VTT TECHNICAL RESEARCH CENTRE OF FINLAND LTD

Safety validation of autonomous navigation systems using a ship handling simulator

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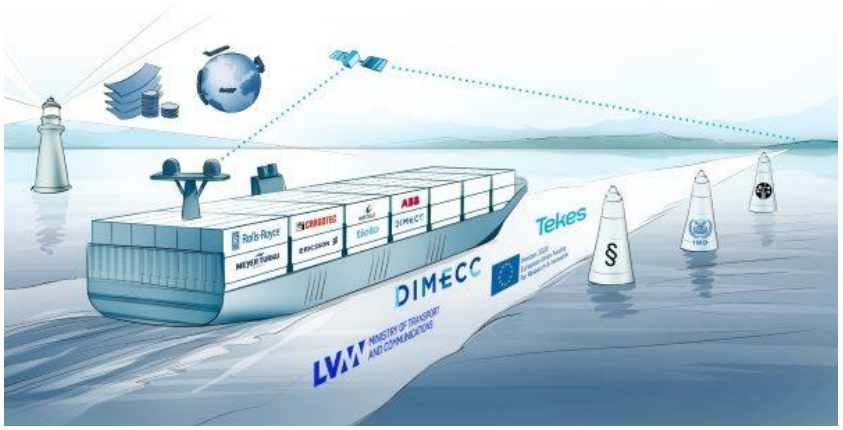
Background: Autonomous ships development in Finland

- AAWA Initiative
  - R&D initiative coordinated by Rolls-Royce Marine
  - Create competences for autonomous vessels in real use
  - Develop commercially-viable short- to medium-term solutions
  - Enable first autonomous ship prototypes for trials at sea
- One Sea Ecosystem
  - Create world's first autonomous marine transport system to the Baltic Sea
  - Network of maritime industry companies
  - Vision of fully autonomous ships in 2025
- Test area for autonomous vessels
  - 150 km^2 dedicated test range at Gulf of Bothnia
  - Closed for other traffic during test campaigns



Increased safety through increased level of autonomy?

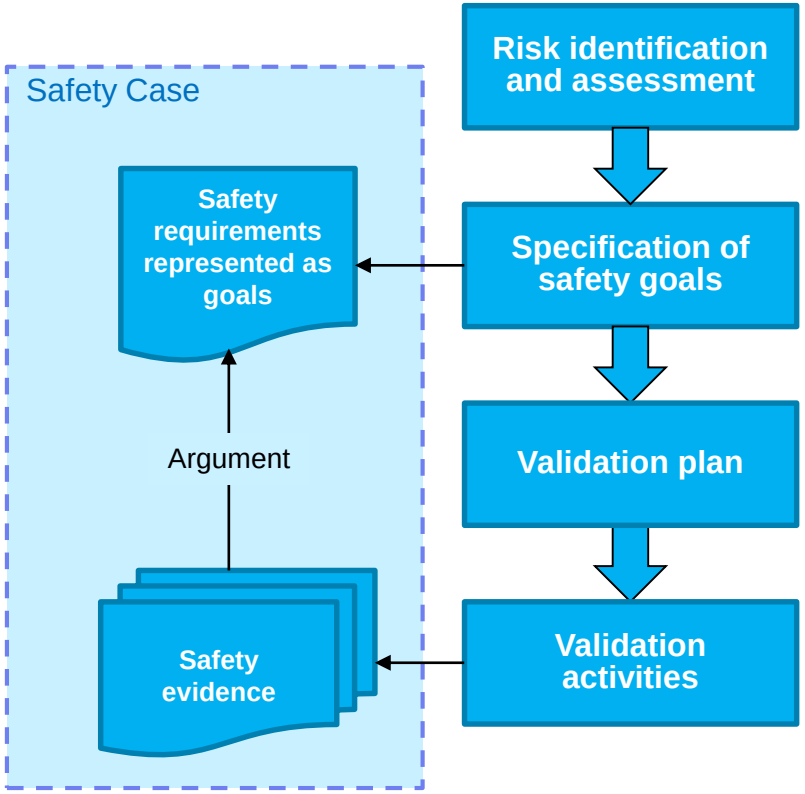
- Improved safety is an essential target when increasing the automation level, but we can't take safety increase as granted
  - Introduction of new technologies always brings along uncertain elements
    - Integration of autonomous ships into existing marine transport environment
    - Learning curve in safety performance
- Currently, maritime safety authorities have no fixed methods for approval of autonomous ship prototypes

