Appendices: control actions' catalogue

<table>
<tr><td rowspan="2">Control action number:</td><td rowspan="2">1</td><td>IMO

Flag state administration → Classification societies</td></tr>
</table>

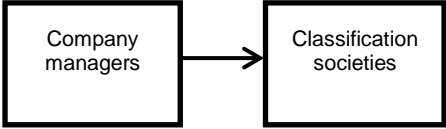|	
Control action name:	*International legislation*
Type:	Input
Textual description:	Codes, legal acts and regulation governing various aspects of unmanned shipping
Rationale:	International Maritime Organisation or flag states shall maintain regulatory control over shipping, including unmanned ships
Hazards resulting:	All hazards

Potential for inadequacy:	*Control action is not provided*	*Unsafe control action is provided*	*Control action is provided in wrong time*	*Control action is provided for too short or too long*
Consequences:	Substandard conditions and act in unmanned shipping	Improper regulatory supervision over unmanned shipping		
Potential causes:	Need for regulation is not recognized; works are obstructed	Regulatory bodies have inadequate understanding of maritime industry		
Feasible mitigation measures and potential	Workshops, conferences, lobbying — 3 Procedures on regulations' creation — 3	Workshops, conferences, lobbying — 3 Procedures on regulations' creation — 3		
Protection against control degradation	Providing control action #2, proactive international and within-industry cooperation	Providing control action #2, proactive international and within-industry cooperation		
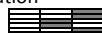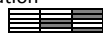
Control action number:	2		Classification societies →	IMO Flag state administration

Control action name:	*Suggestions for improvement*
Type:	Feedback
Textual description:	Suggestions for improvement or update of legislation
Rationale:	Classification societies should cooperate with Administration on improvement of international regulations

Hazards resulting:	All hazards			
Potential for inadequacy:	*Control action is not provided*	*Unsafe control action is provided*	*Control action is provided in wrong time*	*Control action is provided for too short or too long*
Consequences:	Improper regulatory supervision over unmanned shipping	Improper regulatory supervision over unmanned shipping		
Potential causes:	Classification societies fail to deliver reports; Administration fails to process reports	Incorrect reports are delivered, data is processed incorrectly		
Feasible mitigation measures and potential	Obligation to share data 3 Lobbying 3	Procedures on cooperation on regulations creation 3		
Protection against control degradation	Ensuring that suggestions are not ignored			

Control action number:	**3**		IMO Flag state administration	→	Company managers

Control action name:	*International legislation*
Type:	Input
Textual description:	Codes, legal acts and regulation governing various aspects of unmanned shipping
Rationale:	International Maritime Organisation or flag states shall maintain regulatory control over shipping, including unmanned ships

Hazards resulting:	All hazards			
Potential for inadequacy:	*Control action is not provided*	*Unsafe control action is provided*	*Control action is provided in wrong time*	*Control action is provided for too short or too long*
Consequences:	Improper regulatory supervision over unmanned shipping	Improper regulatory supervision over unmanned shipping	Legislation is issued before consulting interested parties	
Potential causes:	Need for regulation is not recognized; works are obstructed	Regulatory bodies have inadequate understanding of maritime industry	Pressure from society, intended misuse	
Feasible mitigation measures and potential	Workshops, conferences, lobbying 3	Workshops, conferences, lobbying 3	Procedures on legislation creation 3	
Protection against control degradation	Providing control action #4, proactive international and within-industry cooperation Accident/incident investigations	Providing control action #4, proactive international and within-industry cooperation Accident/incident investigations		

Control action number:	4		Company managers → IMO Flag state administration

Control action name:	*Suggestions for improvement*
Type:	Feedback
Textual description:	Suggestions for improvement or update of legislation
Rationale:	Company managers or industry associations should cooperate on improvement of international regulations

Hazards resulting:	All hazards			
Potential for inadequacy:	*Control action is not provided*	*Unsafe control action is provided*	*Control action is provided in wrong time*	*Control action is provided for too short or too long*
Consequences:	Improper regulatory supervision over unmanned shipping	Improper regulatory supervision over unmanned shipping	Legislation is issued before consulting interested parties	
Potential causes:	Need for cooperation is not recognized, associations' members disagreements	Associations' members disagreements	Delay to e.g. complexity of issue in question, lack of data or resources	
Feasible mitigation measures and potential	Procedures on cooperation on laws' creation 3	Procedures on cooperation on laws' creation 3	Procedures on cooperation on laws' creation 3	
Protection against control degradation	Ensuring that suggestions are not ignored			

Control action number:	5a	Company managers → Classification societies

Control action name:	*Suggestions for improvement*
Type:	Feedback
Textual description:	Suggestions for improvement or update of rules for classification
Rationale:	Company managers or industry associations should cooperate on improvement of classification rules and thereby on a level of safety

Hazards resulting:	All hazards

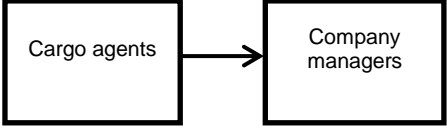| Potential for inadequacy:	*Control action is not provided*	*Unsafe control action is provided*	*Control action is provided in wrong time*	*Control action is provided for too short or too long*
Consequences:	Improper regulatory supervision over unmanned shipping	Improper regulatory supervision over unmanned shipping	Suggestions submitted after the rules' update is issued	
Potential causes:	Need for cooperation is not recognized, associations' members disagreements	Associations' members disagreements	Delay to e.g. complexity of issue in question, lack of data or resources	
Feasible mitigation measures and potential	Procedures on cooperation on rules' creation 3	Procedures on cooperation on rules' creation 3	Procedures on cooperation on rules' creation 3	
Protection against control degradation	Ensuring that suggestions are not ignored			

Control action number:		5b			Company managers → Classification societies	
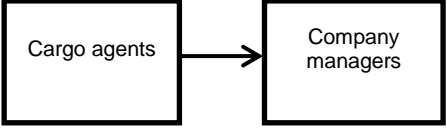
Control action name:	*Operational or statistical data*
Type:	Input
Textual description:	Information sent by company to a classification society in order to improve their services
Rationale:	Classification societies should have a complete picture of unmanned shipping daily routine in order to provide with complex services

Hazards resulting:	All hazards			
Potential for inadequacy:	*Control action is not provided*	*Unsafe control action is provided*	*Control action is provided in wrong time*	*Control action is provided for too short or too long*
Consequences:	Classification societies have improper model of unmanned shipping operations' practice	Classification societies have improper model of unmanned shipping operations' practice	Classification societies have improper model of unmanned shipping operations' practice	
Potential causes:	Managers not willing to share sensitive data	Incorrect processing or interpretation of data	Reports are too complex to combine	
Feasible mitigation measures and potential	Obligation to send certain kinds of information 3	Automatic reporting 3 Use of leading safety indicators 3	Automatic reporting 3 Use of leading safety indicators 3	
Protection against control degradation	Ensuring that data is used solely to improve safety			

Control action number:		6a			

Classification societies → Company managers

Control action name:	*Rules for classification*				
Type:	Input				
Textual description:	Rules issued by classification societies which shall be followed by all vessels and companies				
Rationale:	Such rules are traditional in shipping industry, requiring all actors to implement minimum standards of safety performance				
Hazards resulting:	All hazards				

Potential for inadequacy:	*Control action is not provided*		*Unsafe control action is provided*		*Control action is provided in wrong time*	*Control action is provided for too short or too long*
Consequences:	Improper regulatory supervision over unmanned shipping		Improper regulatory supervision over unmanned shipping		Improper regulatory supervision over unmanned shipping	
Potential causes:	Need for issuing or development of rules for classification is not recognized		Cooperation between various industry actors is flawed		Rules are being compiled too long	
Feasible mitigation measures and potential	Procedures on cooperation on rules' creation	3	Procedures on cooperation on rules' creation	3	Procedures on cooperation on rules' creation 3	
	Issuing company procedures exceeding the requirements of rules for classification	2	Issuing company procedures exceeding the requirements of rules for classification	2	Issuing company procedures exceeding the requirements of rules for classification 2	
Protection against control degradation	Providing control action #5a Review of accident/incident reports		Providing control action #5a and #5b Review of accident/incident reports		Providing control action #5a and #5b	
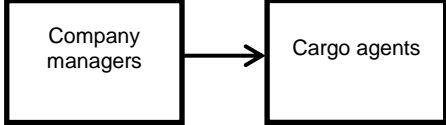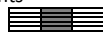
Control action number:		6b		Classification societies → Company managers	

Control action name:	*External audits*			
Type:	Inspection			
Textual description:	Inspections aiming in ensuring that remote control company and its employees follow rules for classification, international regulations and code of good practice			
Rationale:	Any non-compliance with the above shall be identified and corrected			
Hazards resulting:	All hazards			

