An assessment of the potential impact of unmanned vessels on maritime transportation safety

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Agenda

• Introduction

• Methods suitable for safety assessment and results obtained
  – What-if analysis
  – Causal model
  – System-theoretic approach

• Discussion

• Concluding remarks
Unmanned vessels:

- Expected to enter into operation by the mid of next decade
- No or extremely limited crew on board
- Operating by remote control or autonomously
- Highly-advanced technology
- Environmentally friendly
- Cost-effective
- Safe?

Introduction

‘Manned’ shipping accidents by type - global values

How to ensure that unmanned ships at least do not reduce the safety of maritime transportation?
What-if analysis of autonomous vessels’ safety


EVALUATION OF UNMANNED SHIP’S ACCIDENT’S LIKELIHOOD:
1. Assess qualitatively the potential occurrence of each HFACS-MA causal category in future maritime accidents where unmanned ships are involved;
2. Review historical accident reports for manned ships to determine the causal factor(s) leading to the accidents;
3. Attribute each defined causal factor to causal categories as per HFACS-MA;
4. Assess qualitatively the impact of the unmanned ships’ introduction on accident’s likelihood, based on knowledge extracted in Step 3 and classification scheme in Step 1.

EVALUATION OF ACCIDENT’S CONSEQUENCES:
1. Determine impact on unmanned ship’s accident output based on outcome factors.

LIKELIHOOD AND CONSEQUENCES ASSESSMENT

WHAT-IF ANALYSIS

Root causes → Direct causes → Accident → Situation assessment → Damage control ↔ Decision making
What-if analysis – accident likelihood

The overview of HFACS-MA framework applied

### What-if analysis – accident likelihood

#### Level V: External factors

<table>
<thead>
<tr>
<th>Legislation gaps</th>
<th>The deficiencies of existing rules or codes that guide the maritime industry and relevant authorities [34]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Administration overights</td>
<td>The deficiencies of the governing authorities in implementing the existing rules or codes, or the negligence in performing their duties</td>
</tr>
<tr>
<td>Design flaws</td>
<td>Poor system design, such as poor consideration on ergonomics and maintainability of the system/components [35]</td>
</tr>
</tbody>
</table>

#### Level IV: Organisational influences [36]

<table>
<thead>
<tr>
<th>Resource management</th>
<th>Encompasses the realm of corporate-level decision making regarding the allocation and maintenance of organisational assets (such as personnel, money, equipment and facilities)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organisational climate</td>
<td>The working atmosphere within the organisation which includes culture, policies and structure</td>
</tr>
<tr>
<td>Organisational process</td>
<td>Refers to corporate decisions and rules that govern the everyday activities within the organisation. This includes the establishment/use of standard operational procedures and formal methods for maintaining oversight of the workforce</td>
</tr>
</tbody>
</table>

#### Level III: Unsafe Supervision

<table>
<thead>
<tr>
<th>Inadequate supervision</th>
<th>The factors that supervision fails to identify a hazard, recognise and control risk, provide guidance, training and/or oversight etc., resulting in human error or an unsafe situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planned inappropriate operation</td>
<td>The factors that supervision fails to adequately assess the hazards associated with an operation and allow for unnecessary risk</td>
</tr>
<tr>
<td>Failure to correct known problem</td>
<td>The factors that supervision fails to correct known deficiencies in documents, processes or procedures, or fails to correct inappropriate or unsafe actions of individuals create an unsafe situation</td>
</tr>
<tr>
<td>Supervisory violations</td>
<td>The factors that supervision willfully disregards instructions, guidance, rules or operating instructions whilst managing organisational assets create an unsafe situation</td>
</tr>
</tbody>
</table>

