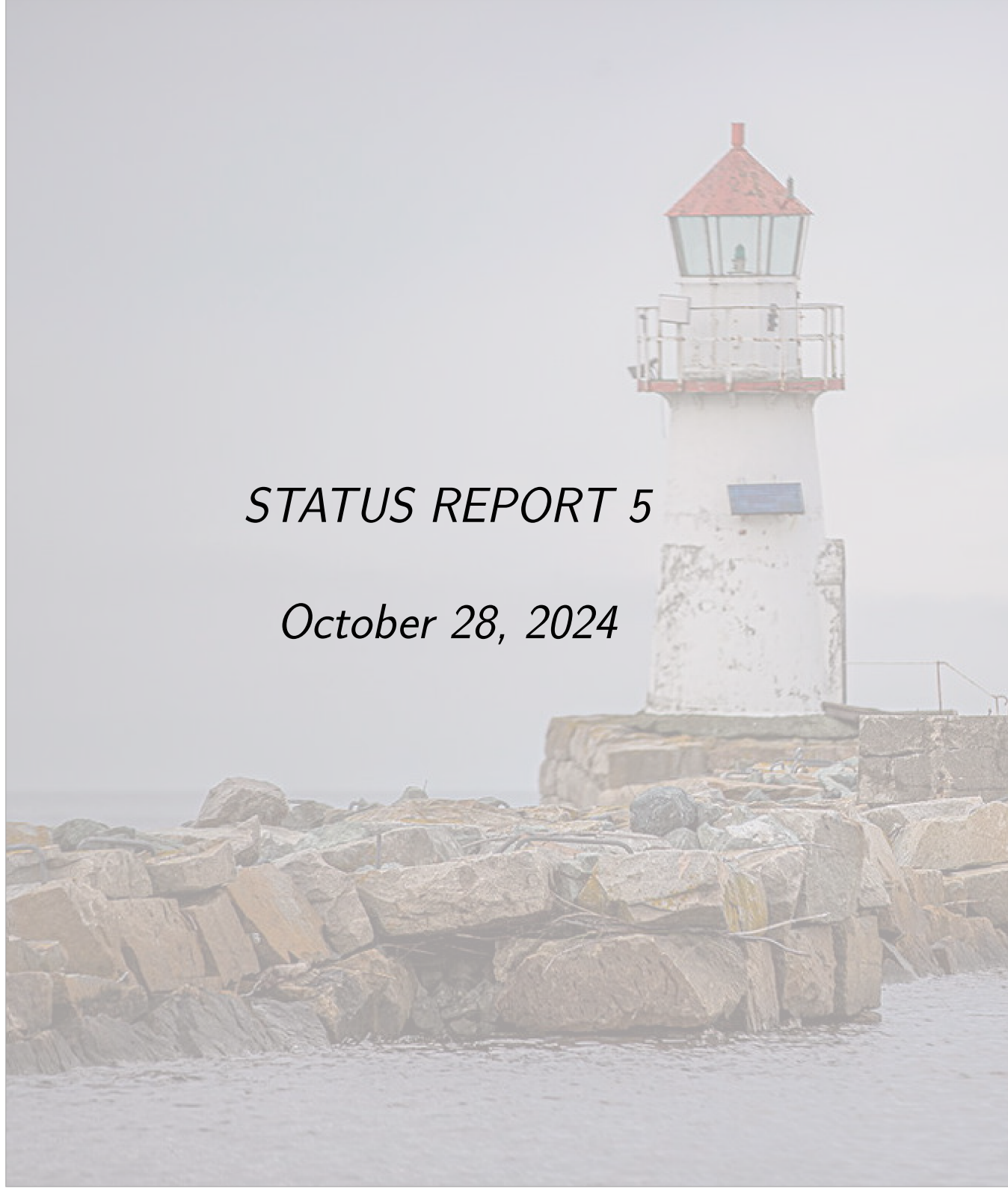

STATUS REPORT 5

October 28, 2024

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SEA

PREFACE AND CONTENTS

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Preface

This report summarises the work, both planned and executed, the results, and the findings so far in the project SEACo – Safer, Easier and more Accurate Co-simulations. This report is the fifth official status report in the project and will report on the news since the last status report.

The intention with these status reports is to inform the steering committee, as well as the advisory board, about the developments in the project. These status reports are classified as open documents and are freely distributable. The plan is to publish at least two status reports annually.