Potential for inadequacy:	*Control action is not provided*		*Unsafe control action is provided*		*Control action is provided in wrong time*		*Control action is provided for too short or too long*	
Consequences:	Potentially inadequate practice remains unnoticed		Potentially inadequate practice remains unnoticed		Potentially inadequate practice remains unnoticed		Potentially inadequate practice remains unnoticed	
Potential causes:	Company does not comply with ISM Code		Audits are performed not according to procedures. Auditing procedures are not exhaustive		Audits are performed too rarely. Audits are performed in a way that does not allow to assess all necessary activities		Audits are performed not according to procedures. Auditing procedures are not exhaustive. Auditing procedures are too complex to follow	
Feasible mitigation measures and potential	Obligatory compliance with all regulations	3	Elaboration and constant improvement of auditing procedures	3	Elaboration and constant improvement of auditing procedures	3	Elaboration and constant improvement of auditing procedures	3
					Proper cooperation between auditors and the audited company	3		
Protection against control degradation	Obligatory periodical audits							
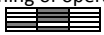
Control action number:	7a		Cargo agents → Company managers

Control action name:	*Cargo information and stowage*
Type:	Feed
Textual description:	Quantitative and qualitative information pertaining to commodities intended for shipment
Rationale:	Company managers shall have full information pertaining to cargo loaded on board in order to guarantee its safe delivery

Hazards resulting:	1.4 Vessel is incapable of properly containing dangerous chemicals or energy
	2.5 Vessel does not meet stability criteria
	2.6 Vessel's watertight integrity is not maintained (due to shear forces, bending moments or puncture)
	3.1 Vessel's cargo is not loaded/stowed properly
	3.2 Vessel is unable to maintain proper cargo stowage conditions
	4.3 Vessel does not meet fire safety precautions
	4.4 Vessel's watertight integrity is not maintained
	5.1 Vessel is unable to maintain integrity of tanks containing oils or oily mixtures
	6.3 System does not meet international, classificatory or national regulations

Potential for inadequacy:	*Control action is not provided*	*Unsafe control action is provided*	*Control action is provided in wrong time*	*Control action is provided for too short or too long*
Consequences:	Company has improper model of cargo's properties Cargo is not accepted	Accepted cargo does not match its declared quantity or quality Information on cargo's properties are not understood Cargo is stowed incorrectly	Cargo is rejected	
Potential causes:	Improper cargo acceptance procedures	Improper cargo loading procedures Cargo loading procedures misinterpreted Cargo information misinterpreted	Cargo information delivery is delayed	
Feasible mitigation measures and potential	Implementation of cargo acceptance procedures	3	Issuing and improvement of procedures	3	Implementation of cargo acceptance procedures	3	
Protection against control degradation	Legal consequences for non-compliance	Legal consequences for non-compliance		
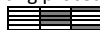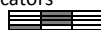
Control action number:	7b		Cargo agents → Company managers

Control action name:	*Commercial pressure*
Type:	Input
Textual description:	Pressure from cargo shipper to act in unsafe way in order to e.g. deliver cargo in shorter time
Rationale:	Actors unfamiliar with specificity of unmanned shipping may put some pressure on company to act in an unsafe manner
Hazards resulting:	All hazards

Potential for inadequacy:	*Control action is not provided*	*Unsafe control action is provided*	*Control action is provided in wrong time*	*Control action is provided for too short or too long*
Consequences:		Operators ignore system's limitation to satisfy client's expectations		
Potential causes:		Improper cooperation between company and cargo agents		
Feasible mitigation measures and potential		Implementation of strict policy with regard to operational limits and commercial pressure 2		
Protection against control degradation		Implementation of disciplinary procedure for violation of limits		
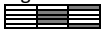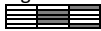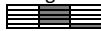
Control action number:	7c		Cargo agents → Company managers

Control action name:	*Payments*
Type:	Input
Textual description:	Payments for cargo shipments
Rationale:	Company operating/managing the vessel shall be paid for cargo shipments

Hazards resulting:	All hazards			

Potential for inadequacy:	*Control action is not provided*	*Unsafe control action is provided*	*Control action is provided in wrong time*	*Control action is provided for too short or too long*
Consequences:	Company does not have sufficient resources to operate the vessel safely and efficiently	Company does not have sufficient resources to operate the vessel safely and efficiently	Company periodically has insufficient resources to operate the vessel safely and efficiently	
Potential causes:	Payment backlogs Margins' miscalculation Lack of shipment orders	Margins' miscalculation	Payment backlogs Margins' miscalculation Lack of shipment orders	
Feasible mitigation measures and potential	Implementation of procedures for freight rate calculation 2 Implementation of advance payments 3	Implementation of procedures for freight rate calculation 2 Implementation of advance payments 3	Implementation of procedures for freight rate calculation 2 Implementation of advance payments 3	
Protection against control degradation	Efficient marketing policy Shareholders' supervision	Shareholders' supervision	Efficient marketing policy Shareholders' supervision	

Control action number:	8		Company managers → Cargo agents

Control action name:	*Vessel info*
Type:	Feedback
Textual description:	Vessel general description, information of available cargo space and cargoes possible to carry
Rationale:	Cargo agents shall have sufficient information about the vessel in order to trust her with their cargo. This may be particularly significant in early stages of autonomous shipping technology development as shippers may be unwilling to utilise such a novel way of transportation.

Hazards resulting:	3.1 Vessel's cargo is not loaded/stowed properly
	3.2 Vessel is unable to maintain proper cargo stowage conditions

Potential for inadequacy:	Control action is not provided		Unsafe control action is provided		Control action is provided in wrong time		Control action is provided for too short or too long	
Consequences:	Cargo is not loaded		Cargo is loaded improperly		Cargo is loaded improperly			
Potential causes:	Improper marketing procedures		Improper marketing procedures Information is given in an incomprehensible form		Improper marketing procedures Information is given in an incomprehensible form			
Feasible mitigation measures and potential	Implementation of procedures on cooperation with clients	3	Implementation of procedures on cooperation with clients	3	Implementation of procedures on cooperation with clients	3		
Protection against control degradation	Constant monitoring of clients' satisfaction		Constant monitoring of clients' satisfaction		Constant monitoring of clients' satisfaction			

Control action number:	9	Shore-based control centre → Company managers

Control action name:	*Operational reports*
Type:	Feedback
Textual description:	Operational experience passed to upper hierarchy levels
Rationale:	Operators should share their experience with company managers in order to constantly improve the system in a form of i.e. reports or meetings.
Hazards resulting:	All hazards

Potential for inadequacy:	*Control action is not provided*		*Unsafe control action is provided*		*Control action is provided in wrong time*		*Control action is provided for too short or too long*	
Consequences:	Company managers do not have proper model of operations		Company managers do not have proper model of operations		Company managers do not have up-to-date model of operations			
Potential causes:	Operational reports are not prepared. Reports are not processed. Lack of procedure for suggestions' communication		Incorrect reports are prepared. Reports are misunderstood		Reports processing is delayed			
Feasible mitigation measures and potential	Implementation of procedures for reports' submission	3	Implementation of simple procedure for reports' submission	3	Proper assignment of resources and workforce	2		
	Implementation of key safety indicators	2						
Protection against control degradation	Operators shall be encouraged to submit reports. The reports should mandatorily be referred to.		Operators shall be encouraged to submit complex reports. The reports should mandatorily be referred to.		User-friendly system for suggestions' submission			

Control action number:	10a		Company managers → Shore-based control centre

Control action name:	*Operational procedures and their updates*
Type:	Input
Textual description:	Procedures to be followed by operators as part of their daily routine as well as during emergency situations.
Rationale:	Operators' decisions should be based not only on their experience, but also on prescriptive advices.

Hazards resulting:	All hazards

Potential for inadequacy:	*Control action is not provided*		*Unsafe control action is provided*		*Control action is provided in wrong time*		*Control action is provided for too short or too long*	
Consequences:	Operators not following proper procedures		Operators not following proper procedures		Operators not following proper procedures			
Potential causes:	Procedures are not issued Procedures are not available to operator		Procedures are not updated Procedures are not understood Procedures are incorrect		Procedure updates are delayed			
Feasible mitigation measures and potential	Training of operators	2	Constant revision of procedures by external experts	3	Training of operators	2		
			Training of operators	2				
Protection against control degradation	Providing control action #9 Revisions of accident/incident reports		Providing control action #9 Revisions of accident/incident reports		Providing control action #9			

Control action number:	10b		Company managers → Shore-based control centre

Control action name:	*Audits*
Type:	Inspection
Textual description:	Periodical checks to ensure that procedures are being followed
Rationale:	Operations shall be audited not only by external institutions, but also by company's personnel familiar with them.

Hazards resulting:	All hazards			
Potential for inadequacy:	***Control action is not provided***	***Unsafe control action is provided***	***Control action is provided in wrong time***	***Control action is provided for too short or too long***
Consequences:	Potentially inadequate practice remains unnoticed	Potentially inadequate practice remains unnoticed	Potentially inadequate practice remains unnoticed	Potentially inadequate practice remains unnoticed
Potential causes:	Internal auditing procedures are not followed	Audits are performed not according to procedures Auditing procedures are not exhaustive	Audits are performed too rarely Audits are performed in a way that does not allow to assess all necessary activities	Audits are performed not according to procedures Auditing procedures are not exhaustive Auditing procedures are too complex to follow
Feasible mitigation measures and potential	Elaboration and constant improvement of auditing procedures — 3 Implementation of leading safety indicators — 2	Elaboration and constant improvement of auditing procedures — 3	Elaboration and constant improvement of auditing procedures — 3 Implementation of leading safety indicators — 2	Elaboration and constant improvement of auditing procedures — 3
Protection against control degradation	Employment of a person assigned solely with auditing duties.			