#### Level II: Preconditions [37]

<table>
<thead>
<tr>
<th>Condition of operator(s)</th>
<th>The conditions of an individual that have adverse influence to perform his/her job, i.e. mental and physiological status and mental/physical limitations of the practitioners</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software</td>
<td>The non-physical part of the system including organisational policies, manuals, checklist layouts, charts, maps, software and computer programs</td>
</tr>
<tr>
<td>Hardware</td>
<td>The physical part of the workplace. It includes the equipment of work stations, displays, controls and seats, etc.</td>
</tr>
<tr>
<td>Physical environment</td>
<td>The factors of nature environment which can affect the actions of individuals result in human error or an unsafe situation</td>
</tr>
<tr>
<td>Technological environment</td>
<td>The factors emphasise on the artificial environmental constructions, e.g. harbours, waterways and traffic control issues</td>
</tr>
<tr>
<td>Liveware</td>
<td>The peripheral liveware refers to the system’s human-human interactions including such factors as management, supervision, crew interactions and communications</td>
</tr>
</tbody>
</table>

#### Level I: Unsafe acts

<table>
<thead>
<tr>
<th>Skill-based errors</th>
<th>Errors involve slips and lapses. Slips are an unintentional action where the failure involves attention whilst lapses are an unintentional action where the failure involves memory [37]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rule-based mistakes</td>
<td>Mistakes involve inappropriate matching of environmental signs to the situational component of well-tried troubleshooting rules [32]</td>
</tr>
<tr>
<td>Knowledge-based mistakes</td>
<td>Mistakes happen when an individual has run out of applicable problem-solving routines and is forced to work on-line, using slow, sequential, laborious and resource limited conscious processing [32]</td>
</tr>
<tr>
<td>Routine violations</td>
<td>Causal factors tend to be defined by nature and often tolerated by governing authority [38]. They occur every day as people repeatedly modify or do not strictly comply with work procedures, often because of poorly designed or defined work practices [37]</td>
</tr>
<tr>
<td>Exceptional violations</td>
<td>Causal factors tend to be a one-time breach of a work practice, such as safety regulations being deliberately ignored to carry out a task. Even so, the intention was not to commit a malevolent act but just to get the job done [37]</td>
</tr>
</tbody>
</table>

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What-if analysis – accident consequences

We assigned the value of ‘consequences greater for unmanned ships’ whenever at least one of the following outcome factors was identified in an accident report:
• crew had to directly intervene by either inspecting ship’s enclosed spaces or manually reconfiguring its sub-systems;
• crew had to cooperate with other actors under pressure of time;
• crew was obligated to assist other seafarers should the vessel they collided with need to be abandoned;
• decisions on further actions could not be efficiently taken from remote command post;
• better maintenance of on board equipment before accident could have limited its outcome.

We assigned the value of ‘consequences lesser for unmanned ships’:
• whenever an accident report mentioned fatalities, serious injury or it was evident that humans’ presence on board during an accident restricted number of possible options of counteracting the effects of accident (e.g. when a person was missing in muster station and so CO₂ could not be released);

Should the circumstances of ‘greater’ and ‘lesser’ outcome occur simultaneously, the value was assigned based on more detailed analysis regarding which of them would be more relevant, with potential for avoiding fatalities greatly lowering the hypothetical consequences.
How will the autonomous vessels affect maritime safety?

Likelihood of accident for unmanned vessel in compare to traditional one

What-if analysis – results

How will the autonomous vessels affect maritime safety?

Consequences for unmanned vessel in compare to traditional one

What-if analysis – results

How will the autonomous vessels affect maritime safety?

Likelihood and consequences of unmanned ship's accidents compared with conventional one

Causal risk model

A standardized risk model for ship-ship collision

Causal risk model

- Model of potential failure propagation during the autonomous vessel’s accident
- Model allows for safety quantification in terms of risk level
- Major challenge – lack of data
- Other (qualitative) methods may be better to elaborate on safety and the ways to control it

System-Theoretic Process Analysis (STPA) is a method of assessing system’s safety by analysing the interactions between its components and the ways in which those can be unsafe.

The nature of such interactions shall ensure that the system as a whole remains within safety limits.

