Preliminary Hazard Analysis for an Innovative Container Feeder Concept

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The MOSES project

AutoMated Vessels and Supply Chain Optimisation for Sustainable Short SEA Shipping

Significantly **enhance the SSS component** of the European container supply chain by **stimulating sustainable feeder services** to ports with limited or no infrastructure!
The MOSES project – Innovative Feeder

Innovations

• Environmentally sustainable propulsion for minimal emissions during sailing, (near) zero emissions in port

• Highly-automated cargo handling for independence from the availability of port services

• Envisioned future autonomous functionalities

• Based on a different business model → Direct container transport from terminals to small, non-feeder ports
The MOSES Innovative Feeder – Use cases

**Eastern MED-Greece**
Decongest Piraeus container terminal and integrate small Greek ports into the container supply chain

**Western MED-Spain**
Decongest truck transport traffic in Valencia port and connect two Sagunto and Gandia satellite ports

**Differences in operational context:**
- Expected container demand → Capacity
- Round trip distance → Range and service speed
The MOSES Innovative Feeder – Greek I

- Length, $L_{BP} = 80$ m
- Capacity = 177 TEU
- Design speed ($T_{summer}$) = 10 kn
- Range = 266 nm

Bridge at fore for better visibility

**Forecastle for preventing water ingress**

*(IMO Open-top Containerships guidelines (1994))*

- Hybrid, methanol Internal Combustion Engine (ICE) and batteries
- Fully battery powered

2 x Azimuth thrusters for unloading with DP
The MOSES Innovative Feeder – Greek II

- Hybrid, methanol Internal Combustion Engine (ICE) and batteries
- Fully battery powered

Length, $L_{BP} = 71$ m
Capacity = 106 TEU
Design speed ($T_{summer}$) = 10 kn
Range = 266 nm

Bridge at fore for better visibility

Conventional cargo hatch

2 x Azimuth thrusters for unloading with DP
The MOSES Innovative Feeder – Spanish

Length, $L_{BP} = 132$ m  
Capacity = 670 TEU  
Design speed ($T_{summer}$) = 5 kn  
Range = 85 nm

- 2 x Azimuth thrusters for unloading with DP
- Selected for sailing at 10 kn for additional power in bad weather conditions
- Hybrid, methanol Internal Combustion Engine (ICE) and batteries
- Fully battery powered

Bridge located midships (SOLAS, Annex A, Ch. V, Reg. 22)
The need for risk assessment in design

The maritime industry is currently searching for solutions to decrease emissions and increase efficiency for achieving sustainability goals

New vessel designs with innovations related to powering configurations and automation

- Design requirements for innovative solutions may not yet be in place
- **Risk-based design approaches** (see, e.g., Papanikolaou 2009; Lloyd’s, 2016) can provide evidence for approving safe operation

Risk assessment techniques applied from the early design stages - Examples:

- Autonomous, small passenger ferry - Preliminary Hazard Analysis (PHA) for risk-reducing measures (Thieme et al., 2019)
- Systems Theoretic Process Analysis (STPA) for autonomous ships at different autonomy levels (Ventikos et al., 2020)
- Autonomous inland waterways ship - Hazard Identification (HAZID) that integrates safety and (cyber)-security (Bolbot et al., 2021)
Hazard analysis methodology

1. **Brainstorming expert sessions** → Hazards, hazardous events, worst case consequences, risk reducing measures

2. **Separate expert assessments for each hazardous event** → Frequency and consequence severity indices (FI, SI)

3. **Average of assessments** → Calculation of risk index (RI) for each hazardous event

4. Documentation in worksheet

Typically used in the early stages of system design (Rausand 2011) for “establishing the initial system safety requirements (SSRs) for design from preliminary and limited design information” (Ericson 2005).
Hazard analysis methodology

<table>
<thead>
<tr>
<th>FI</th>
<th>Frequency</th>
<th>Definition</th>
<th>F (per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Frequent</td>
<td>Likely to occur several times per year</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Reasonably probable</td>
<td>Likely to occur several times in the ship's lifetime</td>
<td>0.1</td>
</tr>
<tr>
<td>2</td>
<td>Remote</td>
<td>Likely to occur once in the ship's lifetime</td>
<td>0.01</td>
</tr>
<tr>
<td>1</td>
<td>Extremely remote</td>
<td>Unlikely to occur during the ship's lifetime</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>