Control action number:	10c			Company managers → Shore-based control centre	

Control action name:	*Trainings*			
Type:	Input			
Textual description:	Trainings improving operators' skills in operations, procedures, mental models etc.			
Rationale:	Operators should constantly improve their understanding of the system's behaviour			
Hazards resulting:	All hazards			

Potential for inadequacy:	**Control action is not provided**	**Unsafe control action is provided**	**Control action is provided in wrong time**	**Control action is provided for too short or too long**
Consequences:	Operator's insufficient skills	Operator has improper mental model of the system	Operator is unprepared to perform his/her duties	Operator is unprepared to perform his/her duties
Potential causes:	Operator's self-over-confidence Need for training is not recognized	Trainings are insufficient Tutor's mental model of system is incorrect	Operator is allowed to perform duties before completing training	Trainings are inefficient due to i.e. budget restrictions Trainings are prolonged and thus considered 'boring'
Feasible mitigation measures and potential	Trainings being mandatory 3	Procedures on trainings 3	Procedures on trainings 3	Optimized standards of trainings 3
Protection against control degradation	Compulsory renewal of operator's licenses	Trainings should be given by senior operators		
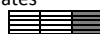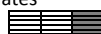
Control action number:		11		Hydrographic office → Charts / Nautical publications

Control action name:		*Updates*		
Type:		Input		
Textual description:		Updates of nautical information		
Rationale:		Virtual Captain shall have full and reliable information regarding the area of operation		

Hazards resulting:	1.2 Vessel enters a No Go Area			
	1.6 System does not provide assistance to person in distress			
	2.1 Vessel enters a No Go Area			
	6.2 Vessel contributes to delay of other ships' traffic			
	6.3 System does not meet international, classificatory or national regulations			

Potential for inadequacy:	*Control action is not provided*	*Unsafe control action is provided*	*Control action is provided in wrong time*	*Control action is provided for too short or too long*
Consequences:	Improper model of vessel's environment	Improper model of vessel's environment	Improper model of vessel's environment	
Potential causes:	Updates are not issued Control actions #14,16 inadequate	Inaccurate surveys Improper data processing	Updates' processing is delayed	
Feasible mitigation measures and potential	Procedures for issuing updates — 3	Procedures for updates' creation — 3	Procedures for issuing updates — 3	
Protection against control degradation				
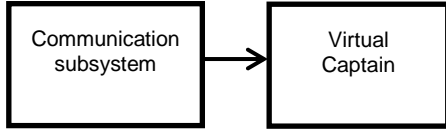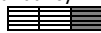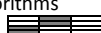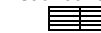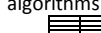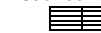
Control action number:	12		Charts Nautical publications	→	Passage plan

Control action name:	*Model of environment*
Type:	Input
Textual description:	Nautical information provided to VC
Rationale:	VC shall have full and reliable information regarding the operational area

Hazards resulting:	1.2 Vessel enters a No Go Area 1.6 System does not provide assistance to person in distress 2.1 Vessel enters a No Go Area 6.2 Vessel contributes to delay of other ships' traffic 6.3 System does not meet international, classificatory or national regulations

Potential for inadequacy:	*Control action is not provided*		*Unsafe control action is provided*		*Control action is provided in wrong time*		*Control action is provided for too short or too long*	
Consequences:	Improper model of vessel's environment		Improper model of vessel's environment		Improper model of vessel's environment			
Potential causes:	Nautical data is not issued Communication with vessel is flawed		Improper nautical data is issued Data analysis algorithms are improper		Nautical data is provided with delay			
Feasible mitigation measures and potential	Nautical publications management procedures	3	Nautical publications management procedures	3	Nautical software/hardware maintenance	3		
	Ensuring control actions #14, 16	3	Development of data analysis algorithms	3				
Protection against control degradation			Constant search for improved software solutions					
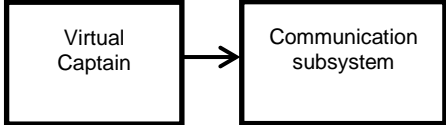
Control action number:	13		Shore-based control centre → Passage plan

Control action name:	*Updates*
Type:	Input
Textual description:	Strategic-level passage plan or its updates
Rationale:	Passage planning should be at least supervised by operator. Similarly, major updates should be accepted by him/her.

Hazards resulting:	1.2 Vessel enters a No Go Area
	1.3 Vessel improperly interacts with other man-made objects
	1.6 System does not provide assistance to person in distress
	2.1 Vessel enters a No Go Area
	2.2 Propulsion/steering gear operational parameters cannot be maintained
	2.4 Vessel's navigational capabilities are severed by weather conditions
	6.2 Vessel contributes to delay of other ships' traffic
	6.3 System does not meet international, classificatory or national regulations

Potential for inadequacy:	*Control action is not provided*		*Unsafe control action is provided*		*Control action is provided in wrong time*		*Control action is provided for too short or too long*	
Consequences:	Vessel has no model of mission objectives		Vessel has incorrect model of mission objectives		Vessel has incorrect model of mission objectives			
Potential causes:	Procedures for passage planning are not followed Communication with vessel is flawed		Procedures for passage planning are incorrect Procedures for passage planning are not followed		Procedures for passage planning are incorrect Procedures for passage planning are not followed			
Feasible mitigation measures and potential	Ensuring control actions #14, 16	3	Development of passage planning procedures	3	Development of passage planning procedures	3		
	Development of passage planning procedures	3						
			Data integrity control algorithms	3				
	Development of fail-to-safe mechanism	2						
Protection against control degradation								

Control action number:	**14a**	Shore-based control centre → Communication subsystem

Control action name:	*Strategic decisions' relay*
Type:	Input
Textual description:	Decisions made by operator are relayed to the VC via communication link
Rationale:	Major system's adjustments or updates must be periodically transmitted to the vessel in order to maintain overall supervision

Hazards resulting:	All hazards			
Potential for inadequacy:	*Control action is not provided*	*Unsafe control action is provided*	*Control action is provided in wrong time*	*Control action is provided for too short or too long*
Consequences:	Strategic decisions are not relayed to the vessel	Incorrect decisions are relayed to the vessel	Decisions' transmission is delayed	Incomplete data set is transmitted to the vessel
Potential causes:	Data connection between control centre and communication subsystem flawed; Need for strategic decision is not recognized; Operator is unable to make decision	Data transfer incorrect; Operator's attitude / lack of skill	Data transfer rate insufficient; Improper data buffering	Data connection between control centre and communication subsystem flawed
Feasible mitigation measures and potential	Redundancy — 3; Operational procedures — 2; Fail-to-safe mechanism — 2	Error identification algorithms — 2; Trainings — 3	Redundancy — 3; Transmission control algorithms — 3	Redundancy — 3; Error identification algorithms — 2
Protection against control degradation	Trainings			

Control action number:		14b	Shore-based control centre → Communication subsystem	

Control action name:	*System updates relay*
Type:	Input
Textual description:	Software updates
Rationale:	VC's as well as other software shall be updated periodically to eliminate bugs, implement new regulations, improve performance etc.

Hazards resulting:	All hazards			
Potential for inadequacy:	***Control action is not provided***	***Unsafe control action is provided***	***Control action is provided in wrong time***	***Control action is provided for too short or too long***
Consequences:	VC uses outdated software	VC uses inadequate software, improper decisions are made	VC uses outdated software Updates' installation interferes with VC's decision-making process	Incomplete updates are transferred Improperly prepared updates are issued
Potential causes:	Need for updates is not recognized Updates are not issued	Incorrect update is issued Update is issued in an improper format Update is sent do improper part of the system	Update takes too long to compile Improper update management procedures/algorithms	Improper update management procedures/algorithms
Feasible mitigation measures and potential	Procedures for updates management　3	Procedures for updates management　3　On-shore testing of updates　3	Procedures for updates management　3　On-shore testing of updates　3	Procedures for updates management　3
Protection against control degradation	Implementing a constant-improvement culture	Implementing a constant-improvement culture		
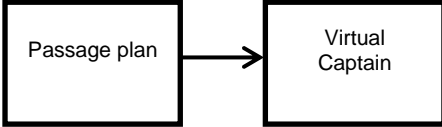
Control action number:	15		Communication subsystem → Shore-based control centre

Control action name:	*Feedback relay*
Type:	Feedback
Textual description:	Data regarding status of both vessel and environment
Rationale:	Data provided by sensors shall periodically be transmitted to the shore-based control centre for analysis