  → Technology developer / user is responsible for presenting the safety evidence

  → Robust validation methodology required

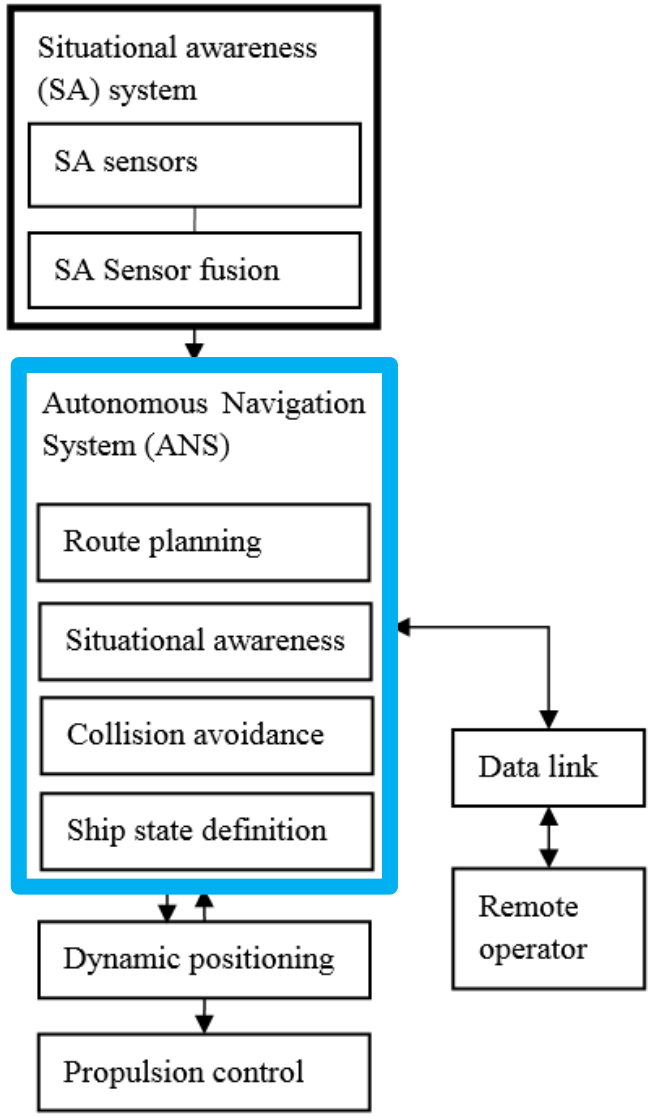
Safety validation of autonomous systems - overview

- Overall target: Autonomous vessel needs to be at least as safe as a corresponding conventional vessel
  - ”Safety equivalence”
  - No increased risk in own operation
  - No additional risk to others
- The main objective of validation: Create a plausible demonstration of an autonomous system’s safety and present it in an understandable way



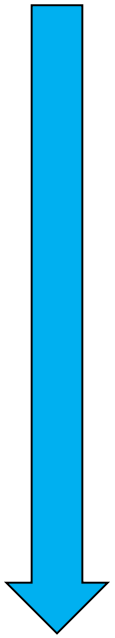
Autonomous navigation system

- Autonomous navigation system makes the navigational decisions
  - Inputs: Situational model (sensor data), ship system status data, possible commands by remote operator
  - Function: Situational interpretation and navigational decision-making
  - Outputs: Commands for the ship's propulsion systems, data provided for remote operator



Methods for producing the safety evidence

- Different complementary approaches possible for producing the safety evidence:
  - Analysis of documented earlier experience
  - Analytical methods
  - Numerical methods
  - Experimental methods
    - Model testing
    - **Simulator testing**
      - Hardware-in-the-loop testing
      - **Ship handling simulator**
    - Field testing

