Automation Levels of Automated/Autonomous Ships

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1. INTRODUCTION

Against the backdrop of rapidly progressing ICT and sensor technology, research and development of automated and autonomous ships is now advancing with the aims of enhancing navigational safety and improving the maritime work environment. Demonstration experiments and similar activities for practical application are also underway, not only in Japan, but also in many other countries, with the momentum to reach commercial use within several years. In Japan, the MEGURI 2040 Project (Joint Technological Development Program for the Demonstration of Unmanned Ships) is being promoted with the support of the Nippon Foundation, and demonstrations of six unmanned ships by a consortium of five partners will be conducted under the project by the end of FY 2021 (March 2022).

On the other hand, acceptance by society is essential for practical application of these systems, and public knowledge of autonomous ships and understanding that they are safe is necessary for heightening acceptance and achieving wide dissemination. In order to support practical application of autonomous ships and heighten their acceptance in society so as to support dissemination, the Japan Ship Technology Research Association (JSTRA) is carrying out the “Safety Assessment of Unmanned Ships Project” in conjunction with the MEGURI 2040 Project with the support of the Nippon Foundation under a 4 year plan that began in FY 2020. In this project, the JSTRA will prepare the safety evaluation environment for conducting a preliminary evaluation and safety assessment of the demonstration experiments in the MEGURI 2040 Project and will also summarize the safety requirements for realizing unmanned navigation and unified guidelines for handling automated and remotely operated ships and unmanned ships.

Although the expressions “unmanned ship” or “automated ship” have been used until now, these terms do not necessarily give a firm image of the ships and ship operation which is envisioned. For example, in the case of an unmanned ship, what does “unmanned” actually mean? Does it include intervention by the crew during operation? The images assumed by people differ. In particular, the modes of operation considering human involvement are diverse, ranging from manual operation to fully automated operation. A common recognition of the system image, for example, which modes of automated operation are the targets of development and evaluation, which is shared by all related parties is necessary.

Therefore, this report describes the automation levels which define automation system and their relationship with the ship operators that use them, and their necessary conditions.

2. CONTROL MODES AND AUTOMATION LEVELS

In general, when a human operator performs a task, such as maintaining or transitioning a controlled object, for example, ship operation, to a desired state, the operator acquires information on the controlled object through his or her own five senses, recognizes the situation based on the acquired information, and makes decision of the action that should be taken. The operator then gives commands concerning the action to be executed to the actuator of the controlled object through the controllers, and the task is realized by repeating this loop. When the controlled object is large or in a remote location, information on the controlled object is acquired by collecting information by sensors in addition to the operator’s five senses, and integrating and displaying the information on a display device. In this case, the control loop comprises the controlled object, sensors, information display device, operator, controllers and actuators. In automation, a control system is included in this loop, and performs the processes of integrated display of the sensor information, decision making of actions, and issuance of operational commands to realize those actions in place of the human operator.

There are several stages in this control, ranging from manual control to fully automated control. Sheridan defined the control

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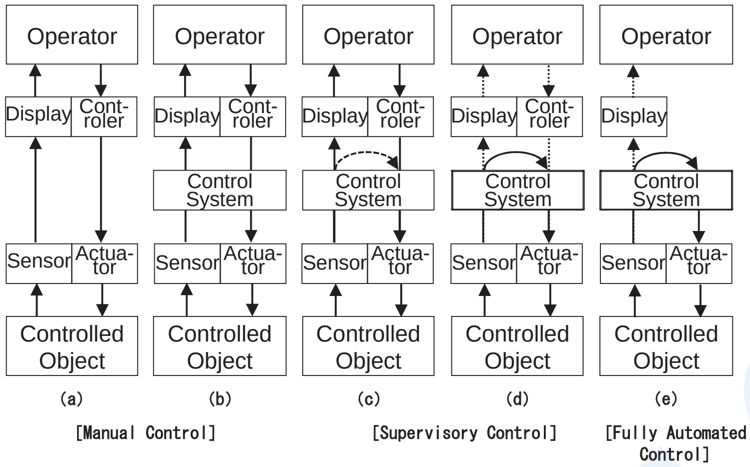

Figure 1 Range of control modes [1)]

modes [1)] shown in Fig. 1 through research on supervisory control of teleoperator robots.

In Fig. 1, (a) shows the diagram of the “Manual Control” mode. In (b), a control system is included in the loop, and performs information acquisition and display, and transmits the control commands set by the operator to the actuator, but control itself is performed by the operator. In (c) and (d), the control system performs some fraction of control, and minor loops are closed through the computer. In (c), the operator’s loop is responsible for the main fraction of control, and the control system loop provides assistance, and in (d), the relationship is reversed, as the control system performs the main fraction, and the operator provides assistance. The control mode in (c) and (d) is called the “Supervisory Control” mode, since the operator supervises the process of the control and the actions of the control system. When necessary, the operator intervenes in control by the control system by issuing control commands to realize the control target. Finally, (e) is the “Fully Automated Control” mode. In this mode, the operator can monitor the controlled object and the actions of the control system by way of information display devices, but cannot intervene in the control system. The concept of these modes is an index which expresses the relationship between the operator and control.