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OVERVIEW AND OUTLOOK

Project Metrics:

- KSP project
- September 2021 – April 2026
- 19.5 MNOK (5.6 MNOK to industry)
- **2024:** 6.9 MNOK
- 5 technical work packages
- International Advisory Board
- One Ph.D. candidate (NTNU)

Project Leader:

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SEA

Safer, Easier and more Accurate Co-Simulations

Project description

During the last few years, the maritime industry has started using co-simulation successfully to boost digital collaboration and innovation based on existing investments and knowledge. Still, several technical challenges remain, and collaboration is inhibited by tools that are often too complicated to use and not unified.

In the SEACo project, we aim to tackle these inhibitors of rapid digital innovation head on. We seek to contribute to more reliable and easier-to-use co-simulations of maritime systems by drawing on the knowledge and the skills acquired over the past decade. To ensure high interactivity and value creation, several key partners from academia and the industry are committed and eager to contribute: SINTEF, DNV, Kongsberg Maritime, Equinor, Aukra Maritime and NTNU.

The project consists of five technical work packages (WPs). A short presentation of each WP will be given in this status report.

Status

At the time of writing, Project Manager Stian Skjong is out on paternity leave, and Lars T. Kyllingstad is performing his duties until September when he is expected back to work.

The SECo project had a project workshop 5–6 September in Ålesund in 2023. The topic for the workshop was partner relevance and contributions, and we had lots of discussions about the focused areas in the project. All partners agreed that the project is still quite relevant and addresses important key questions within the scope of co-simulations that are relevant in industrial applications. Based on these discussions, work-plans for 2024 was created and approved in the steering committee meeting which took place 14th February this year. Since the project have had a slow start we have some work to do in order to catch up with our planned work.

Another workshop was held 24–25 April this year in Trondheim. Most of the workshop was spent in focused working groups dealing with the following three topics, each of which cuts across most or all of the project research areas:

1. How to collaborate on case studies in practice (tools, platform, etc.).
2. Model assurance in co-simulation.
3. Modelling a ship and its environment.

Magnus Steinstø, the project's Ph.D. Candidate, who started May 1st, is well underway doing his mandatory subjects at NTNU. His Ph.D. topic will involve all work-packages in the project, but with a main focus on WP3-WP4, also introducing structural analysis and CFD simulations to the work-packages' problem formulations. We will involve him more in the research objectives in the rest of the project period when he has completed most of his mandatory Ph.D. work. Since Magnus was employed late in the project, we have applied for a project prolongation to also include all the Ph.D. work, which is scheduled to last until 31th April 2026. Note that at this stage

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Project Leader:

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we only plan to have budget for 2025 in the project, except NTNU.

SEACo will be presented at two conferences this year, the ICMASS conference taking place in Trondheim in October, and the ICBGM conference taking place in San Diego in July. In addition, a few journal articles are in the pipeline and expected to be submitted for the review by the end of this year.

Outlook

The summer holidays are closing in and the next action in the project is to present *Energy Conservation and Co-simulation: Background and Challenges* on the ICBGM conference. We have now about 1.5 years left in the project when neglecting the project extension due to the Ph.D. candidate. We believe that close collaboration between research institutes and industry, both domestic and international, is crucial to fulfil the project's deliveries and vision.

IDENTICAL ENVIRONMENTAL CONDITIONS

Work Package Metrics:

- WP number 1
- 14.2% of total budget
- 1000 000 NOK in 2024

WP Leader (temporary):

Lars T. Kyllingstad
Senior Research Scientist
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Description

In this work package we will seek to standardise the description of environmental models for current, wind, and waves as used in most maritime co-simulation systems and develop a standardised co-simulation interface for each. Added focus is put on waves because of their higher complexity and fidelity. Transitions between sea states pose an additional challenge, as simply changing parameters causes abrupt changes in the sea state realisation.

For multiple models to share the same environment one typically can either share values (e.g. sharing the surface acceleration for given positions) or formulations (e.g. parameterised predefined models). These approaches have different pros and cons, such as the ability to include vessel-generated waves or estimating values between time steps. It is therefore possible that multiple sharing strategies should be available, to suit different use cases.

Another important issue is to what extent extensions to the standards can be proposed to facilitate more efficient environment sharing strategies.

Status

Progress in this work package has been slow due to an unforeseen personnel shortage. Early in the year, we continued the work from 2023 on choosing a way in which to compactly *specify* an environment, and a way to *realise* a specified environment in an unambiguous manner. Two methods have been investigated based on sharing a realisation of the environment or sharing the methods to transfer statistical descriptions of the environment into realisation of the environment.

What we mean by the latter is that if two or more subsystems are given the same environment description, they should all end up with the same values for variables like surface elevation, current velocity and so on at given points in space and time. A prototype implementation of this in the form of a C++ library named *MarEnv* has been developed. The idea is that any model which wants to support "SEACo-conforming" environment sharing can call on this library. (To that end, the library will eventually be released as Free and Open Source Software.) The environment description, the accompanying algorithms for realising the environment, and the *MarEnv* library interface must at minimum support all the use cases defined by the SEACo project.