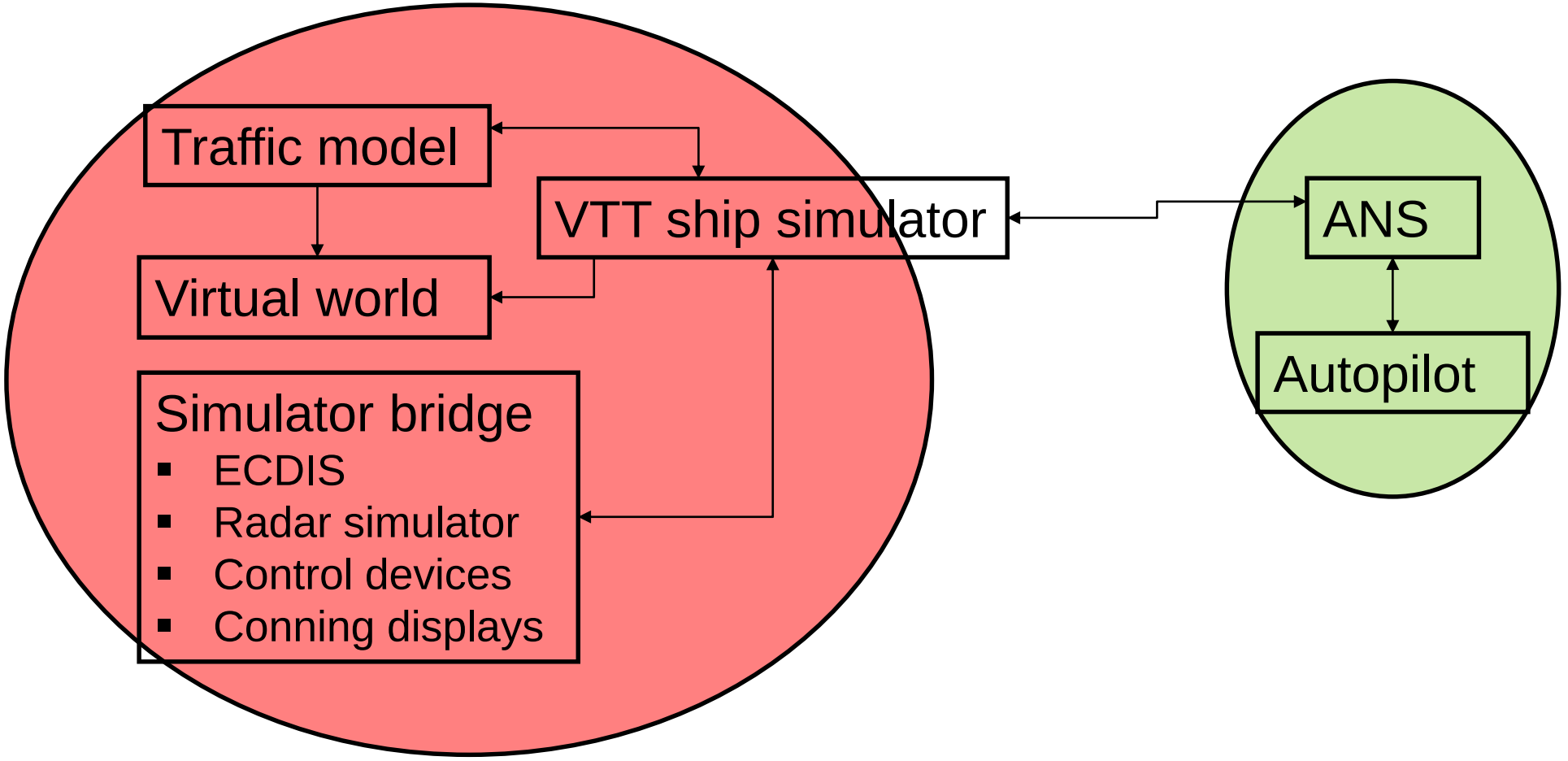


Increasing realism & specificity

VTT Ship handling simulator

- VTT ship handling simulator provides typical mid-size bridge simulator features
  - ECDIS, radar simulator, control devices for rudders, propulsors and joysticks
  - Hydrodynamical ship model including all essential environmental effects, also six-degree-of-freedom model
  - Tug+escort tug simulation capabilities
  - Traffic simulation
  - Virtual world
  - Apilot – autonomous ship pilot for autonomous ships (v1.0 introduced, under development)