Sheridan also proposed a 10-step “Scale of degrees of automation” [1)] as levels that show the relationship between an automatic control system and the human operator. These automation levels are summarized centering on operation methods that can be taken with information given by the operator. Table 1 shows the automation levels.

Table 1 Automation levels according to Sheridan [1) 2)]

Automation level	Definition
1	The human operator performs all tasks without support from the control system.
2	The system offers a complete set of action alternatives, and the operator selects and executes one of those alternatives.
3	The system suggests a small number of effective action alternatives to the operator. The operator decides whether to execute one of the small number of alternatives or not, and the action is executed by the operator.
4	The system offers one suggestion to the operator. The operator decides whether to execute that suggestion or not, and the action is executed by the operator.
5	The system suggests one the most effective action to the operator. If the operator approves the suggestion, it is executed by the system.
6	The system offers one suggestion to the operator. If the operator does not veto the suggestion within a certain time, the system executes that suggestion.
6.5	The system presents one suggestion to the operator, and simultaneously executes that suggestion.
7	The system decides and executes all actions automatically and informs the operator of the actions taken.
8	The system decides and executes all actions automatically and informs the operator of the action taken if requested by the operator.
9	The system decides and executes all actions automatically. The actions executed are reported to the operator only if the system judges reporting to be necessary.
10	The system decides and executes all actions automatically.

It may be noted that Table 1 shows 11 automation levels [2], as level 6.5 was added by Inagaki et al. to soften the shock of automation.

Here, the levels where major changes occur in the relationship between the system and human operators are as follows.

(1) Between Levels 1 and 2: At Level 2, supporting information is provided as reference for policy decisions concerning control.

(2) Between Levels 4 and 5: Transition from execution of control by a human to control by the system.

(3) Between Levels 6 and 7: Means of human intervention are eliminated, and the system only reports the control results.

(4) Between Level 9 and Level 10: Even reporting to the human is stopped.

In terms of the control modes described above, Level 1 to Level 4 are the “Manual Control” mode, Levels 5 and 6 are the “Supervisory Control” mode, and the “Fully automated control” mode begins from Level 6.5.

These levels of automation proposed by Sheridan are used in study of the human factor in automation of the operation of aircraft and nuclear power plants, and have also been introduced as the most widely used classification method for automation systems, including study [3] of the human factor in the concept of automated driving at automation Levels 2 and 3 by the National Highway Traffic Safety Administration (NHTSA) in the United States. Thus, Sheridan’s automation levels cover the full spectrum from manual to fully automated control. Although little experience is currently available for unmanned ships, when setting the automation levels for unmanned ships, it is thought that Sheridan’s automation levels can contribute to study of the definitions of those automation levels and the items that should be considered when establishing those definitions.

3. AUTOMATION LEVELS OF OTHER INDUSTRIES OF TRANSPORTATION

As automation levels of transportation other than shipping industry, the following reports the Levels of Driving Automation and flight operation levels of drones.

3.1 Levels of Driving Automation

Driving automation levels were prepared independently by various organizations, including the German Federal Highway Research Institute (BASt) [4], the above-mentioned National Highway Traffic Safety Administration (NHTSA) [5] and the Society of Automotive Engineers (SAE) [6] from the beginning of the 2010s until around 2015.

In 2016, the NHTSA and the European Road Transport Research Advisory Council (ERTRAC) decided that the Levels of Driving Automation (LoDA) defined in SAE document SAE J3016 should be adopted, and following that decision, the SAE’s LoDA were also adopted worldwide as automation levels for automated driving systems.

3.1.1 SAE Levels of Driving Automation

The SAE’s initial Levels of Driving Automation (LoDA) for on-road motor vehicles were announced in 2014 as SAE J3016 (2014) [6].

The LoDA provide a classification method for driving automation systems, and are classified according to differences in the mutual roles of the human driver and the driving automation system. The LoDA in SAE J3016 (2014) [6] comprise the six levels in Table 2.

Table 2 Summary of levels of driving automation for on-road vehicles in 2014 Edition of SAE J3016

SAE Level	Definition
Human driver monitors the driving environment.	
LoDA 0 No Automation	The full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems
LoDA 1 Driver Assistance	The driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task
LoDA 2 Partial Automation	The driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task.
Automated driving system monitors the driving environment.	
LoDA 3 Conditional Automation	The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene.
LoDA 4 High Automation	The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene.
LoDA 5 Full Automation	The full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver.

In this table, “driving mode” refers to types of driving scenarios such as expressway merging, high speed cruising, traffic jams and the like. Dynamic Driving Task (DDT) means all of the real-time functions required to operate a vehicle, for example, acceleration and deceleration, lane keeping, etc.

SAE J3016 has been revised twice in the past, and the 3rd Edition was released in April 2021. The main additions to date include the following.

- Addition of a fallback function (DDT Fallback) to the LoDA.
- Clarification of functions, including remote control of the Automated Driving System (ADS), which is an automation system.
- Introduction of the concept of Operational Design Domain (ODD) in order to incorporate the limits of the automation system and the response when those limits are exceeded into the automation system.
- Introduction of the concept of the subtask Object and Event Detection and Response (OEDR).
- Addition of detailed descriptions of the human driver or user (at levels where human driving is not assumed), the Automated Driving System, and the other vehicle components and systems, which are the “three primary actors” that play roles in driving.

