Safety Verification for Autonomous Ships

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Børge Rokseth, Odd Ivar Haugen & Ingrid Bouwer Utne
Objectives of the presented work

Exploring the possibility of using STPA as a foundation for safety verification

Identifying design requirements and necessary functionality for safety for autonomous ships at an early stage in the concept development

Gaining insight into how autonomous ship functionality should be designed to make it possible to gain sufficient levels of confidence
What are autonomous ships?
What are autonomous ships?

Plan journey
- Make tentative trajectory
- Determine system settings for each leg

Update plan to accommodate changing conditions and real-time data
- Change, or deviate from, trajectory
- Reconfigure power and propulsion
- Deviate from planned operating modes

Remote control control mode
- SCC

Indirect remote control mode
- ASS

Autonomous control mode
Why autonomous ships?

Potential benefits:
- More efficient use of space in ship design
- More efficient use of crew and their skill
- More efficient use of fuel

Slow steaming feasible?
Renewable energy feasible?
Many smaller ferries?
Less waiting
The verification challenge

The safety verification challenge:

- Think of all potential hazardous scenarios
- Test how the system handles them
Safety Verification

- Maximize confidence that the system is safe
- Identify what must be verified
- Facilitate proper verification (make a verifiable design/system)
- Put the design/system to the test and fix weaknesses
Verification activities

- Simulator-based testing
- Sea trials
- Software-testing
- Document review
- Code review
- ....
Using STPA to develop a verification program

**Step 1**: Conduct STPA to find:
- Hazardous scenarios
- Safety constraints

**Step 2**: For each scenario, identify:
- Key variables
- Verification objectives (aims)
- Acceptance criteria

**Step 3**: For each verification objective determine suitable means (verification activities for verification)

**Step 4**: Describe setup, execution, and concrete acceptance criteria for each activity
Case study

Autonomous ships
Step 1: STPA

• Accidents:
  – A-1: The ship collides with a moving obstacle
  – A-2: The ship collides with a stationary obstacle

• Hazards:
  – H-1: The ship violates a specified minimum separation distance to an obstacle
  – H-2: Ship violates COLREG or rules for sensible behavior on the sea (A-1)
### Step 1: STPA

<table>
<thead>
<tr>
<th>Control action</th>
<th>Not provided</th>
<th>Provided</th>
</tr>
</thead>
<tbody>
<tr>
<td>Update trajectory (SCC)</td>
<td><strong>UCA-1:</strong> The trajectory is not updated by SCC to avoid obstacles or ensure COLREG compliance when the ship is under indirect remote control (H-1,2)</td>
<td><strong>UCA-2:</strong> A trajectory which is such that loss of maneuverability will result in violation of minimum specified separation distance to an obstacle, is provided (H-1,2)</td>
</tr>
</tbody>
</table>
Step 1: STPA

UCA-2: A trajectory which is such that loss of maneuverability will result in violation of minimum specified separation distance to an obstacle, is provided

• **SC**: There are two options to avoid this:
  – Ensure that loss of maneuverability will not occur
  – Update the trajectory such that loss of maneuverability will not result in violation

• **Scenario**: The remote operator incorrectly believes that the maneuverability will remain sufficient to avoid violation following any WCSF
  – **SC**: The autonomous ship must include a function to online assess whether nominal trajectory will result in violation in the event of any single failure
Online consequence analysis
Step 1: Refined STPA

Refined STPA of “Online Consequence Analysis (OCA) function”:

• **UCA:** OCA incorrectly provides “an affirmative” for the nominal trajectory
  
  – **SC:** Potential outcome of each candidate WCSF must be correctly estimated online for the given system configuration and set of circumstances

• **Scenario:** The OCA underestimates the consequences of a WCSF candidate because the embedded logics are based on an analysis that disregards relevant mechanisms or factors
Step 2: Key variables, verification objectives and acceptance criteria

**Scenario:** The OCA underestimates the consequences of a WCSF candidate because the embedded logics are based on analyses that disregards relevant mechanisms or factors

- **Estimated reduction in maneuverability**
- **Actual reduction in maneuverability**

**Verification objectives:**
Verify that all relevant mechanisms and factors that determine the reduction in maneuverability as a consequence of each candidate WCSF, has been modelled

**General acceptance criterion:**
Estimated reduction in maneuverability shall not be smaller than the actual reduction in any system configuration or circumstance
Step 3: Verification activities

**Verification objective:** Verify that all relevant mechanisms and factors that determine the reduction in maneuverability as a consequence of each candidate WCSF, has been modelled.

- Check whether OCA will under-estimate maneuvering capacity remaining after any WCSF candidate
- Check assumptions. Has all relevant factors been accounted for by the model
- Specify simulator test scenarios by identifying questionable assumptions to test
- Simulator based testing
- Review model documentation
- Verify simulation-based tests
- Practical trials
Step 4: Setup and execution

Review model documentation

Aim
Verify that all relevant factors which may affect the performance of the system after the occurrence of the WCSF have been considered
Specify relevant simulator test scenarios

Setup
A system expert will go through the documentation for the model for estimating the remaining maneuverability after potential WCSFs

Acceptance criterion
Any mechanisms and factors that may have a significant effect on the maneuverability capabilities of the vessel following potential WCSFs must be accounted for realistically in the online model
Step 4: Setup and execution

Simulator-based testing

Aim

Compare online model for estimating remaining maneuverability after WCSF to results from high-fidelity simulator model for all candidate WCSFs in a wide selection of system configurations and environmental circumstances

Setup

WCSF scenario
System configuration
Environmental conditions

High-fidelity system simulator

Remaining maneuverability capability

Online estimator

Acceptance criterion

The losses in maneuverability estimated by the online estimator must be at least as severe as those estimated by the high-fidelity simulator
Conclusion

• Enables development/outlining of safety verification program in early concept development phase
• Integrates design and verification management
• Further work will focus on conducting a more comprehensive case study for autonomous ships in cooperation with industry partners