The former method involves transfer of environment realisations between models. This method is "tried-and-tested" in several projects where ship simulations are integrated with other models. A mock-up environment object has been implemented where wave realisations in the form of amplitudes, directions and frequencies are outputs coupled to other model inputs. To test this method a kinematic and dynamic ship model has been developed based on R/V Gunnerus where the kinematic model provides displacements and velocities and the dynamic model incorporates the influence of external forces (eg. crane reaction forces, propulsors and moorings). A post-processor visualisation of Co-simulations of the environment

IDENTICAL ENVIRONMENTAL CONDITIONS

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WP Leader (temporary):

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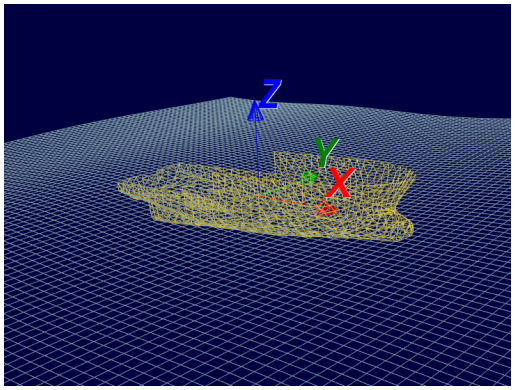

Figure 2.1: Visualisation of dynamic ship in realised environment

and ship FMUs has been implemented in VTK and Python and is seen in Figure 2.1.

Progress of current activities

Planned
Actual

Identify models: Identify relevant environmental models through literature study and project group discussions. Document the identified environmental models, with pros and cons for use in co-simulation.

Investigate sharing strategies: Identify possible sharing principles and their pros and cons when applied to different scenarios and models, implement proofs of concepts, and document the most promising strategies.

Implement sharing: Implement the relevant environmental sharing strategies, for the purpose of testing their applicability for co-simulation and widespread use.

Plans for next period

The planned activities for the next period are to:

- Gather feedback through project workshops
- Test the implementation in increasingly realistic cases
- Distribute prototype ship and environment FMUs to project partners
- Improve the methods and implementation based on feedback and testing
- Improve the VTK based visualisation tool to aid debugging

COORDINATE SYSTEM TRANSFORMATIONS

Work Package Metrics:

- WP number 2
- 8.0% of total budget
- 510 000 NOK in 2024

WP Leader:

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Description

In this work package, we seek to establish a method for communicating and solving coordinate system representations between independent models reliably. The aim is to detect whether a given transformation can be safely performed outside the models when time lags cause no issues. In cases where this is not possible, the work packages seek to find the best method for performing the transformation without introducing significant inaccuracy.

Status

To address the challenges associated with coordinate transformations, internal interviews were conducted within SINTEF Ocean. These interviews revealed that merely mapping the relevant coordinate systems is insufficient. Consequently, an in-depth study was undertaken to examine the requirements and difficulties of both static and dynamic coordinate system transformations. This study highlighted the key challenges and potential solutions.

To further assess the needs and requirements for coordinate system transformations, a realistic use-case was established, as shown in Figure 3.1. This use-case is well-known in the offshore wind turbine maintenance industry, where the goal is to align the DP vessel and the crane/gangway perpendicularly to the wind turbine landing spot. This scenario involves various coordinate frames, representations, and connections, effectively illustrating the complexity of coordinate system transformations. FMUs for the DP vessel, crane/gangway, and turbines have been developed and are ready for co-simulation. To facilitate comparison, the same models have been implemented in MATLAB/Simulink, providing a monolithic simulation environment where timing issues such as time-lags are not a concern.

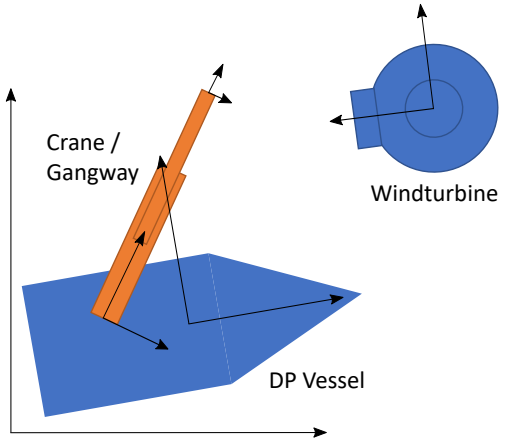

Figure 3.1: Overview of FMUs and coordinate frames in WP2 use-case.

In addition to the 3-DOF use-case depicted in Figure 3.1, a simplified 1-DOF version is also presented to deepen the understanding of the fundamentals of coordinate transformations, focusing solely on heave motion.