Based on the added items, the conditions that differentiate the LoDA levels can be summarized as follows and have been incorporated in the SAE’s LoDA [7)] in the revision of 2021, as shown in Table 3.

a) Whether the driving automation system performs either the longitudinal or the lateral vehicle motion control subtask of the DDT.
b) Whether the driving automation system performs both the longitudinal and the lateral vehicle motion control subtasks of the DDT simultaneously.
c) Whether the driving automation system also performs the OEDR subtask of the DDT.
d) Whether the driving automation system also performs DDT fallback.
e) Whether the driving automation system is limited by an ODD.

Table 3　Summary of levels of driving automation in 2021 Edition of SAE J3016

Level of driving automation	Definition
LoDA 0 No Driving Automation	The performance by the driver of the entire DDT, even when enhanced by active safety systems.
LoDA 1 Driver Assistance	The sustained and ODD-specific execution by a driving automation system of either the lateral or the longitudinal vehicle motion control subtask of the DDT (but not both simultaneously) with the expectation that the driver performs the remainder of the DDT.
LoDA 2 Partial Driving Automation	The sustained and ODD-specific execution by a driving automation system of both the lateral and longitudinal vehicle motion control subtasks of the DDT with the expectation that the driver completes the OEDR subtask and supervises the driving automation system.
LoDA 3 Conditional Driving Automation	The sustained and ODD-specific performance by an ADS of the entire DDT with the expectation that the DDT fallback- ready user is receptive to ADS- issued requests to intervene, as well as to DDT performance- relevant system failures in other vehicle systems, and will respond appropriately.
LoDA 4 High Driving Automation	The sustained and ODD-specific performance by an ADS of the entire DDT and DDT fallback without any expectation that a user will need to intervene.
LoDA 5 Full Driving Automation	The sustained and unconditional (i.e., not ODD-specific) performance by an ADS of the entire DDT and DDT fallback without any expectation that a user will need to intervene.

Although this classification concept includes items specific to self-driving cars, for example, items a) and b) above, it is nevertheless important for studying the automation levels of automated and autonomous ships, and has been incorporated in the guidelines of some classification societies.

3.2　Flight Operation Levels of Unmanned Aerial Vehicles (UAVs)

Unmanned aerial vehicles (UAVs) are a class of unmanned fixed-wing airplanes and rotorcraft which are capable of remotely operated or automatic flight. Accompanying the reduced cost and improved performance of UAVs, drones, a type of unmanned rotorcraft, are now used in an increasingly wide range of applications. For example, high expectations are placed on drones as a means of unmanned cargo transportation.

From the viewpoints of encouraging the use of drones and ensuring safety, the Public-Private Sector Conference on Improving the Environment for UAVs held in April 2016 set flight operation levels [8)] for the automation levels for drones.

Figure 2 shows the flight operation levels of aerial unmanned vehicles (UAVs). The following three items may be mentioned as factors that determine the flight operation goals (level of full-scale operation) of UAVs.

(1)　Control method: Remote control or Automated control?

(2)　Visual range: Flight range within the visual line of sight (VLOS)? (If beyond VLOS, the flight range is also considered within visual range if an assistant is present.) Or beyond visual line of sight (BVLOS)?

(3)　Populated areas: Is the flight zone a populated area? Or is it a less-populated area (areas with low possibility of entry by third parties, sea areas, rivers, lakes and marshes, forests, etc.)?

The following four flight operation levels for drones are set based on combinations of these three factors.

Level 1: Remotely piloted flight within VLOS
Level 2: Automatic or automation flight within VLOS
Level 3: BVLOS flight over less-populated areas (without deploying an assistant)
Level 4: BVLOS flight overpopulated areas above third parties (without deploying an assistant)

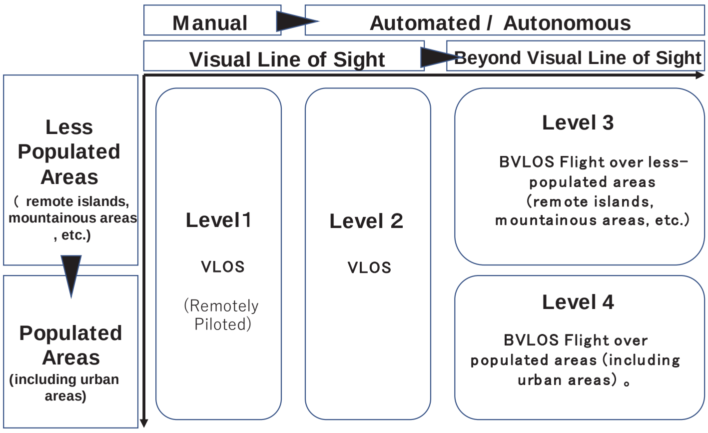

Figure 2 Flight operation levels of UAVs
(Source: Ministry of Land, Infrastructure, Transport and Tourism, Civil Aviation Bureau, Directions of New System for Realization of Level 4 UAVs)

At present (2021), it is necessary to take safety measures and obtain the approval of the Ministry of Land, Infrastructure, Transport and Tourism in order to fly drones in the following airspaces.