### Matrices adapted from the IMO FSA Guidelines (2015)

<table>
<thead>
<tr>
<th>SI</th>
<th>Severity</th>
<th>Safety</th>
<th>Environment</th>
<th>Property</th>
<th>Supply chain</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>None</td>
<td>No injuries</td>
<td>No pollution</td>
<td>No damage to equipment, ship</td>
<td>No disruption</td>
</tr>
<tr>
<td>1</td>
<td>Minor</td>
<td>Single or minor injuries</td>
<td>Minor (local) pollution</td>
<td>Local damage to equipment, ship</td>
<td>Minor delays</td>
</tr>
<tr>
<td>2</td>
<td>Significant</td>
<td>Multiple or severe injuries</td>
<td>Significant pollution</td>
<td>Non-severe damage to ship</td>
<td>Significant delays</td>
</tr>
<tr>
<td>3</td>
<td>Severe</td>
<td>Single fatality or multiple severe injuries</td>
<td>Severe pollution, contained locally</td>
<td>Severe damage to ship</td>
<td>Severe delays</td>
</tr>
<tr>
<td>4</td>
<td>Catastrophic</td>
<td>Multiple fatalities</td>
<td>Severe pollution, not contained</td>
<td>Total loss</td>
<td>Cargo delivery disrupted</td>
</tr>
</tbody>
</table>

### The SI does not need to include damages in all categories

### Four different RIs have been calculated

<table>
<thead>
<tr>
<th>FI</th>
<th>Frequency</th>
<th>Severity (SI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Frequent</td>
<td>Minor 5, Significant 6, Severe 7, Catastrophic 8</td>
</tr>
<tr>
<td>3</td>
<td>Reasonably probable</td>
<td>Minor 4, Significant 5, Severe 6, Catastrophic 7</td>
</tr>
<tr>
<td>2</td>
<td>Remote</td>
<td>Minor 3, Significant 4, Severe 5, Catastrophic 6</td>
</tr>
<tr>
<td>1</td>
<td>Extremely remote</td>
<td>Minor 2, Significant 3, Severe 4, Catastrophic 5</td>
</tr>
</tbody>
</table>

### No acceptability criteria have been used – comparative ranking

**High-Risk**
Preliminary Hazard Analysis – Scope

**System component**
- Engine and propulsion machinery
- Fuel/energy storage system
- Cargo space
- Accommodation superstructure

**Operational phases**
- Sailing (open sea, shipping lane, port manoeuvring)
- Cargo operations during (un)loading at berth

**Types of hazards**
- System complexity
- Market volatility and variability
- Extreme weather
- Energy source
- Crane operation
- Evacuation
- Situation awareness
Preliminary Hazard Analysis – Results

12 Hazardous events

2 hazardous events (sailing):
- Evacuation
- Situation awareness

4 hazardous events (sailing):
- Energy source

3 hazardous events (all, sailing):
- System complexity
- Market volatility/variability
- Extreme weather

2 hazardous events (loading at berth):
- Crane operation and extreme weather

1 hazardous event (sailing):
- Water ingress in extreme weather conditions

* Hazards apply for all three concept designs
Most frequently expected:

- Position of the container crane on board impedes operation of port cranes
- Water accumulates in cargo hold in harsh weather conditions due to open top design
Preliminary Hazard Analysis – Results

9 High risk events / system component

Cargo space:
- Onboard crane impedes port cranes
- Water accumulation in cargo hold

Accommodation:
- Mustering process takes too long
- Limited visual monitoring of the cargo space

Fuel/Energy storage:
- Methanol leakage
- Batteries overheating

Engine/Propulsion machinery:
- Hybrid configuration operation & maintenance
- Generator fails due to load variations in extreme weather
- Design speed too specific

* Hazards apply for all three concept designs
Preliminary Hazard Analysis – Results

3 Highest risk events / system component

**Cargo space:**
Onboard crane impedes port cranes → Slower cargo handling →

\[ RI_{Supp.Chain} = 7 \]

**Accommodation:**
Limited visual monitoring of the cargo space → Fire, cargo shift/loss not detected →

\[ RI_{Safety} = 7 \]