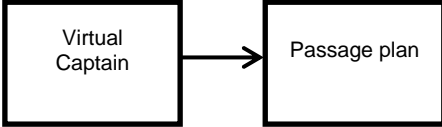| Hazards resulting:	All hazards			
Potential for inadequacy:	*Control action is not provided*	*Unsafe control action is provided*	*Control action is provided in wrong time*	*Control action is provided for too short or too long*
Consequences:	SBCC has no information regarding vessel's status	SBCC has incorrect information on vessel's status	SBCC has outdated information on vessel's status	SBCC has incomplete information on vessel's status
Potential causes:	Control action #17 inadequate Data connection between control centre and communication subsystem flawed	Control action #17 inadequate Data transfer incorrect	Control action #17 inadequate Data transfer rate insufficient Improper data buffering	Control action #17 inadequate
Feasible mitigation measures and potential	Redundancy — 3	Error identification algorithms — 2	Redundancy — 3 Transmission control algorithms — 3	Redundancy — 3 Error identification algorithms — 2
Protection against control degradation	Performance tests of communication link	Performance tests of communication link		

Control action number:	**16**		Communication subsystem → Virtual Captain
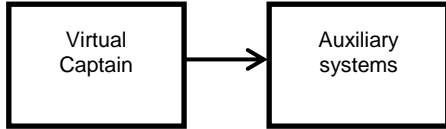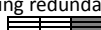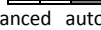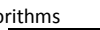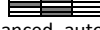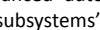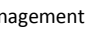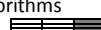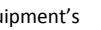
Control action name:	*Decisions' and updates' relay*
Type:	Input
Textual description:	Decisions made by operator are relayed to the VC via communication link
Rationale:	Major system's adjustments or updates must be periodically transmitted to the vessel in order to maintain overall supervision

Hazards resulting:	All hazards

Potential for inadequacy:	*Control action is not provided*		*Unsafe control action is provided*		*Control action is provided in wrong time*		*Control action is provided for too short or too long*	
Consequences:	Strategic decisions are not relayed to the vessel		Incorrect decisions are relayed to the vessel		Decisions' transmission is delayed		Incomplete data set is transmitted to the vessel	
Potential causes:	Control actions #14a,b inadequate Data connection between vessel and communication subsystem flawed Communication subsystem malfunction Shipborne antenna malfunction Vessel outside communication range Data is transferred to different vessel		Control actions #14a,b inadequate Data transfer incorrect Operator's attitude / lack of skill Other vessel's data is transmitted		Control actions #14a,b inadequate Data transfer rate insufficient Improper data buffering		Control actions #14a,b inadequate Data connection between control centre and communication subsystem flawed	
Feasible mitigation measures and potential	Redundancy	3	Error identification algorithms	2	Redundancy	3	Redundancy	3
	Error identification algorithms	3	Trainings	3	Transmission control algorithms	3	Error identification algorithms	2
	Global-range communication subsystems to be used	4						
	Fail-to-safe mechanism	2						
Protection against control degradation	Performance tests of communication link		Performance tests of communication link					

Control action number:	17		Virtual Captain → Communication subsystem

Control action name:	*Feedback relay*
Type:	Feedback
Textual description:	Transmission of information pertaining to the status of vessel and environment
Rationale:	Data gathered by on-board sensors should periodically be transmitted to the SBCC for analysis

Hazards resulting:	All hazards

Potential for inadequacy:	*Control action is not provided*		*Unsafe control action is provided*		*Control action is provided in wrong time*		*Control action is provided for too short or too long*	
Consequences:	SBCC has no information regarding vessel's status		SBCC has incorrect information on vessel's status		SBCC has outdated information on vessel's status		SBCC has incomplete information on vessel's status	
Potential causes:	Communication subsystem malfunction Shipborne antenna malfunction Vessel outside communication range Sensors' malfunction		Data transfer incorrect Data processing incorrect On-board data management algorithms flawed Sensors' array insufficient		Data transfer rate insufficient Improper data buffering		Communication subsystem malfunction Shipborne antenna malfunction Data sets' size exceeding transmission slots limits	
Feasible mitigation measures and potential	Redundancy	3	Raw data transfer, on-shore analysis	4	Redundancy	3	Transmission control algorithms	3
	Error identification algorithms	3	Design and implementation of a comprehensive set of sensors	3	Transmission control algorithms	3	Redundancy	3
	Global-range communication subsystems to be used	4						
	Fail-to-safe mechanism	2						
Protection against control degradation	Performance tests of communication link		Performance tests of communication link					

Control action number:	18		Virtual Captain → Passage plan	
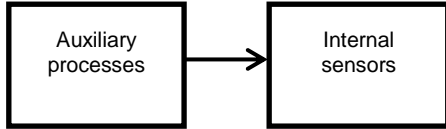
Control action name:	*Ad hoc adjustments*
Type:	Control
Textual description:	Minor adjustments to ship's planned route due to e.g. collision avoidance requirements
Rationale:	VC must be capable of adjusting the passage plan in order to handle navigational situation arising without direct involvement of human operator

Hazards resulting:	1.1 Vessel violates minimum CPA with another ship 1.2 Vessel enters a No Go Area 1.3 Vessel improperly interacts with other man-made objects 2.1 Vessel enters a No Go Area 2.4 Vessel's navigational capabilities are severed by weather conditions 6.2 Vessel contributes to delay of other ships' traffic 6.3 System does not meet international, classificatory or national regulations

Potential for inadequacy:	*Control action is not provided*	*Unsafe control action is provided*	*Control action is provided in wrong time*	*Control action is provided for too short or too long*
Consequences:	Passage plan not adjusted to local conditions	Passage plan adjusted incorrectly	Passage plan adjusted incorrectly	
Potential causes:	Control actions #29,31,34,35 inadequate Passage planning algorithms flawed	Control actions #29,31,34,35 inadequate Passage planning algorithms inaccurate	Control actions #34,35 inadequate Passage planning algorithms inaccurate	
Feasible mitigation measures and potential	Improvement of control algorithms — 3	Improvement of control algorithms — 3	Improvement of control algorithms — 3	
Protection against control degradation				

Control action number:	19		Passage plan → Virtual Captain	
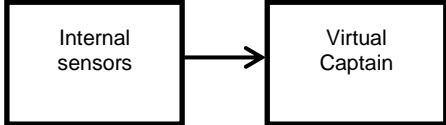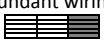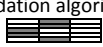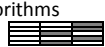
Control action name:	*Model of intentions*
Type:	Feed
Textual description:	Vessel's intended route
Rationale:	Vessel shall follow a pre-programmed route in order to avoid known dangers to navigation

Hazards resulting:	1.1 Vessel violates minimum CPA with another ship 1.2 Vessel enters a No Go Area 1.3 Vessel improperly interacts with other man-made objects 2.1 Vessel enters a No Go Area 2.4 Vessel's navigational capabilities are severed by weather conditions 6.2 Vessel contributes to delay of other ships' traffic 6.3 System does not meet international, classificatory or national regulations

Potential for inadequacy:	*Control action is not provided*		*Unsafe control action is provided*		*Control action is provided in wrong time*		*Control action is provided for too short or too long*	
Consequences:	VC not receiving navigational orders		VC following wrong route		VC not receiving timely navigational orders			
Potential causes:	Control action #13 inadequate Passage plan not prepared Passage plan prepared in unreadable format		Control action #13 inadequate Wrong passage plan uploaded Operator's lack of skill Passage plan misinterpreted by VC		Control action #13 inadequate Passage plan preparation delayed			
Feasible mitigation measures and potential	Protection against switching from AL-3 to AL-5 without prepared passage plan, unless as a fail-to-safe	4	Implementation of passage planning procedures	3	Protection against switching from AL-3 to AL-5 without prepared passage plan, unless as a fail-to-safe	4		
			Automatic strategic passage planning algorithms	3				
Protection against control degradation								

Control action number:		**20**		Virtual Captain → Auxiliary systems	

Control action name:		*Equipment set-points*			
Type:		Control			
Textual description:		Decisions on working parameters of auxiliary subsystems			
Rationale:		VC shall be capable of controlling auxiliary processes by adjusting equipment's working parameters			

Hazards resulting:

1.4 Vessel is incapable of properly containing dangerous chemicals or energy
1.5 Vessel is boarded by unauthorized personnel or such commodities are placed on board
2.2 Propulsion/steering gear operational parameters cannot be maintained
2.3 Vessel is denied passage by coastal state's authorities
2.5 Vessel does not meet stability criteria
2.6 Vessel's watertight integrity is not maintained (due to shear forces, bending moments or puncture)
3.1 Vessel's cargo is not loaded/stowed properly
3.2 Vessel is unable to maintain proper cargo stowage conditions
4.3 Vessel does not meet fire safety precautions
4.4 Vessel's watertight integrity is not maintained
4.5 Vessel's power supply is not provided or insufficient
5.1 Vessel is unable to maintain integrity of tanks containing oils or oily mixtures
5.2 Vessel is unable to maintain proper fuel combustion parameters
6.3 System does not meet international, classificatory or national regulations

Potential for inadequacy:	*Control action is not provided*		*Unsafe control action is provided*		*Control action is provided in wrong time*		*Control action is provided for too short or too long*	
Consequences:	Loss of control over equipment		Loss of control over equipment		Loss of control over equipment		Loss of control over equipment	
Potential causes:	Actuators not reliable Data transmission within the vessel ineffective VC not operational		Inadequate control algorithms Equipment incapable of complying with VC's commands		Data transmission within the vessel ineffective Inefficient control algorithms		Actuators unreliable or incapable of complying with VC's commands	
Feasible mitigation measures and potential	Improved reliability	3	Improved control algorithms	3	Data transmission management algorithms	2	Improved equipment's reliability	3
	Wiring redundancy	3	Enhanced autonomy on subsystems' level	3	Enhanced autonomy on subsystems' level	3		
	Enhanced autonomy on subsystems' level	3	Manual control	1				
	Manual control	1						
Protection against control degradation								