Airspace A: Airspace in skies around airports, etc.

Airspace B: Airspace with an altitude of 150 meters or more above the ground surface or water surface.

Airspace C: Skies above densely inhabited districts set based on the results of the National Census.

Although Level 4 flight in Airspace C is not currently approved, effective use of drones is desired in the future. Therefore, together with setting flight operation Level 4 as a high-risk flight category and encouraging the use of drones by rationalization and simplification of the existing approval and certification system for flights, creation of a drone certification and piloting license system for drone pilots, and establishment of common operation rules which must be observed by drone pilots are being promoted [9].

The distinctive features of the flight operation levels of these UAVs are twofold: the distinction between remotely piloted operation and automatic and automation operation, and the distinction between flight operation levels depending on whether the range is within the visual line of sight (VLOS) or beyond VLOS (BVLOS). These concepts also provide suggestions for how remotely operated ships should be treated when considering the automation levels for automated and autonomous ships in the future.

4. AUTOMATION LEVELS OF SHIPS

The following presents an overview of the automation levels for ships and various types of ship equipment which are now being studied by several organizations.

4.1 International Maritime Organization

Considering the recent increase in projects for developing Maritime Automation Surface Ships (MASS), those are expected to improve safety and economy, the International Maritime Organization (IMO) began an IMO “Regulatory Scoping Exercise (RSE) for the use of Maritime Automation Surface Ships (MASS)” in 2018 in preparation for providing a clear and consistent regulatory framework to designers and owners of MASS and other interested parties. The outcome [10] of the RSE was reported and approved in the 103rd session of the Maritime Safety Committee (MSC 103) held in 2021. Several levels of automation were proposed in this activity.

4.1.1 Degrees of Automation for IMO Regulatory Scoping Exercise (RSE)

In advance of the Regulatory Scoping Exercise for MASS, provisional definitions of “Maritime Automation Surface Ship (MASS)” and the degrees of automation were established so that the RSE could be carried out with consistency among the various organizations involved. The following are the definition of “Maritime Automation Surface Ship (MASS)” and the degrees of automation.

Provisional definition of “Maritime Automation Surface Ship (MASS)”:

"Maritime Automation Surface Ship (MASS) is defined as a ship which, to a varying degree, can operate independent of human interaction."

Provisional definitions of degrees of automation:

Degree One

Ship with an automated process processing function and decision-making support function: Seafarers are on board to perform operation and control of the onboard system and functions.

Degree Two

Remotely controlled ship with seafarers on board: The ship is controlled and operated from another location. Seafarers are available on board for operation of the ship systems and functions.

Degree Three

Remotely controlled ship without seafarers on board: The ship is controlled and operated from another location. There are no seafarers on board.

Degree Four

Fully autonomous ship: The operating system of the ship is able to make decisions and determine actions by itself.

The following two items may be mentioned as factors that determine the degree of automation.

(1) Operation mode: Difference of manually operated ship, remotely operated ship and autonomous ship

(2) Presence of seafarers on board: Are there any seafarers on board the ship?

There was also a view that the above-mentioned degrees of automation should be improved by developing a more detailed system of degrees in order to study safe operation and regulation when conducting the RSE. However, these degrees of automation were used in their existing form in the RSE due to the time required to reach the conclusion of the exercise, and were then studied again after the completion of the RSE.

4.1.2 Other Proposed Automation Levels

In addition to the degrees of automation described in the previous section, several other automation levels were proposed in the RSE conducted by the IMO.

One was a proposal submitted by Australia and four other countries with the aim of strengthening the degrees of automation for the RSE [11]. This proposal was based on the idea that, in order to be socially and ethically acceptable, control and responsibility for automated operation should ultimately rest with a human, even in automated ships, and asserted that an autonomous system should be supervisory control, limited to its operation under the supervision and responsibility of a suitably qualified human.

In this proposal, the factors that determine the level of automation are defined as the “Level of automation (technical)” and “Operational control” by humans, and the levels of autonomy and control are set on this basis. Concretely, the technical levels of automation are set in 4 levels and operational control by humans is set in 2 levels, as described below, and the levels of autonomy and operational control are defined by the combinations of these levels.

Level of autonomy (technical)

A0 – Manual: Manual operation and control of ship systems and functions, including automation at the individual system level for simple tasks and functions.

A1 – Delegated: The permission of a human operator is required for functions, decisions and actions, and the operator can override the system (intervene) at any stage.

A2 – Supervised: The permission of the operator is not required for functions, decisions and actions. The operator is always informed of all decisions taken by the system, and can override the system at any stage.

A3 – Autonomous: The system informs the operator in case of emergency or when ship systems are outside of defined parameters (outside ODD). The permission of the operator is not required for functions, decisions and actions. The operator can override the system at any stage.

Levels of operational control

B0 – No qualified operators on board

Exercise of meaningful human control and supervision is available remotely.

B1 – Qualified operators on board

Qualified operators who exercise meaningful human control/supervision are on board.

The levels of autonomy and control are arranged as a matrix of the technical level of autonomy and the level of operational control, as shown in Table 4.