The aim is not to quantify the safety (mainly due to lack of data) but to ensure that it is controlled in proper manner.
Systemic approach to control the safety – development of safety control structure and interactions

Systemic approach to control the safety – development of safety control structure and interactions

IMO Flag states
Classification societies
Cargo agents
Hydrographic office
Charts Nautical publications
Auxiliary processes
Auxiliary systems
Internal sensors
Outsourced data providers
Company managers
Shore-based control centre
Passage plan
Virtual Captain
Engine / rudder
Environmental sensors
Navigation
GNSS
Alarms / limits
Communication subsystem
Ship’s control model
Autonomous ship

Legend:
- Shore facility
- Communication subsystem
- Within vessel
- Interaction with environment
- Organisational environment
- Coastal state’s authorities

Systemic approach to control the safety – elaboration on mitigation measures and potential
### What is it?

- Control action number: 28
- 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

### Why analysed?

- Why analysed?

### What can be the results of failure?

-危害导致的结果如下：
  1. Vessel violates minimum CPA with another ship
  2. Vessel enters a No Go Area
  3. Vessel improperly interacts with other man-made objects
  4. Vessel’s navigational capabilities are severely impacted by weather conditions
  5. Vessel does not meet stability criteria
  6. Vessel’s cargo is not loaded/stowed properly
  7. Vessel is unable to maintain proper cargo stowage conditions
  8. Vessel does not meet fire safety precautions
  9. Vessel is unable to maintain proper fuel combustion parameters
  10. Vessel contributes to delay of other ships’ traffic
  11. System does not meet international, classificatory or national regulations
  12. System’s interaction with other assets (including unmanned vessels) leads to the emergence of any of above

### What can cause a failure?

- What can cause a failure?

### How can a failure be prevented?

- How can a failure be prevented?

### How to make sure that risk does not reappear?

- How to make sure that risk does not reappear?

### Potential for inadequacy

<table>
<thead>
<tr>
<th>Consequences</th>
<th>Control action is not provided</th>
<th>Unsafe control action is provided</th>
<th>Control action is provided in wrong time</th>
<th>Control action is provided for too short or too long</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessel’s motion components are not known</td>
<td>Vessel’s motion components are measured improperly</td>
<td>Vessel’s motion components are measured with delay</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensors unreliable</td>
<td>Sensors’ malfunction</td>
<td>Non-continuous characteristics of sensors’ operation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Required parameter cannot be measured</td>
<td>Parameters outside sensors’ working range</td>
<td>Sensors’ idleness due to measured phenomenon’s specificity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feasible mitigation measures and potential</td>
<td>Redundant or highly-reliable sensors</td>
<td>Redundant or highly-reliable sensors</td>
<td>Use of highly-sensitive sensors</td>
<td></td>
</tr>
<tr>
<td>Indirect measurement</td>
<td>Implementation of wide-range sensors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protection against control degradation</td>
<td>Constant search for and installation of improved sensors</td>
<td>Constant search for and installation of improved sensors</td>
<td>Constant search for and installation of improved sensors</td>
<td></td>
</tr>
<tr>
<td>Use of leading indicators on sensors’ performance</td>
<td>Use of leading indicators on sensors’ performance</td>
<td>Use of leading indicators on sensors’ performance</td>
<td>Use of leading indicators on sensors’ performance</td>
<td></td>
</tr>
</tbody>
</table>
Systemic approach to control the safety – elaboration on mitigation measures and potential

A total of 48 control functions have been analysed with respect to their position within the system structure, potential scenarios leading to their inadequacy and consequences of such.

Furthermore, potential ways of mitigating such inadequacies were elaborated and evaluated by assignment of the mitigation potential.

A total of 252 recommendations on mitigation measures implementation have been elaborated, each of them pertaining to one of three groups:

• liveware,
• software,
• hardware.

By ‘liveware’ we understand all organisational, legal and operational factors in which a human plays a major and direct part.
Systemic approach to control the safety – communication of the results

Safety control recommendations by type and position within the system

- Organisational environment
- Within shore facilities
- Communication-related
- Within vessel
- Interaction with environment

Organisational

Human

Technical
Systemic approach to control the safety – communication of the results

Safety control recommendations by type and position within the system

- Organisational environment
- Within shore facilities
- Communication-related
- Within vessel
- Interaction with environment

Liveware

Software

Hardware
Uncertainties pertaining to the outcome of the study come as a result of the unmanned shipping technology being in its infancy. No empirical data or reliable models of such ships’ safety performance is available.