Control action number:	**21**	Auxiliary subsystems → Auxiliary processes

Control action name:	*Actuation*
Type:	Control
Textual description:	Control over auxiliary processes
Rationale:	Auxiliary subsystems shall be capable of properly controlling affiliated processes

Hazards resulting:	1.4 Vessel is incapable of properly containing dangerous chemicals or energy 1.5 Vessel is boarded by unauthorized personnel or such commodities are placed on board 2.2 Propulsion/steering gear operational parameters cannot be maintained 2.3 Vessel is denied passage by coastal state's authorities 2.5 Vessel does not meet stability criteria 2.6 Vessel's watertight integrity is not maintained (due to shear forces, bending moments or puncture) 3.1 Vessel's cargo is not loaded/stowed properly 3.2 Vessel is unable to maintain proper cargo stowage conditions 4.3 Vessel does not meet fire safety precautions 4.4 Vessel's watertight integrity is not maintained 4.5 Vessel's power supply is not provided or insufficient 5.1 Vessel is unable to maintain integrity of tanks containing oils or oily mixtures 5.2 Vessel is unable to maintain proper fuel combustion parameters 6.3 System does not meet international, classificatory or national regulations

Potential for inadequacy:	*Control action is not provided*	*Unsafe control action is provided*	*Control action is provided in wrong time*	*Control action is provided for too short or too long*
Consequences:	Loss of control over the process(es)	Loss of control over the process(es)	Loss of control over the process(es)	Loss of control over the process(es)
Potential causes:	Control action #20 inadequate Equipment unreliable Consumables not provided	Control action #20 inadequate Machinery having insufficient capacity Machinery improperly designed/installed	Control action #20 inadequate Delays related to equipment's specificity and processes controlled Improper process management algorithms	Control action #20 inadequate Improper process management algorithms
Feasible mitigation measures and potential	Rigorous maintenance regime — 3 Redundant equipment — 3 Resilience-based design — 1 Procedures on consumables' management — 3	Capacity surpluses by design — 3 Extensive testing — 3	Implementation of leading performance indicators — 3	Implementation of leading performance indicators — 3
Protection against control degradation	External audits of maintenance effort Implementation of leading safety indicators	Implementation of leading safety indicators	Collection and analysis of performance data	Collection and analysis of performance data
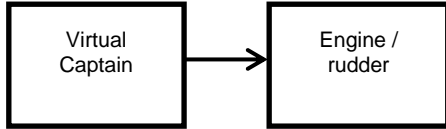
Control action number:		22		Auxiliary processes → Internal sensors	

Control action name:		*Sensing*
Type:		Feed
Textual description:		Examination of processes' status
Rationale:		Auxiliary processes' control must be based on actual state of the processes as measured by sensors

Hazards resulting:	1.4 Vessel is incapable of properly containing dangerous chemicals or energy
	1.5 Vessel is boarded by unauthorized personnel or such commodities are placed on board
	2.2 Propulsion/steering gear operational parameters cannot be maintained
	2.3 Vessel is denied passage by coastal state's authorities
	2.5 Vessel does not meet stability criteria
	2.6 Vessel's watertight integrity is not maintained (due to shear forces, bending moments or puncture)
	3.1 Vessel's cargo is not loaded/stowed properly
	3.2 Vessel is unable to maintain proper cargo stowage conditions
	4.3 Vessel does not meet fire safety precautions
	4.4 Vessel's watertight integrity is not maintained
	4.5 Vessel's power supply is not provided or insufficient
	5.1 Vessel is unable to maintain integrity of tanks containing oils or oily mixtures
	5.2 Vessel is unable to maintain proper fuel combustion parameters
	6.3 System does not meet international, classificatory or national regulations

Potential for inadequacy:	*Control action is not provided*	*Unsafe control action is provided*	*Control action is provided in wrong time*	*Control action is provided for too short or too long*
Consequences:	Confusion over the state of process	Confusion over the state of process	Confusion over the state of process	Confusion over the state of process
Potential causes:	Sensors unreliable Required parameter cannot be measured	Sensors' malfunction Parameters outside sensors' working range Sensor's accuracy insufficient	Non-continuous characteristics of sensors' operation Sensors' idleness due to measured phenomenon's specificity	Non-continuous characteristics of sensors' operation
Feasible mitigation measures and potential	Redundant or highly-reliable sensors ▪ 3 / Indirect measurement ▪ 3	Redundant or highly-reliable sensors ▪ 3 / Implementation of wide-range sensors ▪	Use of highly-sensitive sensors ▪ 3	Implementation of continuously-probing sensors ▪ 4
Protection against control degradation	Constant search for and installation of improved sensors Use of leading indicators on sensors' performance	Constant search for and installation of improved sensors Use of leading indicators on sensors' performance	Constant search for and installation of improved sensors Use of leading indicators on sensors' performance	Constant search for and installation of improved sensors Use of leading indicators on sensors' performance

Control action number:	23		Auxiliary subsystems → Internal sensors

Control action name:	*Sensing*
Type:	Feed
Textual description:	Examination of subsystems' status
Rationale:	Auxiliary subsystems' control must be based on actual state of the processes as measured by sensors

Hazards resulting:	1.4 Vessel is incapable of properly containing dangerous chemicals or energy 1.5 Vessel is boarded by unauthorized personnel or such commodities are placed on board 2.2 Propulsion/steering gear operational parameters cannot be maintained 2.3 Vessel is denied passage by coastal state's authorities 2.5 Vessel does not meet stability criteria 2.6 Vessel's watertight integrity is not maintained (due to shear forces, bending moments or puncture) 3.1 Vessel's cargo is not loaded/stowed properly 3.2 Vessel is unable to maintain proper cargo stowage conditions 4.3 Vessel does not meet fire safety precautions 4.4 Vessel's watertight integrity is not maintained 4.5 Vessel's power supply is not provided or insufficient 5.1 Vessel is unable to maintain integrity of tanks containing oils or oily mixtures 5.2 Vessel is unable to maintain proper fuel combustion parameters 6.3 System does not meet international, classificatory or national regulations

Potential for inadequacy:	*Control action is not provided*		*Unsafe control action is provided*		*Control action is provided in wrong time*		*Control action is provided for too short or too long*	
Consequences:	Confusion over the state of machinery		Confusion over the state of machinery		Confusion over the state of machinery		Confusion over the state of machinery	
Potential causes:	Sensors unreliable Required parameter cannot be measured		Sensors' malfunction Parameters outside sensors' working range Sensor's accuracy insufficient		Non-continuous characteristics of sensors' operation Sensors' idleness due to measured phenomenon's specificity		Non-continuous characteristics of sensors' operation	
Feasible mitigation measures and potential	Redundant or highly-reliable sensors	3	Redundant or highly-reliable sensors	3	Use of highly-sensitive sensors	3	Implementation of continuously-probing sensors	3
	Indirect measurement	3	Implementation of wide-range sensors	3				
Protection against control degradation	Constant search for and installation of improved sensors Use of leading indicators on sensors' performance		Constant search for and installation of improved sensors Use of leading indicators on sensors' performance		Constant search for and installation of improved sensors Use of leading indicators on sensors' performance		Constant search for and installation of improved sensors Use of leading indicators on sensors' performance	

Control action number:	**24**	Internal sensors → Virtual Captain

Control action name:	*Data on equipment and processes' status*
Type:	Feedback
Textual description:	Information on measured values
Rationale:	Information on measured values should be compiled and fed to the VC for it to make informed decisions

Hazards resulting:	1.1 Vessel violates minimum CPA with another ship
	1.2 Vessel enters a No Go Area
	1.3 Vessel improperly interacts with other man-made objects
	1.4 Vessel is incapable of properly containing dangerous chemicals or energy
	1.5 Vessel is boarded by unauthorized personnel or such commodities are placed on board
	2.1 Vessel enters a No Go Area
	2.2 Propulsion/steering gear operational parameters cannot be maintained
	2.3 Vessel is denied passage by coastal state's authorities
	2.4 Vessel's navigational capabilities are severed by weather conditions
	2.5 Vessel does not meet stability criteria
	2.6 Vessel's watertight integrity is not maintained (due to shear forces, bending moments or puncture)
	3.1 Vessel's cargo is not loaded/stowed properly
	3.2 Vessel is unable to maintain proper cargo stowage conditions
	4.3 Vessel does not meet fire safety precautions
	4.4 Vessel's watertight integrity is not maintained
	4.5 Vessel's power supply is not provided or insufficient
	5.1 Vessel is unable to maintain integrity of tanks containing oils or oily mixtures
	5.2 Vessel is unable to maintain proper fuel combustion parameters
	6.2 Vessel contributes to delay of other ships' traffic
	6.3 System does not meet international, classificatory or national regulations