Table 4　Levels of autonomy and control

		Operational control	
		B0: No qualified operators on board	B1: Qualified operators on board
Technical level of autonomy	A0: Manual		A0-B1
	A1: Delegated	A1-B0	A1-B1
	A2: Supervised	A2-B0	A2-B1
	A3: Autonomous	A3-B0	A3-B1

For example, in this table, A2-B0 means the ship is operating at the Supervised level A2 under condition B0, in which the ship is operated remotely by a qualified operator.

These levels of autonomy and control were also used in setting the targets of study in "SAFEMASS Study of the risks and regulatory issues of specific cases of MASS" [12] by the European Marine Safety Agency (EMSA). That study examined the newly arising risks and regulatory issues for ships with autonomy and control levels of A3-B1 (Qualified operator on board operates with an Autonomous level system) and A2-B0 (Remote operation with a Supervised level system).

As one additional case, in the activities of the International Standardization Organization (ISO), the ISO is planning to establish an international standard for the basic terminology and concepts to provide a method of communicating the concepts, etc. related to autonomous ship systems. A general framework that can be used to compare various definitions of "degree of autonomy"[13] was proposed in the 100th session of the Marine Safety Committee (MSC100) of the IMO, and mentioned "Operational complexity," "Automation Level" and "Human Presence" as the three main factors of ship autonomy, and added "Human Responsible" (principle of human responsibility) and "Latency" (delay of timing in regaining control of an emerging problem) as "Additional factors."

Although the details will be omitted here, it appears that this basic thinking follows SAE J3016 [7], which is the most recent concept of driving automation levels for self-driving cars.

4.2　Automation Levels of Lloyd's Register

Lloyd's Register released guidance for autonomous ships, "Cyber Enabled Ships ShipRight Procedure Autonomous Ships Version 1.0, [14]" in 2016 before other classification societies, and this document included definitions of automation levels. In advance of this guidance for autonomous ships, Lloyd's Register released guidance for cyber-enabled ships equipped with ICT and cyber systems, "Deploying Information and Communications Technology in Shipping – Lloyd's Register's Approach to Assurance," proposing a comprehensive certification procedure for assuring safety, quality and reliability. Autonomous ships are positioned as one type of cyber-enabled ship. Furthermore, automation levels were created for autonomous ships, and are not limited to ship-handling but can also be applied to engine operation and various types of information services.

The 7 autonomy levels (AL) are shown below.

Autonomy levels

AL0: Manual – no autonomous function

- All action and decision making is performed manually by the operator.

AL1: On-ship decision support

- All actions at the ship level are taken by a human operator on board the vessel.
- A decision support tool can present options to the operator and influence the actions chosen.

AL2: On and off-ship decision support

- All actions at the ship level are taken by a human operator on board the vessel.

- A decision support tool can present options to the operator and influence the actions chosen.
- Data may be provided from on or off the ship.

AL3: 'Active' human in the loop

- Decisions and actions at the ship level are performed autonomously by the system under human supervision.
- It is possible for the operator to intervene and override high-impact decisions.
- Data may be provided from on or off the ship.

AL4: Human on the loop – supervisory control

- Decisions and actions are performed autonomously by the system under human supervision.
- It is possible for the operator to intervene and override high-impact decisions.

AL5: Fully autonomous (access possible)

- Operation in which decisions and actions are taken by the system with almost no human supervision.

AL6: Fully autonomous (access not possible)

- Operation in which decisions and actions are taken by the system completely without supervision.

The factors that differentiate these levels are as follows:

Whether a decision support system is provided or not (differentiating factor for AL0 and AL1 levels)

Availability of information from off the ship (AL1 and AL2)

Transition from a human operator executing actions to the system executing actions (AL2 and AL3)

Whether human intervention is possible or not (AL4 and AL5)

Whether human access to the system is possible or not (AL5 and AL6)

From the viewpoint of control modes, levels AL0 to AL2 are the "Manual Control" mode, AL3 and AL4 are the "Supervisory Control" mode and AL5 and AL6 are the "Fully Automated Control" mode.

4.3 Automation Levels of DNV

DNV released its Class guidelines: Autonomous and remotely operated ships [15] in 2018. This Guideline defines levels of autonomy. DNV thinks that the level of autonomy differs depending on the context in which automation is used, and therefore proposed guidelines for the levels of autonomy in ship-handling work ("navigation functions"), which requires a high order of observation, analysis and judgment, and the levels of autonomy in engine operation work ("engineering functions"), which can be divided into automatic support and automatic operation. The following introduces the levels of autonomy for navigation functions.

Based on the operational requirements and hazards to navigation set forward as part of the CONOPS / HAZID (Concept of Operations / Hazard Identification Study), the DNV guideline specifies the tasks which should be performed by a human operator and the location where the tasks, etc. are performed, and defines the "levels of autonomy for navigation functions" as follows.

Levels of autonomy for navigation functions

M: Manually operated functions

DS: System decision supported function

DSE: System decision supported function with conditional system execution capabilities

- Human acknowledgement is required before execution by the system.
- Referred to as "Human in the Loop."

SC: Self-controlled function

- The system will execute the function.
- The human is able to override the action.
- Referred to as "Human on the Loop."