**Cargo space:**
Water accumulates in cargo hold (open top design) → Stability degradation, damage to cargo →

\[ RI_{Safety} = RI_{Property} = RI_{Supp.Chain} = 8 \]

* Hazards apply for all three concept designs
Considerations for more detailed design

### Engine and Propulsion Machinery Requirements

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Hazardous event</th>
<th>Risk reducing measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hybrid configuration is complex</td>
<td>Technical failures cannot be handled by the crew onboard</td>
<td><strong>Optimal manning</strong> related to automation level</td>
</tr>
<tr>
<td>Extreme weather conditions</td>
<td>Generator system fails due to inability to cope with load variations</td>
<td>The battery system, the power and battery management systems should be designed to <strong>cope with transient loading</strong> efficiently and safely, providing <strong>sufficient power redundancy</strong> in different conditions</td>
</tr>
</tbody>
</table>
Considerations for more detailed design

Fuel/ Energy Storage System Requirements

**Hybrid (Methanol ICE + batteries)**

- Methanol-related risks are covered extensively by:
  - Interim Guidelines for the Safety of Ships using Methyl/Ethyl alcohol as fuel (IMO 2020) – **double wall piping, fuel handling system isolation**
  - Class notations and Guidelines (ABS, 2022), (DNV, 2019) – **bunkering connections**

**Additional risk reduction:**
- **Optimal manning level** to avoid methanol leakage near hot surfaces in Engine room

**Hybrid and fully Electric**

- **Fire-proof** battery room (Class standards)
- **Detailed risk assessment** for the system arrangement

**Fully Electric**

- Energy storage requirements (**23-37 MWh**) > 4 x battery capacity on Yara Birkeland (NRP, 2021)
- Likely occurrence of hazardous situations not covered by Class requirements
# Considerations for more detailed design

<table>
<thead>
<tr>
<th>Accommodation Superstructure Requirements</th>
<th>Cargo Space Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>• <strong>Bridge 360° visibility and sensors</strong> for monitoring cargo space</td>
<td>• <strong>Crane position optimization</strong> and detailed risk assessment in accordance with, e.g., class notation Crane (DNV, 2017)</td>
</tr>
<tr>
<td>• <strong>Relative position to machinery, fuel handling, and batteries</strong> → requirements from DNV LFL class notation and IMO IGF Code</td>
<td>• <strong>Safe cargo operations without with DP</strong> → additional hazard identification</td>
</tr>
<tr>
<td>• <strong>Relative position to LSAs</strong> → detailed risk analysis for crew access and compliance with IMO Evacuation Analysis (SOLAS Reg. III/31.1.4)</td>
<td>• <strong>Water accumulation in cargo hold</strong> covered by:</td>
</tr>
<tr>
<td></td>
<td>• <strong>Hatchcoverless Class notation</strong> (DNV, 2017)</td>
</tr>
<tr>
<td></td>
<td>• Model testing and Intact and Damage stability assessment – <strong>IMO Interim Guidelines for Open-top Containerships</strong> (1994)</td>
</tr>
<tr>
<td></td>
<td>• <strong>IACS rules:</strong> Open top container holds – Water supplies, – Ventilation, – Bilge Pumping (2022)</td>
</tr>
</tbody>
</table>
Conclusions

Issues covered by existing international regulations and class rules:

- Methanol as fuel and batteries as energy source
- Evacuation effectiveness with respect to the position of the accommodation superstructures
- Stowage of the onboard crane during sailing
- Water accumulation in cargo holds in extreme weather due to open-top design

More detailed risk assessment required for:

- Optimal manning as a function of the targeted automation level
- Situation awareness from the bridge
- (Un)loading without using mooring lines through DP
- Handling load variations in extreme weather conditions
Thank you for your attention!

Konstantinos Louzis, NTUA
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A typical container feeder

Small feeder: 300 – 1000 TEU
Feeder: 1000 – 2000 TEU
Feedermax: 2000 – 3000 TEU

Typically geared: 1/3 of very small ships (100 – 499 TEU) and 60% of feeders (1500 – 2499 TEU)

Max service speed 20 kn – slower than large container ships

Bridge typically positioned aft