Potential for inadequacy:	*Control action is not provided*	*Unsafe control action is provided*	*Control action is provided in wrong time*	*Control action is provided for too short or too long*
Consequences:	VC has no data on the state of process or equipment's status	VC has improper data on the state of process or equipment's status	VC has outdated data on the state of process or equipment's status	
Potential causes:	Control actions #22,23,25 inadequate Data transmission ineffective	Control actions #22,23,25 inadequate Data transmission ineffective	Control actions #22,23,25 inadequate Data transmission ineffective	
Feasible mitigation measures and potential	Redundant wiring — 3	Data integrity validation algorithms — 2	Data transmission management algorithms — 2	
Protection against control degradation				

Control action number:	**25**	Engine / rudder → Internal sensors

Control action name:	*Sensing*
Type:	Feed
Textual description:	Examining engine/rudder status
Rationale:	State of propulsion and steering subsystems should be known to the VC for it to make informed decisions

Hazards resulting:	1.1 Vessel violates minimum CPA with another ship 1.2 Vessel enters a No Go Area 1.3 Vessel improperly interacts with other man-made objects 2.1 Vessel enters a No Go Area 2.2 Propulsion/steering gear operational parameters cannot be maintained 2.5 Vessel does not meet stability criteria 4.3 Vessel does not meet fire safety precautions 4.5 Vessel's power supply is not provided or insufficient 5.2 Vessel is unable to maintain proper fuel combustion parameters 6.2 Vessel contributes to delay of other ships' traffic 6.3 System does not meet international, classificatory or national regulations

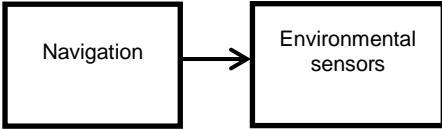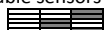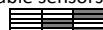| **Potential for inadequacy:**	*Control action is not provided*		*Unsafe control action is provided*		*Control action is provided in wrong time*		*Control action is provided for too short or too long*	
Consequences:	Confusion over the state of machinery		Confusion over the state of machinery		Confusion over the state of machinery		Confusion over the state of machinery	
Potential causes:	Sensors unreliable Required parameter cannot be measured		Sensors' malfunction Parameters outside sensors' working range Sensor's accuracy insufficient		Non-continuous characteristics of sensors' operation Sensors' idleness due to measured phenomenon's specificity		Non-continuous characteristics of sensors' operation	
Feasible mitigation measures and potential	Redundant or highly-reliable sensors	3	Redundant or highly-reliable sensors	3	Use of highly-sensitive sensors	3	Implementation of continuously-probing sensors	3
	Indirect measurement	3	Implementation of wide-range sensors	3				
Protection against control degradation	Constant search for and installation of improved sensors Use of leading indicators on sensors' performance		Constant search for and installation of improved sensors Use of leading indicators on sensors' performance		Constant search for and installation of improved sensors Use of leading indicators on sensors' performance		Constant search for and installation of improved sensors Use of leading indicators on sensors' performance	

Control action number:		26	Virtual Captain → Engine / rudder	

Control action name:		*Equipment set-points*
Type:		Control
Textual description:		Decisions on working parameters of propulsion and steering subsystems
Rationale:		VC shall be capable of controlling auxiliary processes by adjusting equipment's working parameters

Hazards resulting:	1.1 Vessel violates minimum CPA with another ship
	1.2 Vessel enters a No Go Area
	1.3 Vessel improperly interacts with other man-made objects
	2.1 Vessel enters a No Go Area
	2.2 Propulsion/steering gear operational parameters cannot be maintained
	2.4 Vessel's navigational capabilities are severed by weather conditions
	2.5 Vessel does not meet stability criteria
	3.1 Vessel's cargo is not loaded/stowed properly
	3.2 Vessel is unable to maintain proper cargo stowage conditions
	4.3 Vessel does not meet fire safety precautions
	5.2 Vessel is unable to maintain proper fuel combustion parameters
	6.2 Vessel contributes to delay of other ships' traffic
	6.3 System does not meet international, classificatory or national regulations
	6.5 System's interaction with other assets (including unmanned vessels) leads to the emergence of any of above

Potential for inadequacy:	*Control action is not provided*		*Unsafe control action is provided*		*Control action is provided in wrong time*		*Control action is provided for too short or too long*	
Consequences:	Loss of control over propulsion or rudder		Loss of control over propulsion or rudder		Loss of control over propulsion or rudder		Loss of control over propulsion or rudder	
Potential causes:	Actuators not reliable Data transmission within the vessel ineffective		Inadequate control algorithms Equipment incapable of complying with VC's commands		Data transmission within the vessel ineffective Inefficient control algorithms		Actuators unreliable or incapable of complying with VC's commands	
Feasible mitigation measures and potential	Improved reliability of machinery	3	Improved control algorithms	3	Data transmission management algorithms	2	Improved equipment's reliability	3
	Redundant wiring	3	Enhanced autonomy on subsystems' level	3	Enhanced autonomy on subsystems' level	3		
	Enhanced autonomy on subsystems' level	3	Manual control	1				
	Manual control	1						
Protection against control degradation	Maintenance of equipment		Maintenance of equipment					

Control action number:	27		Engine / rudder → Navigation	

Control action name:	*Regulation*
Type:	Control
Textual description:	Control over vessel's course and speed
Rationale:	Main engine and rudder shall be capable of properly influencing vessel's movements

Hazards resulting:	1.1 Vessel violates minimum CPA with another ship 1.2 Vessel enters a No Go Area 1.3 Vessel improperly interacts with other man-made objects 2.1 Vessel enters a No Go Area 2.2 Propulsion/steering gear operational parameters cannot be maintained 2.4 Vessel's navigational capabilities are severed by weather conditions 2.5 Vessel does not meet stability criteria 3.1 Vessel's cargo is not loaded/stowed properly 3.2 Vessel is unable to maintain proper cargo stowage conditions 4.3 Vessel does not meet fire safety precautions 5.2 Vessel is unable to maintain proper fuel combustion parameters 6.2 Vessel contributes to delay of other ships' traffic 6.3 System does not meet international, classificatory or national regulations 6.5 System's interaction with other assets (including unmanned vessels) leads to the emergence of any of above

Potential for inadequacy:	Control action is not provided		Unsafe control action is provided		Control action is provided in wrong time		Control action is provided for too short or too long	
Consequences:	Loss of control over vessel's movement		Loss of control over vessel's movement		Loss of control over vessel's movement		Loss of control over vessel's movement	
Potential causes:	Control actions #21,26 inadequate Machinery unreliable Consumables not provided		Control actions #21,26 inadequate Machinery having insufficient capacity Machinery improperly designed/installed		Control actions #21,26 inadequate Delays related to equipment's specificity and processes controlled Improper process management algorithms		Control actions #21,26 inadequate Improper process management algorithms	
Feasible mitigation measures and potential	Rigorous maintenance regime	3	Capacity surpluses by design	3	Implementation of leading performance indicators	3	Implementation of leading performance indicators	3
	Redundant machinery	3	Extensive testing	3				
	Resilience-based design	1						
	Procedures on consumables' management	3						
Protection against control degradation	External audits of maintenance effort Implementation of leading safety indicators							

Control action number:	28		Navigation → Environmental sensors

Control action name:	*Sensing*
Type:	Feed
Textual description:	Examination of processes' status
Rationale:	Vessel's course and speed as well as other elements of her movement should be measured for VC to make informed decisions

Hazards resulting:	1.1 Vessel violates minimum CPA with another ship 1.2 Vessel enters a No Go Area 1.3 Vessel improperly interacts with other man-made objects 2.1 Vessel enters a No Go Area 2.2 Propulsion/steering gear operational parameters cannot be maintained 2.4 Vessel's navigational capabilities are severed by weather conditions 2.5 Vessel does not meet stability criteria 3.1 Vessel's cargo is not loaded/stowed properly 3.2 Vessel is unable to maintain proper cargo stowage conditions 4.3 Vessel does not meet fire safety precautions 5.2 Vessel is unable to maintain proper fuel combustion parameters 6.2 Vessel contributes to delay of other ships' traffic 6.3 System does not meet international, classificatory or national regulations 6.5 System's interaction with other assets (including unmanned vessels) leads to the emergence of any of above

Potential for inadequacy:	*Control action is not provided*	*Unsafe control action is provided*	*Control action is provided in wrong time*	*Control action is provided for too short or too long*
Consequences:	Vessel's motion components are not known	Vessel's motion components are measured improperly	Vessel's motion components are measured with delay	
Potential causes:	Sensors unreliable Required parameter cannot be measured	Sensors' malfunction Parameters outside sensors' working range Sensor's accuracy insufficient	Non-continuous characteristics of sensors' operation Sensors' idleness due to measured phenomenon's specificity	
Feasible mitigation measures and potential	Redundant or highly-reliable sensors 3 Indirect measurement 3	Redundant or highly-reliable sensors 3 Implementation of wide-range sensors 3	Use of highly-sensitive sensors 3	
Protection against control degradation	Constant search for and installation of improved sensors Use of leading indicators on sensors' performance	Constant search for and installation of improved sensors Use of leading indicators on sensors' performance	Constant search for and installation of improved sensors Use of leading indicators on sensors' performance	

Control action number:		**29**		Environmental sensors → Virtual Captain	

Control action name:	*Data on vessel's motion and environment*
Type:	Feedback
Textual description:	Information on measured values
Rationale:	Information on measured values shall be compiled and transmitted to VC for it to make informed decisions. Data pertaining to ship's movement and the environment is sometimes strongly linked.