A: Autonomous function

- The system will execute the function with no possibility for human intervention.

The following may be mentioned as factors that differentiate these levels of autonomy:

Whether a decision support system is provided or not (differentiating factor for M and DS levels)

Transition from mainly human execution of actions to execution by the system, and whether human approval is required for execution or not (DS and DSE)

Transition from human approval before execution of actions by the system to a human override capability (DSE and SC)
Whether human intervention is possible or not (SC and A)

In many cases, these distinctions overlap with the factors in the Lloyd's Register guidance.

The above-mentioned example of levels of autonomy for navigation functions was prepared in line with the content of the SAE guidelines for automobiles [7]. While it was necessary to study the effect of the different characteristics of ships and self-driving cars, the fact that this study incorporated the content of the automotive guidelines [7] in the guidelines for autonomous ships is important.

4.4 Automation Levels of Bureau Veritas

Bureau Veritas released Guidelines for Autonomous Shipping [16] in 2019. The scope of the Guidelines includes systems used to enhance automation in shipping, ships equipped with automation systems capable, to varying degrees, of making decisions and performing actions, their associated remote control centers and surface propulsion systems. Because the environment in which these systems and equipment operate is expressed as including human interaction, the Guidelines define the three items "Degrees of automation," "Degrees of direct control" of the automation system, and "Degrees of remote control," and the condition of an automation system is characterized by the combination of those three degrees.

The content of the three items is described below.

Degrees of automation

A0: Human operated
- A human makes all decisions and controls all functions.
- The human is located aboard the ship (crew).
- The system or ship can perform information acquisition, but cannot analyze the information, make decisions or execute actions in place of the human.

A1: Human directed
- The human makes decisions and executes actions.
- The system or ship can perform information acquisition, analyze the information and suggest actions, but cannot make decisions or execute actions on behalf of the human.
- The human can be located aboard the ship (crew) or outside the ship at a remote call control center (operators).

A2: Human delegated
- The human can reject decisions made by the system.
- The system or ship can perform information acquisition and information analysis, and initiate actions, but confirmation by the human is necessary.
- The human can be located aboard the ship (crew) or outside the ship at a remote call control center (operators).

A3: Human supervised
- The human is always informed of decisions and actions, and can take control at any time.
- The system or ship can perform information acquisition and information analysis, and initiate actions under human supervision. Confirmation by the human is not necessary.
- The human can be located aboard the ship (crew) or outside the ship at a remote call control center (operators).

A4: Full automation
- The human can take control at any time.
- The system or ship can perform information acquisition and analysis, make decisions and execute operation without human intervention or supervision. The system invokes functions without informing the human, except in case of emergency.
- Supervision can be performed aboard the ship (crew) or outside the ship at a remote call control center (operators).

Degrees of direct control

DC0: No direct control
- There is no crew to monitor and control the system or ship, or to respond to system errors.

DC1: Available direct control
- The crew is onboard and can respond to alerts from the system, but may not be at the control station.

DC2: Discontinuous direct control

- The system or ship is monitored and controlled by the crew at the control station aboard. However, monitoring and control may be discontinuous for short periods.
- The crew is always available at the control station aboard, ready to take control in case of a warning or alert from the system.

DC3: Full direct control

- The system or ship is monitored and controlled at all times by the crew from the control station aboard.

Degrees of remote control

RC0: No remote control

- There are no operators in the remote control center outside the ship.

RC1: Available remote control

- Operators are available in the remote control center, and can respond to warnings from the system, etc.
- Operators may not be at the control station.

RC2: Discontinuous remote control

- The system or ship is monitored and controlled by operators from a remote control station outside the ship. However, monitoring and control may be discontinuous for short periods.
- Operators are always available at the remote control station, ready to take control in case of a warning from the system.

RC3: Full remote control

- The system or ship is monitored and controlled at all times by operators from a remote control station outside the ship.

In these Guidelines, the characterization of an automation system is expressed by the degrees of automation, which represent the relationship between the human and the system when performing tasks comprising information acquisition, information analysis, decision and action selection, and action implementation, and the degree of control, which is expressed in terms of whether operators or present on the ship or at a remote location or not, the control modes described in Chapter 2, and whether monitoring is performed continuously or not, etc.

The following are factors that differentiate the degrees of automation.

Whether a decision support system is provided or not

Whether human approval is required before execution of an action or not

Whether there is a human intervention function or not

Whether the system reports to the human operator or not

Many of these factors overlap with the factors in the Lloyd’s Register classification system.

The factors which differentiate the degree of control include the following, in addition to direct control and remote control.

Whether an operator is present or not

Whether there are time periods when a human is not present or not, and if so, the duration of the periods

Regarding continuous monitoring (“full control”) in the degrees of control, this was described clearly for the first time here. However, since temporary interruptions of continuous monitoring are also allowed in Level 3 automated driving of self-driving cars, it is thought that this should also be added to study of the automation levels of ships.

4.5 Automation Levels of Nippon Kaiji Kyokai (ClassNK)

ClassNK released Guidelines for Automated and Autonomous Operation on Ships Ver. 1.0 [17] in 2020. These Guidelines are applicable to Automated Operation Systems (AOS) and Remote Operation Systems (ROS) which automatically operate some or all of the human decision-making processes of situational awareness, decision and action in shipboard work, and to ships equipped with such systems.