The subjective uncertainty assessment, borrowed from the risk analysis, and applied in system-theoretic approach tends to reflect the analyst’s level of background knowledge in each of five categories:

<table>
<thead>
<tr>
<th>Category</th>
<th>Uncertainty magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenomena</td>
<td>Low level or no understanding</td>
</tr>
<tr>
<td>Model</td>
<td>No basis for models or models give poor predictions</td>
</tr>
<tr>
<td>Assumptions</td>
<td>Poor justifications for the assumptions made, oversimplifying the analysed phenomena</td>
</tr>
<tr>
<td>Data</td>
<td>Not available or reliable</td>
</tr>
<tr>
<td>Consensus</td>
<td>Lack of consensus</td>
</tr>
</tbody>
</table>

Systemic approach to control the safety – communication of the results – handling the uncertainty

<table>
<thead>
<tr>
<th>Control function number:</th>
<th>Engine / rudder</th>
<th>Navigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Potential causes:
- Control functions #21,26 inadequate
- Machinery unreliable
- Consumables not provided
- Control functions #21,26 inadequate
- Machinery having insufficient capacity
- Machinery improperly designed/installed
- Control functions #21,26 inadequate
- Improper process management algorithms

### Feasible mitigation measures and potential

<table>
<thead>
<tr>
<th>Rigorous maintenance regime</th>
<th>3</th>
<th>Capacity surpluses by design</th>
<th>3</th>
<th>Implementation of leading performance indicators</th>
<th>3</th>
<th>Implementation of leading performance indicators</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Redundant machinery</td>
<td>3</td>
<td>Extensive testing</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resilience-based design</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Procedures of consumables’ management</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Uncertainty magnitude

<table>
<thead>
<tr>
<th>Category</th>
<th>Significant</th>
<th>Moderate</th>
<th>Minor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenomena</td>
<td>Low level or no understanding</td>
<td>Medium level of understanding</td>
<td>High level of understanding</td>
</tr>
<tr>
<td>Model</td>
<td>No basis for models or models give poor predictions</td>
<td>Some basis for models, level of simplifications adopted varies across the model; alternative hypotheses exist</td>
<td>Strong basis for the models, which give good predictions</td>
</tr>
<tr>
<td>Assumptions</td>
<td>Poor justifications for the assumptions made; oversimplifying the analysed phenomena</td>
<td>Reasonable justifications for the assumptions made, although simplifying the analysed phenomena</td>
<td>Seen as reasonable</td>
</tr>
<tr>
<td>Data</td>
<td>Not available or reliable</td>
<td>Data of varying quality is available</td>
<td>Much reliable data is available</td>
</tr>
<tr>
<td>Consensus</td>
<td>Lack of consensus</td>
<td>Various views exist among experts</td>
<td>Broad agreement among experts</td>
</tr>
</tbody>
</table>
Systemic approach to control the safety – communication of the results – handling the uncertainty

Breakdown of the uncertainties by its magnitude, type of relevant mitigation measure and position within the system.
Systemic approach to control the safety – results in details

For the full catalogue of measures which can be taken to ensure unmanned ships’ safety, please refer to the following scientific papers:

Discussion

• The lack of data pertaining to the actual design and performance of unmanned vessels’ system did not allow for a quantitative analysis.
• It has also caused the qualitative analysis to be performed on a very low level of details.
• Therefore, the level of risk in unmanned ships’ operation could not be evaluated quantitatively.
• Instead, certain measures aiming in ensuring safety have been elaborated and suggested.
Concluding remarks

• Unmanned vessels can potentially reduce the likelihood of maritime accidents. Meanwhile, their consequences can become more serious. This can be attributed to the fact that failure propagation could not be properly safeguarded against as there will be no crew to control the damage.

• Therefore, certain safety recommendations must be created and implemented. Concurrent application of various safety assessment methods can be of use in this case.

• Feasibility of certain solutions is burdened with significant uncertainties – more research is required.

• Unfortunately, the present stage of technology development does not allow for highly-detailed analysis. However, this may change in the nearest future.
Advanced Autonomous Waterborne Application - AAWA
Thank you!