the problem should be put aside. The problems that cannot be dealt with should be reduced to the minimum influence status.

TSMERUAV.05: Surveillance/ Measurement/ Analysis Requirements

Source: authors

Guideline	Applicability
TSMERUAV.05:	-Meet the monitoring/ measurement/ analysis requirements of the project with consideration of the reference conditions. Diagnostic evaluation should include the following:
TSMERUAV.05.01:	-All equipment in the engine room should also be selected as the source of the valid data by selecting suitable software, hardware, or firmware as the requirements of this standards.
TSMERUAV.05.02:	-All parameters and methods should be able to meet the irregular, nonfixed method to analyze trends, assessment, and management.
TSMERUAV.05.03:	-All the results presented in this request should be based on those that do not affect the normal operation of the ship.
TSMERUAV.05.04:	-All relevant presentation results should be regularly stored and backed up. When necessary, the data should be available at any time.
TSMERUAV.05.05:	-To present the principle of the safe operation of the system, the requirements of this standard should be able to work with system compatibility testing.

TSMERUAV.05.06:	-All equipment required by this code should be able to exclude any person for intentional interference factors and not affect the authenticity of the database.

TSMERUAV.06: Inspection Requirements

Source: authors

Guideline	Applicability
TSMERUAV.06:	-For the test requirements, the project should consider reference conditions and diagnostic evaluation as follows:
TSMERUAV.06.01:	-Shipyard inspection should be performed by a surveyor. The construction progress should be inspected until the classification requirements of the project test are completed. The relevant inspection scope must include the layout of the engine room, layout of the primary engine and auxiliary engine, primary shaft and thruster, vibration data chart, cabin management chart, steering gear chart, power and control chart, and spare parts data.
TSMERUAV.06.02:	-After the construction of the ship, to maintain the health status of the machinery and equipment, the relevant inspection must be performed based on the Classification Society, which shall contain the annual inspection, intermediate inspection, special inspection, continuous inspection, and stern shaft sampling and temporary inspection.
TSMERUAV.06.03:	-Relevant inspection contents should have historical records of machine running records, causes of failure, analysis results, maintenance and replacement of spare parts, and relevant results, including health status, risk assessment, and management reports.
TSMERUAV.06.04:	-If relevant professionals consider it necessary, any factors should be excluded to allow the actual verification experiment on site.

TSMERUAV.07: Appendix description

Source: authors

Guideline	Applicability
TSMERUAV.07.01:	-The establishment of equipment maintenance/ maintenance program: Shipowners and ship management units should develop a series of periodic maintenance, management, and safety programs for Unmanned Autonomous Marine Engine room maintenance and implement these programs effectively in the Unmanned Autonomous Marine Engine room to ensure that the maintenance of machinery, the smooth collection of data, appropriate analysis, proper management of the cabin, and the effective transportation of technology are attained.
TSMERUAV.07.02:	-System Database/ Experience Database System: The equipment and machines involved in this specification should have the historical experience of system operations when they are stationary or in an operating state. Relevant information should be properly available onboard the ship and at the shore-based monitoring center and must be backed up.
TSMERUAV.07.03:	-Emergency Response Plan: When an intelligent ship is involved in situations that threaten the equipment and facilities of the engine room, emergency response plans should be based on the contingency mechanism provided by the relevant personnel and units to ensure that the victimization is not continued.

TSMERUAV.07.04:	-The Unmanned Autonomous Marine Engine Room Maintenance Program: When an intelligent ship is involved in situations that threaten the equipment and facilities of the engine room, the protective equipment must be provided to ensure the smooth operation of the machinery and equipment.
TSMERUAV.07.05:	-Training Program for Talent Cultivation: The relevant technical staff and management personnel required by the standards, the owner of the ship, and the ship management unit are responsible for the training program. The relevant units of local government agencies and classification societies can provide suitable assistance.
TSMERUAV.07.06:	-Unmanned Autonomous Marine Engine Room Satellite Navigation System: the Unmanned Autonomous Marine Engine room satellite navigation, positioning, and control system, should have a remote connection control function, and the satellite function should have two satellite connection systems.

TSMERUAV.08: Noun definition

Source: authors

Guideline	Applicability
TSMERUAV.08.01:	-Information file: When the system-related equipment and facilities are supplied by the cooperative manufacturer, original manufacturer, or agent, information about the software, hardware, or firmware should include the device principle, operation instructions, and maintenance instructions as well as related restrictions and other information.
TSMERUAV.08.02:	-Diagnostic evaluation: Refers to the measurement results through monitoring/ measurement/ analysis for conducting a series of health diagnoses of various running statuses of the machine and equipment. The measurement results should include information collected by the sensor or actuator, data processing and analysis, storage of historical data, analysis of the reasonable method, and presentation.
TSMERUAV.08.03:	-Reference conditions: Refer to the system for monitoring/ measurement/ analysis, and refer to all types of relevant factors, including manmade, marine, environmental, economic, and regulatory requirements.