In order to categorize the AOS and ROS, the Guidelines use the following four indexes.

(1) Scope of automation

(2) Scope of remote operation

(3) Fallback Executor

(4) Contents of ODD

Of these, examples of categorization are provided for the three indexes (1) Scope of automation, (2) Scope of remote operation and (3) Fallback Executor, as shown below.

<u>Scope of automation</u>

Level 0:

- Humans execute all subtasks.
- The Fallback Executor of the subtasks is human.

Level I:

- Computer systems execute some decision-making subtasks.
- Fallback execution of the subtasks is shared between humans and computer systems.

Level II:

- Computer systems execute all decision-making subtasks.
- The Fallback Executor of the subtasks is a computer system.

<u>Scope of remote control</u>

Level 0:

- Crew onboard execute all subtasks.
- The Fallback Executor of the subtasks is the crew onboard.

Level I:

- Some decision-making subtasks are executed remotely.
- Fallback execution of the subtasks is shared between the crew onboard and the remote operators in a Remote Operation Center (ROC).

Level II:

- All decision subtasks are executed remotely.
- Fallback execution of the subtasks is the remote operators in a Remote Operation Center (ROC).

<u>Fallback Executor</u>

Level 0:

- A human executes Fallback.
- The Fallback Executor is a human.

Level I:

- Fallback execution is shared between humans and computer systems.
- Fallback Executor is a human and computer systems.

Level II:

- A computer system executes Fallback.
- The Fallback Executor is a computer system.

In these categories, the nature and Fallback Executors of the respective indexes are defined in the categories, and are used in classification of automation systems.

However, these categories are set individually in order to explain the elements in an easy-to-understand manner. Actual systems can be classified by combinations of the indexes of these three elements. For example, a system in which “Computer systems perform some decision-making processes, and a human executes Fallback” is as shown by the combination in Table 5.

Table 5　Example of combination of AOS, ROS and Fallback

Category			Executor of task				Executor of Fallback	
			Onboard		ROC			
AC	RC	FB	Human	CS	Human	CS	Human	CS
I	0	0	○	○			◎	
I	I	0	○			○	◎	
I	I	0		○	○		◎	

AC: Scope of automation
RC: Scope of remote control
FB: Fallback Executor
ROC: Remote Operation Center
CS: Computer system
◎: Executes all
○: Shared execution

As in the DNV Guidelines, from the standpoint that the levels of automation cannot be determined uniquely but will change depending on the task, circumstances, etc., the levels in the ClassNK Guidelines were shown as a basic method of categorization for an abstract object for the scope of automation, the scope of remote operation and the Fallback Executor. Therefore, the factors which differentiate the levels were not clearly specified.

Here, it may be noted that the addition of a "Fallback Executor" is a new concept in the expression of automation levels in the maritime field.

4.6　Automation Levels of American Bureau of Shipping (ABS)

The ABS released a Guide for Autonomous and Remote Control Functions [18] in 2021. The Guide is applicable to all marine vessels and offshore units (referred to collectively as "vessels"). The autonomous functions covered by the Guide focus on functional capabilities that enable operation of marine vessels and offshore units, and do not imply unmanned operation.

The "Function Categories" which are the objects of application cover a diverse range: Navigation (NAV), Maneuvering (MNV), Mooring / Unmooring (MOR), Docking / Undocking (DOC), Propulsion (PRP), Auxiliary (AUX), Environmental Protection (ENV), Cargo Handling (CGH), Ballast and Trim (BAL) and Industrial Processes (IND). Levels of autonomy are applied to all of these functions. These functions have been codified and are used when describing the notations of the autonomous functions shown below.

The ABS Guide defines "Smart-to-Autonomy" levels by the three levels of "Smart," "Semi-Autonomy" and "Full Autonomy," and the notation is also set on this basis. The definitions of these levels of autonomy are presented below.

Smart-to-Autonomy levels

Autonomy level 1 – Smart: System augmentation of human functions.

- The system provides passive decision support, such as system anomaly detection, diagnostics, prognostics, decision/action alternatives, etc.
- Notation: SMART

Autonomy level 2 – Semi-Autonomy: Human augmentation of system functions.

- The system builds on a smart foundation and is governed by a combination of system and human decisions and actions.
- Notation: AUTONOMOUS

Autonomy level 3 ‐ Full Autonomy: No human involvement in system functions.

- The system makes decisions and takes actions autonomously.
- Humans only perform a supervisory function. An override function enables intervention in the system.
- Notation: AUTONOMOUS

In order to clarify the roles of humans, the Guide also defines "Operations supervision levels." For the operations supervision levels, two "Operator locations" (onboard vessel or remote location) and three "Required attention levels" are defined, and the operations supervision level is then defined by combinations of the two.

The required attention levels are shown below, followed the operations supervision levels, which are shown in Table 6.

Required attention levels

Required attention level 1: Continuous supervision

- Throughout the operation of the function, continuous (uninterrupted) supervision by the operator is required.