Hazards resulting:	1.1 Vessel violates minimum CPA with another ship
	1.2 Vessel enters a No Go Area
	1.3 Vessel improperly interacts with other man-made objects
	1.6 System does not provide assistance to person in distress
	2.1 Vessel enters a No Go Area
	2.4 Vessel's navigational capabilities are severed by weather conditions
	2.5 Vessel does not meet stability criteria
	3.1 Vessel's cargo is not loaded/stowed properly
	3.2 Vessel is unable to maintain proper cargo stowage conditions
	6.2 Vessel contributes to delay of other ships' traffic
	6.3 System does not meet international, classificatory or national regulations
	6.5 System's interaction with other assets (including unmanned vessels) leads to the emergence of any of above

Potential for inadequacy:	*Control action is not provided*		*Unsafe control action is provided*		*Control action is provided in wrong time*		*Control action is provided for too short or too long*	
Consequences:	Vessel's motion components and environmental conditions are not known		Improper data is fed to VC		Outdated information is fed to VC			
Potential causes:	Control actions #28,30 inadequate Data transmission within the vessel ineffective		Control actions #28,30 inadequate Data transmission within the vessel ineffective		Control actions #28,30 inadequate Data transmission within the vessel ineffective Information overflow			
Feasible mitigation measures and potential	Redundant wiring	3	Data integrity validation algorithms	2	Data transmission management algorithms	2		
Protection against control degradation								

Control action number:	30		GNSS → Environmental sensors

Control action name:	*Sensing*
Type:	Input
Textual description:	Data provided by Global Navigation Satellite System
Rationale:	The data is a vital information for the purposes of navigation process

Hazards resulting:	1.1 Vessel violates minimum CPA with another ship
	1.2 Vessel enters a No Go Area
	1.3 Vessel improperly interacts with other man-made objects
	2.1 Vessel enters a No Go Area
	2.4 Vessel's navigational capabilities are severed by weather conditions
	6.2 Vessel contributes to delay of other ships' traffic
	6.3 System does not meet international, classificatory or national regulations

Potential for inadequacy:	*Control action is not provided*		*Unsafe control action is provided*		*Control action is provided in wrong time*		*Control action is provided for too short or too long*	
Consequences:	Data on vessel's position, course and speed missing		Data on vessel's position, course and speed inaccurate					
Potential causes:	GNSS offline Vessel's antenna array unreliable		GNSS malfunction Vessel's antenna array malfunction					
Feasible mitigation measures and potential	Use of dead reckoning	2	Use of dead reckoning	2				
	Use of eNavigation techniques	2	Use of eNavigation techniques	2				
Protection against control degradation								
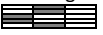
Control action number:	31	Environment → Environmental sensors

Control action name:	*Sensing*
Type:	Input
Textual description:	Examining the environment
Rationale:	Environmental conditions should be known to the VC for it to make informed decisions on adjustment of certain parameters

Hazards resulting:	1.1 Vessel violates minimum CPA with another ship
	1.2 Vessel enters a No Go Area
	1.3 Vessel improperly interacts with other man-made objects
	1.6 System does not provide assistance to person in distress
	2.1 Vessel enters a No Go Area
	2.4 Vessel's navigational capabilities are severed by weather conditions
	2.5 Vessel does not meet stability criteria
	2.6 Vessel's watertight integrity is not maintained (due to shear forces, bending moments or puncture)
	3.1 Vessel's cargo is not loaded/stowed properly
	3.2 Vessel is unable to maintain proper cargo stowage conditions
	4.4 Vessel's watertight integrity is not maintained
	6.2 Vessel contributes to delay of other ships' traffic
	6.3 System does not meet international, classificatory or national regulations

Potential for inadequacy:	*Control action is not provided*		*Unsafe control action is provided*		*Control action is provided in wrong time*		*Control action is provided for too short or too long*	
Consequences:	VC's lack of 'situation awareness'		VC's 'situation awareness' flawed		VC's 'situation awareness' flawed		VC's 'situation awareness' flawed	
Potential causes:	Sensors unreliable Required parameter is not measured		Sensors' malfunction Parameters outside sensors' working range		Non-continuous characteristics of sensors' operation Sensors' idleness due to measured phenomenon's specificity		Non-continuous characteristics of sensors' operation	
Feasible mitigation measures and potential	Providing control action #40	2	Redundant or highly-reliable sensors	3	Use of highly-sensitive sensors	3	Use of continuous probing	3
	Redundant or highly-reliable sensors	3	Use of wide-range sensors	3	Use of continuous probing	3		
Protection against control degradation	Constant search for and installation of improved sensors Use of leading indicators on sensors' performance		Constant search for and installation of improved sensors Use of leading indicators on sensors' performance		Constant search for and installation of improved sensors Use of leading indicators on sensors' performance		Constant search for and installation of improved sensors Use of leading indicators on sensors' performance	

Control action number:		**32**		Other unmanned ships → Environmental sensors	

Control action name:		*Data exchange*
Type:		Input
Textual description:		Data exchanged between unmanned ships
Rationale:		It might be beneficial for unmanned vessels to, for instance, coordinate collision avoidance actions. At minimum, Automatic Identification System standard data should be exchanged.

Hazards resulting:	1.1 Vessel violates minimum CPA with another ship
	1.2 Vessel enters a No Go Area
	1.3 Vessel improperly interacts with other man-made objects
	2.1 Vessel enters a No Go Area
	2.3 Vessel is denied passage by coastal state's authorities
	2.4 Vessel's navigational capabilities are severed by weather conditions
	6.2 Vessel contributes to delay of other ships' traffic
	6.3 System does not meet international, classificatory or national regulations
	6.4 System's communication subsystem unintentionally interferes with other assets

Potential for inadequacy:		*Control action is not provided*		*Unsafe control action is provided*		*Control action is provided in wrong time*		*Control action is provided for too short or too long*	
Consequences:		Important information about other vessel is missing Coordination cannot be carried out		Information about other vessel is incorrect Coordination is carried out incorrectly		Information about other vessel is outdated Coordination is carried out incorrectly			
Potential causes:		Own vessel's sensors/antenna array malfunction Other vessel does not transmit necessary data Radio communication jammed Data reception algorithms flawed Vessels use different data transfer standards		Own vessel's sensors/antenna array malfunction Other vessel transmits incorrect data Data reception algorithms flawed		Other vessel transmits outdated data Data reception algorithms flawed Information overflow			
Feasible mitigation measures and potential		Redundant antennas	3	Redundant antennas	3	Redundant antennas	3		
		Use of data from other sources	2	Use of data from other sources	2	Use of data from other sources	2		
		Implementation of global standard for data exchange	4						
Protection against control degradation		International and industry cooperation		International and industry cooperation					

Control action number:	**33**	Virtual Captain → Other unmanned ships
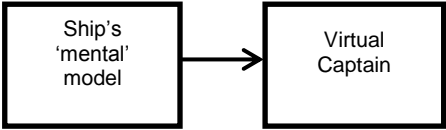
Control action name:	*Data exchange*
Type:	Feed
Textual description:	Data exchanged between unmanned ships
Rationale:	It might be beneficial for unmanned vessels to, for instance, coordinate collision avoidance actions. At minimum, Automatic Identification System standard data should be exchanged.

Hazards resulting:
1.1 Vessel violates minimum CPA with another ship
2.3 Vessel is denied passage by coastal state's authorities
6.2 Vessel contributes to delay of other ships' traffic
6.3 System does not meet international, classificatory or national regulations
6.4 System's communication subsystem unintentionally interferes with other assets
6.5 System's interaction with other assets (including unmanned vessels) leads to the emergence of any of above

Potential for inadequacy:	*Control action is not provided*	*Unsafe control action is provided*	*Control action is provided in wrong time*	*Control action is provided for too short or too long*
Consequences:	Other vessel is missing important information about own ship. Coordination cannot be carried out	Other vessel receives incorrect information about own ship. Coordination is carried out incorrectly	Other vessel receives incorrect information about own ship. Coordination is carried out incorrectly	
Potential causes:	Control action #29 inadequate. Own or other vessel's sensors/antenna array malfunction. Data transfer algorithms flawed. Vessels use different data transfer standards	Control action #29 inadequate. Own or other vessel's sensors/antenna array malfunction. Data transfer algorithms flawed	Control action #29 inadequate. Own or other vessel's sensors/antenna array malfunction. Data transfer algorithms flawed	
Feasible mitigation measures and potential	Redundant antennas — 3; Data transfer management algorithms — 3; Implementation of global standard for data exchange — 4	Redundant antennas — 3; Data transfer management algorithms — 3	Redundant antennas — 3; Data transfer management algorithms — 3	
Protection against control degradation	International and industry cooperation			

Control action number:		34	Shore-based control centre → Alarms / limits	

Control action name:	*Update*
Type:	Control
Textual description:	Adjustments of parameters' limits
Rationale:	Working parameters of the system shall be kept within certain limits. These could be altered by operators based on phase of vessel's voyage or weather conditions for instance
Hazards resulting:	All hazards