VTT Ship handling simulator envinronment



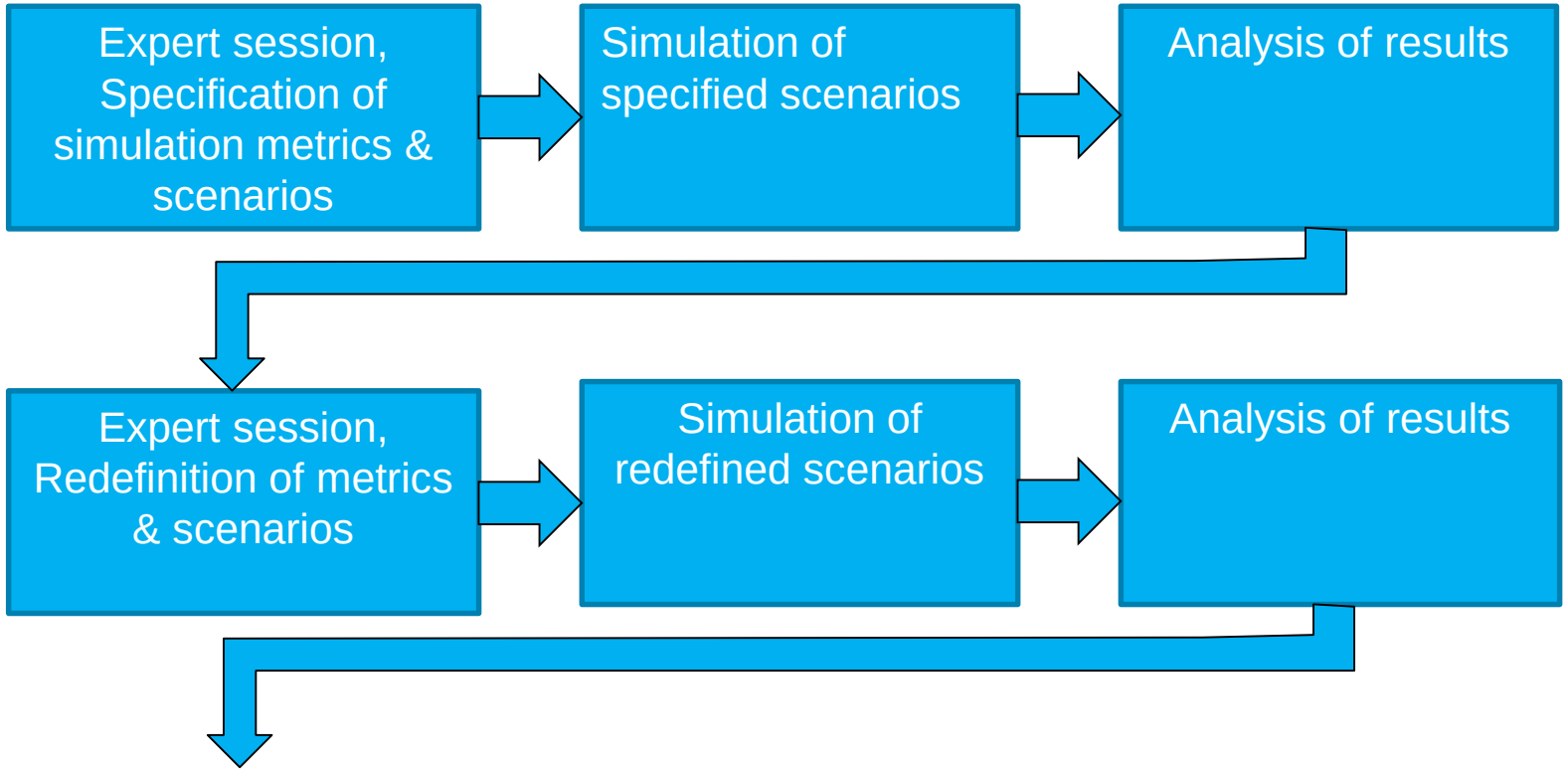
VTT simulator environment for ANS validation

- State vectors of traffic vessels are provided to ANS-ship
- VTT's ship handling simulator offers a flexible platform for the ANS validation
  - ANS-system can be integrated to simulator as it would be installed to ship
  - Simulation scenarios can be conducted in specific region applying the desired environmental conditions
  - Complex traffic simulations with several traffic vessels can be carried out
  - All ships including the traffic vessels are simulated using comprehensive physical models with realistic response times
  - Different kind of vessels available: from VLCCs to small motor boats

VTT simulator environment for ANS validation

- Traffic vessels's routes are based on track-autopilot simulations
  - Autopilot tries to follow to track as accurate as possible
- Traffic vessels have to react to ANS vessel during evasive actions
  - Control of traffic vessels can be transferred to simulation supervisor, that is, manual, heading autopilot or 'trigger' based controls are available during simulations
  - Supervisor: experienced seafarer
  - In order to conduct fast-time simulations, one possibility is to apply Apilot for the traffic vessels in order to generate critical amount of simulation scenarios