Required attention level 2: Periodic supervision

- Throughout the operation of the function, supervision by the operator is required at set intervals. The length of the interval and means of ensuring supervision by the operator are determined by the vessel operator and documented in the Concept of Operations (ConOps) document.

Required attention level 3: As needed basis (as required by system notification or the operational mode)

- Throughout the operation of the function, supervision by the operator is required on an as needed basis only. Details are determined by the vessel operator and documented in the Concept of Operations document.

Table 6　Operations supervision levels

Operations supervision level and its code	Required attention level	Operator location
OP1	**Required attention level 1**: Continuous supervision	Onboard vessel
OP2	**Required attention level 2**: Periodic supervision	Onboard vessel
OP3	**Required attention level 3**: As needed basis	Onboard vessel
RO1	**Required attention level 1**: Continuous supervision	Remote location
RO2	**Required attention level 2**: Periodic supervision	Remote location
RO3	**Required attention level 3**: As needed basis	Remote location

Both the required attention levels and the object functions are attribute values of the class notation AUTONOMOUS. For example, the notation AUTONOMOUS (NAV, OP1, RO1) indicates that an Autonomous Function related to navigation of the vessel is operated under continuous supervision by operators located both onboard the vessel and at a remote location.

In addition to the levels of autonomy, the ABS Guide also describes the roles of humans and the system by combinations of required attention levels and operator work locations (onboard the vessel or remote location).

The levels of autonomy provide a comparatively simple system of notation, and the required attention levels correspond to the degrees of direct and remote control in the BV Guidelines. This provides a graduated scale of the condition of continuous monitoring by humans, which is an important study item when considering automated and autonomous ships, and thus is an important issue for study.

5.　FACTORS IN CLASSIFICATION OF AUTOMATION LEVELS

As an overview of the automation levels discussed here, in many proposed automation level classification schemes, the automation system is perceived as a system that supports or acts in place of operational work in which the respective tasks of information acquisition, situational awareness, decision and action are performed as a loop, and the level of automation is set based on the extent to which the automation system supports or replaces those human tasks.

Moreover, the levels of automation range from manual control to fully automated control. Concretely, many automation level classification schemes were established based on four levels of control modes, that is, manual, delegated, supervised and full automatic (fully autonomous). The divisions of these levels correspond to the transition from manual control to supervisory control and then fully automatic control in the control modes proposed by Sheridan. Even comparatively complex systems can be explained convincingly by using these control modes. In particular, because the roles that humans play and the level where the entity that executes control changes can be expressed in easily understood terms, this is a good index for appropriately understanding the outline of automation system operation.

The following may be mentioned as factors for classifying automation levels based on these control modes.

- Presence/absence of a function that provides information support
- Requirement for human approval prior to action
- Transition from human to system as the entity executing control
- Presence/absence of a means of intervention
- Reporting of control results to a human

Next, the following factors that classify the automation level other than the items related to the control mode are as follows.:

- Requirement of continuous supervision
- Presence or absence of operators, and their location

Where continuous supervision is concerned, Level 3 automation of self-driving cars allows cases where continuous supervision is not required, for example, such as the short use of a mobile phone during driving a car. This is also described clearly in the guidelines of classification societies, which were released relatively later. As one example, the ABS Guide classifies operations supervision levels as continuous supervision, periodic supervision or as needed basis.

One further factor is the presence or absence of operators and their location. The locations of operators include the cases where operators are onboard, not onboard, at a remote control center, and not at a center. A total of four cases is possible based on the combinations of these cases. The automation level schemes of many classification societies use the factor of operator location in combination with the degree of supervision by the operator. Moreover, although there is currently no mention of whether remote control of ships is limited to within the visual line of sight, it will also be necessary to add this as an issue for study in the future, particularly when considering unmanned small craft.

Finally, the automation levels for self-driving cars include the concepts of the dynamic driving task (DDT) and the operational design domain (ODD), and the concept of object and event detection and response (OEDR), etc. as subtasks. These concepts are described in the ConOps document, which is necessary when creating an automation system, as shown in Table 3. Many classification societies have also followed this conceptual framework. Although consideration of the cost of incorporating this kind of concept is considered necessary, this concept must also be included as a factor in classification of automation levels.

6. CONCLUSIONS

This report has examined the contents of past studies on automated and autonomous ships and the relationship between humans and the functions of the various types of automation systems that realize such vessels, and the definitions of automation levels which have been proposed in order to obtain a common understanding. The report has also presented an overview of automation levels for automobiles, a sector where automation is progressing, and unmanned aerial vehicles (drones), together with the automation levels established to date by various maritime-related organizations and several classification societies. The factors for classifying automation levels were also summarized. These factors clarify the differences in the relationship between humans and the respective system, and have also clarified the tasks in which humans are required, such as continuous supervision and intervention during abnormalities, etc.

This study has clarified the history of efforts to create automation levels up to the present and the functions of automation systems defined in terms of automation levels were clarified, and has arranged the factors which are effective when describing automation systems.

As can be seen in the automation levels for self-driving cars, it can be thought that diverse factors will also be added to the automation levels of automated ships and evolve as automation systems evolve. From this viewpoint, the author hopes that the contents of this survey will be used in future studies of the automation levels of ships.

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