Potential for inadequacy:	*Control action is not provided*		*Unsafe control action is provided*		*Control action is provided in wrong time*		*Control action is provided for too short or too long*	
Consequences:	Unsafe system's states remain unnoticed OR Operator's assistance is requested too frequently, leading to belittling of emergencies		Unsafe system's states remain unnoticed OR Operator's assistance is requested too frequently, leading to belittling of emergencies		Limits are improperly set for conditions prevailing			
Potential causes:	Improper procedures on limits' adjustments Operators' lack of skill/experience Operators are given too great flexibility in adjusting the limits Control actions #14a,16 inadequate		Improper procedures on limits' adjustments Operators' lack of skill/experience Operators are given too great flexibility in adjusting the limits Control actions #14a,16 inadequate		Improper procedures on limits' adjustments Operators' lack of skill/experience Operators are given too great flexibility in adjusting the limits			
Feasible mitigation measures and potential	Implementation of proper procedures	3	Implementation of proper procedures	3	Implementation of proper procedures	3		
	Restriction of a degree to which limits can be adjusted	3	Restriction of a degree to which limits can be adjusted	3	Restriction of a degree to which limits can be adjusted	3		
	Trainings	3	Trainings	3	Trainings	3		
Protection against control degradation	Implementation of 'safety first' culture		Implementation of 'safety first' culture		Implementation of 'safety first' culture			
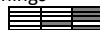
Control action number:	35		Alarms / limits → Virtual Captain

Control action name:	*Warnings*
Type:	Input
Textual description:	Levels of certain parameters that must not be exceeded
Rationale:	VC shall keep operational parameters of the system within limits

Hazards resulting:	All hazards

Potential for inadequacy:	*Control action is not provided*		*Unsafe control action is provided*		*Control action is provided in wrong time*		*Control action is provided for too short or too long*	
Consequences:	Unsafe system's states remain unnoticed		Unsafe system's states remain unnoticed					
Potential causes:	Control action #14a,16,34 inadequate Limits' data cannot be accessed		Control action #14a,16,34 inadequate Data misinterpreted by VC					
Feasible mitigation measures and potential	Fail-to-safe: AL-3	2	Data integrity validation algorithms	3				
Protection against control degradation								

Control action number:		36		Virtual Captain → Ship's 'mental' model	

Control action name:		*Update*			
Type:		Feedback			
Textual description:		Updates of VC's inherent model of the vessel, processes and subsystems			
Rationale:		Model of the system as built-in for VC should constantly be improved and updated			
Hazards resulting:	All hazards				

Potential for inadequacy:	*Control action is not provided*	*Unsafe control action is provided*	*Control action is provided in wrong time*	*Control action is provided for too short or too long*
Consequences:	Mental model incorrect	Mental model incorrect Software errors cause the VC to crash	Mental model incorrect Software errors cause the VC to crash	Mental model incorrect
Potential causes:	Control action #14b inadequate Software malfunction	Control action #14b inadequate Software malfunction	Control action #14b inadequate Software malfunction	Control action #14b inadequate Incomplete data set is downloaded
Feasible mitigation measures and potential	Extensive testing of software 3	Extensive testing of software 3	Extensive testing of software 3	Extensive testing of software 3
Protection against control degradation	Implementing a constant-improvement culture	Implementing a constant-improvement culture	Implementing a constant-improvement culture	Implementing a constant-improvement culture

Control action number:	**37**		Ship's 'mental' model → Virtual Captain

Control action name:	*Mental model*
Type:	Input
Textual description:	VC's inherent model of the vessel, processes and subsystems
Rationale:	VC shall use built-in mathematical model of particular subsystems' operations and the environment

Hazards resulting:	All hazards			
Potential for inadequacy:	*Control action is not provided*	*Unsafe control action is provided*	*Control action is provided in wrong time*	*Control action is provided for too short or too long*
Consequences:	VC cannot make decisions	Decisions are based on inaccurate or incomplete information		
Potential causes:	Model data cannot be accessed	Control action #14b,36 inadequate Pre-programmed models of processes are flawed		
Feasible mitigation measures and potential	Fail-to-safe: AL-3 ▦	2	Extensive tests of software ▦	3		
Protection against control degradation				

Control action number:	38		Coastal state's authorities → Shore-based control centre

Control action name:	*Requests or commands*
Type:	Input
Textual description:	Requests, orders, command and advices issued by coastal states' authorities, such as VTS
Rationale:	Coastal states shall be capable of requiring unmanned ships to follow certain advices issued by them as required due to e.g. traffic, security or environmental concerns
Hazards resulting:	All hazards

Potential for inadequacy:	Control action is not provided	Unsafe control action is provided	Control action is provided in wrong time	Control action is provided for too short or too long
Consequences:	Operator has incomplete model of situation	Operator has improper model of situation	Operator has outdated model of situation	
Potential causes:	Information is not issued or delivered Information is sent to a different company or operator	Inaccurate information is communicated Information is misinterpreted by operator	Outdated information is issued due to e.g. delay in processing	
Feasible mitigation measures and potential	Implementation of a system for identification of unmanned vessels' management companies by authorities and data exchange 〓 3 Procedures on data exchange 〓 3	Procedures on data exchange 〓 3 Trainings 〓 2	Procedures on data exchange 〓 3	
Protection against control degradation	Safety-oriented workshops with different industry players	Safety-oriented workshops with different industry players	Safety-oriented workshops with different industry players	

Control action number:	**39**		Shore-based control centre → Coastal state's authorities	

Control action name:	*Reports*
Type:	Feedback
Textual description:	Reports sent by operators to coastal states' administrations regarding e.g. dangerous goods carried on board, navigational status etc.
Rationale:	Coastal states' administrations should have full picture of situation in their waters – such information may be provided by system's operators

Hazards resulting:	All hazards			
Potential for inadequacy:	*Control action is not provided*	*Unsafe control action is provided*	*Control action is provided in wrong time*	*Control action is provided for too short or too long*
Consequences:	Local authorities have no information on unmanned vessel's operations	Local authorities have improper information on unmanned vessel's operations	Local authorities have outdated information on unmanned vessel's operations	
Potential causes:	Information is not issued or delivered Information is sent to wrong authorities	Information is compiled manually	Reports take too long to compile	
Feasible mitigation measures and potential	Procedures on data exchange 3	Procedures on data exchange 3 Implementation of a system for automatic data exchange 3	Procedures on data exchange 3	
Protection against control degradation	Safety-oriented workshops with different industry players	Safety-oriented workshops with different industry players		

Control action number:	40		Outsourced data providers → Shore-based control centre

Control action name:	*Outsourced data*
Type:	Input
Textual description:	Information provided by third parties
Rationale:	SBCC's personnel may request data that can be provided by external institutions: weather or traffic density information for instance

Hazards resulting:	All hazards			
Potential for inadequacy:	*Control action is not provided*	*Unsafe control action is provided*	*Control action is provided in wrong time*	*Control action is provided for too short or too long*
Consequences:	Outsourced data is not provided; operator does not have full picture of situation in vessel's location	Operator receives incorrect information	Operator receives outdated, therefore incorrect, information	Operator receives incomplete information
Potential causes:	Control action #41 inadequate Requested data not available Requested data delivered in unreadable form Operator ignores the data provided	Control action #41 inadequate Data source unreliable Data misinterpretation	Control action #41 inadequate Data source unreliable Data processing is delayed	Control action #41 inadequate Data license expired
Feasible mitigation measures and potential	Procedures on data exchange and use 3	Procedures on data exchange 3 Trainings 3	Procedures on data exchange 3	Procedures on data exchange 3
Protection against control degradation	Safety-oriented workshops with different industry players Implementing a constant-improvement culture	Safety-oriented workshops with different industry players Implementing a constant-improvement culture	Safety-oriented workshops with different industry players Implementing a constant-improvement culture	Safety-oriented workshops with different industry players Implementing a constant-improvement culture

Control action number:	41		Shore-based control centre → Outsourced data providers

Control action name:	*Requests for outsourced data*
Type:	Feedback
Textual description:	Requests to provide additional data pertaining to weather conditions etc. in vessel's location
Rationale:	Operators may require data available from external sources in order to maintain full situation awareness

Hazards resulting:	All hazards

Potential for inadequacy:	*Control action is not provided*	*Unsafe control action is provided*	*Control action is provided in wrong time*	*Control action is provided for too short or too long*
Consequences:	Additional data is neither requested nor provided; operator does not maintain full situation awareness	Improper data is requested	Data is requested when not required	
Potential causes:	Need for additional information is not recognized	Operator's lack of skill or experience Improper procedures on requesting data	Operator's lack of skill or experience Improper procedures on requesting data	
Feasible mitigation measures and potential	Procedures on data exchange — 3	Procedures on data exchange — 3	Procedures on data exchange — 3	
Protection against control degradation	Safety-oriented workshops with different industry players Implementing a constant-improvement culture	Safety-oriented workshops with different industry players Implementing a constant-improvement culture	Safety-oriented workshops with different industry players Implementing a constant-improvement culture	