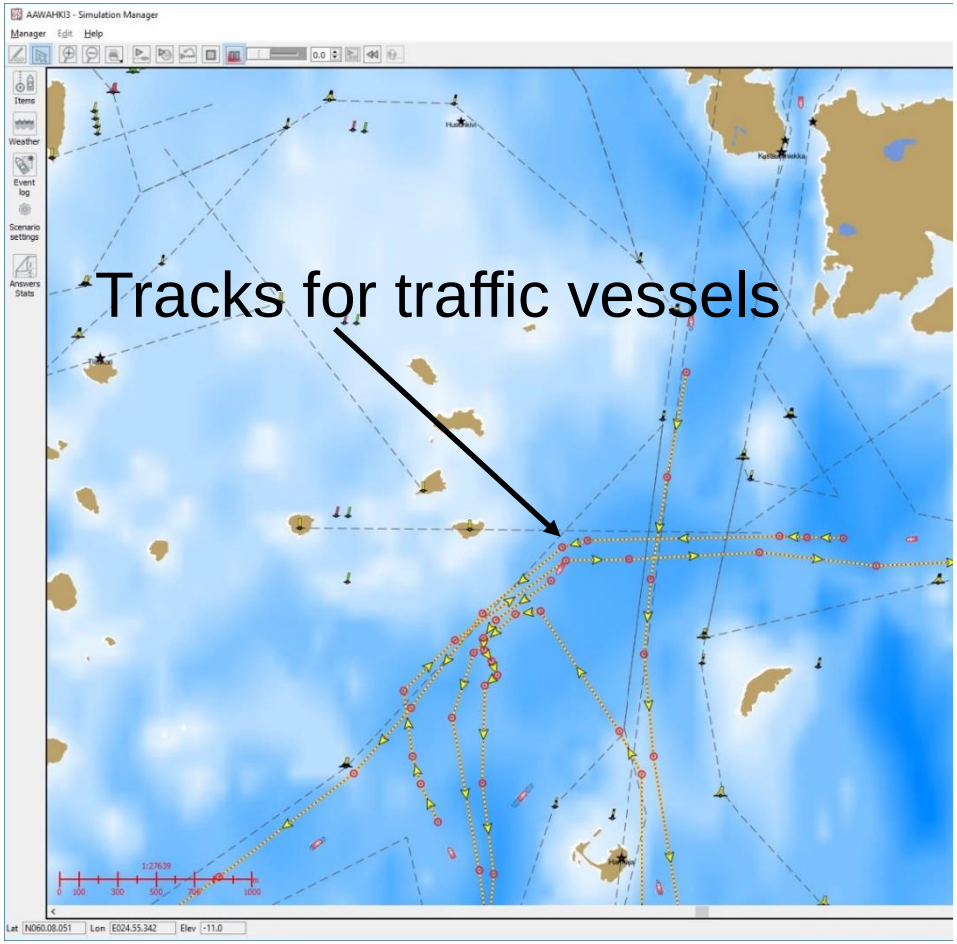
ANS validation process

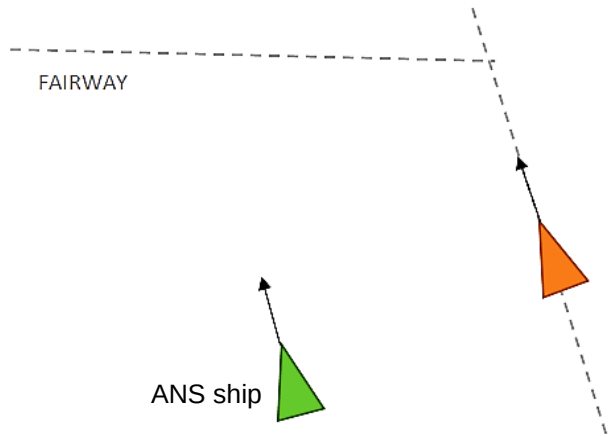


Iterate to achieve final ANS performance evaluation

Scenarios for simulator testing

- Simulation scenarios built to test e.g.:
  - How well COLREGs regulations are followed
  - How proactive/reactive ANS system is
  - Operation in difficult environmental conditions or with degraded ship systems e.g. propulsion
  - Operation with uncertain SA-sensor data





ANS performance criteria

Potential validation metrics for the analysis:

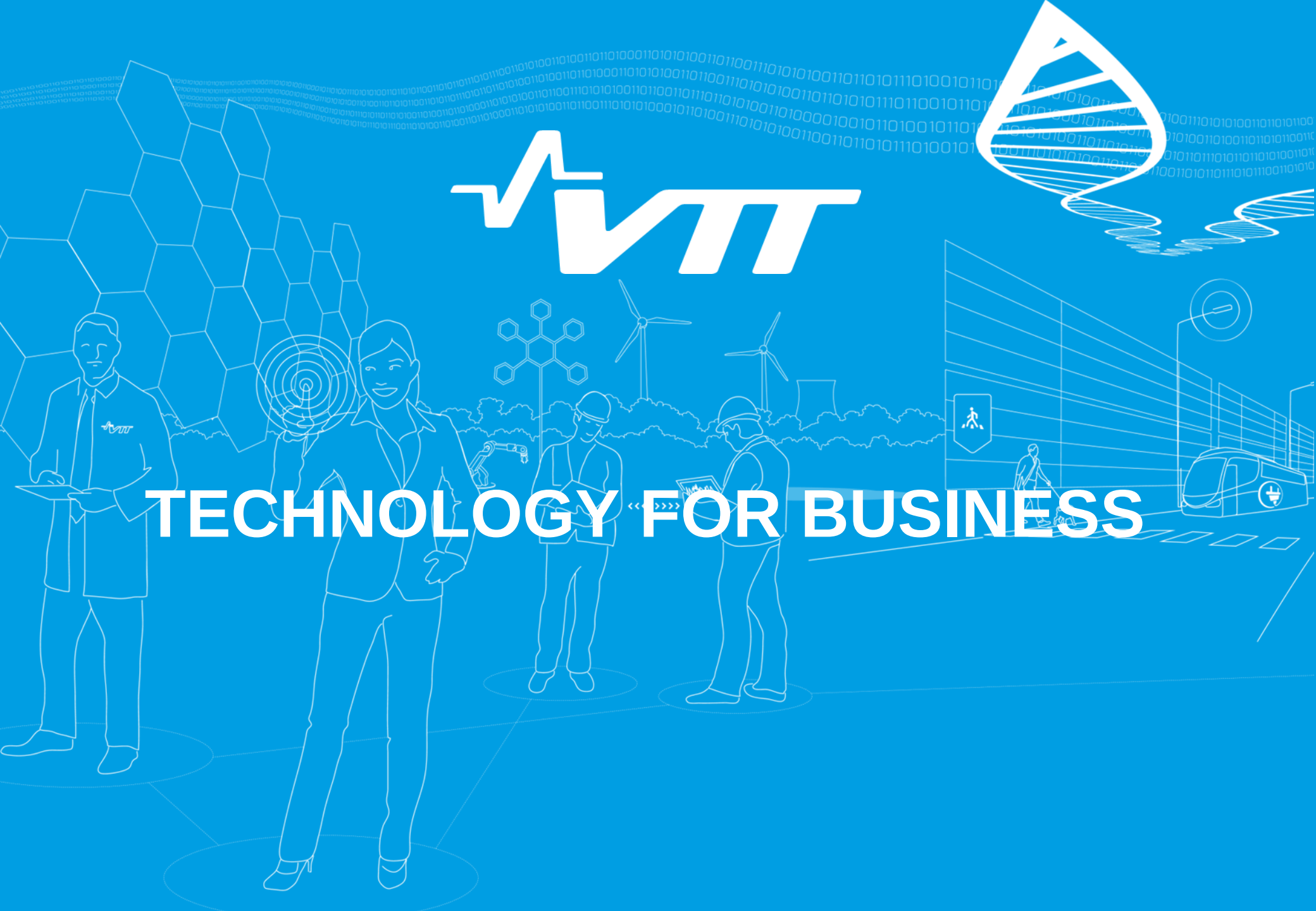
- Situational interpretation:
  - Success rate of situational assessment
- Navigational decision-making:
  - Number of collisions, emergency maneuvers required, unnecessary navigational actions
  - Number of situations requiring human operator assistance
  - Safe bypass distance
  - Safe distance to react
  - Reasonability of navigational actions (expert audit)
  - Clarity of navigational actions to other traffic

Other validation possibilities in ship handling simulator environment

- In addition to ANS validation, other aspects of autonomous vessels can be studied in the simulator environment:
  - Remote control (monitoring & operation)
  - Delay time in communications
  - What kind of data is provided from traffic model to ANS-ship? All information including for example all state vector components or only limited data?
  - Semi-autonomous operation with human operator on-board
  - Remote operator training

Summary

- Technology developer is responsible for demonstrating the safety of an autonomous vessel
- Simulator testing is an important method in producing the safety evidence
- VTT offers comprehensive risk assessment and usability expertise combined with advanced simulator testing facilities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