To gain diverse perspectives on the topic, several informal workshops were organised with participants from various backgrounds. The insights and findings from these workshops, along with other elements discussed, were thoroughly explored and summarised in a paper

COORDINATE SYSTEM TRANSFORMATIONS

Work Package Metrics:

- WP number 2
- 8.0% of total budget
- 510 000 NOK in 2024

WP Leader:

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submitted to the MTEC/ICMASS 2024 conference in Trondheim [1].

Progress of current activities

Planned
Actual

Static transformations: Describe static transformation in co-simulations.

Dynamic transformations: Describe dynamic transformation in co-simulations.

Transformation ontologies: Develop ontology for coordinate system transformations.

Plans for next period

The budget for 2024 has been exhausted, so not much will be done until Christmas. However, we have sufficiently covered static and dynamic transformations and are prepared for the next step after Christmas. With the knowledge gained, the next step will focus on proposing an update to OSP-IS to cover coordinate transformations. The most promising approach is to define all relevant reference frames, such as vectorial notations (Euler angles) or quaternions, specific reference frames like North-East-Down (NED) or Earth-Centered Inertial (ECI), and then require all FMUs to specify their frame type. The system connector can then use this information to correctly connect all the FMUs using predefined available transformations to set up the overall co-simulation.

Based on the proposed OSP-IS coordinate system ontology, a paper will present these ideas with the use case previously discussed. The paper will summarise the findings in this WP, covering static and dynamic transformations. The expected outcome is a mapping of the metadata that must be associated with FMUs and their input or output signals to facilitate the automatic detection of coordinate system representations and determine what transformation, if any, must be applied.

MODULAR TIGHTLY COUPLED SYSTEMS

Work Package Metrics:

- WP number 3
- 22.9% of total budget
- 1 550 000 NOK in 2024

WP Leader:

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Description

There are several examples of interesting maritime systems that are *tightly coupled*, such as the connection between a ship's hull and its crane. Such systems are by nature poorly suited for co-simulation, and attempts to do so will usually be riddled with stability and performance issues. Still, the advantages of co-simulation are so many that it is worth investigating how to tackle these issues.

In this work package, we will perform a systematic study of tightly coupled maritime systems. We will examine the effects of different types of simulation techniques and algorithms and consider their suitability in a practical industrial setting. Based on the results, we will develop model interfaces to support modular modelling and co-simulation of tightly coupled systems.

Status

There has been no activity in this work package in the last period, because the relevant personnel have had to focus on WP1 and WP4. The current status is therefore unchanged since the previous status report: We are studying the toy model shown in Figure 4.1, which is intended as a highly simplified and idealised abstraction of a ship–crane system. We have tested three methods for resolving the tight coupling between the two masses in the model: 1) inserting a damped spring between the models, 2) using a low-pass filter with derivative effects, and 3) applying a PID controller.

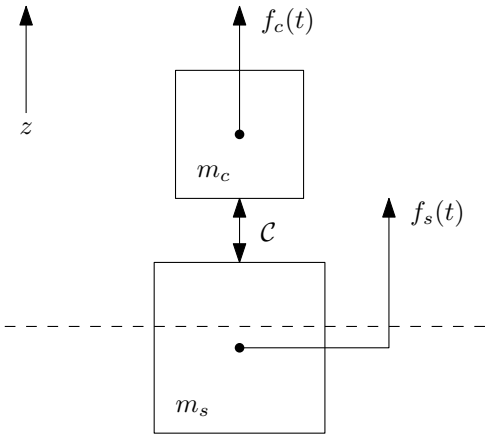

Figure 4.1: Toy model for the ship–crane system. The dashed line represents the "sea level".

Progress of current activities

Planned
Actual

Model selected systems : Extending the 1DOF models with higher degrees of freedom.

Perform simulations and analyse results: The 1DOF models have been simulated and to some extent analysed. The work will be continued also incorporating the models with higher degrees of freedom in the study.

MODULAR TIGHTLY COUPLED SYSTEMS

Work Package Metrics:

- WP number 3
- 22.9% of total budget
- 1 550 000 NOK in 2024

WP Leader:

Lars T. Kyllingstad
Senior Research Scientist
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Plans for next period

We will continue to study the selected system and methods, also extending the study to involve models with higher dimensionality. The goal will be to understand the advantages, drawbacks, and trade-offs associated with each method in terms of accuracy, simulation speed, stability, and so on. If possible, the simulation results will be compared to analytic studies of the system. Specifically, we will investigate the relationship between *method parameters* (e.g. stiffness and damping), *system characteristics* (e.g. the relative mass and position of ship and crane), and *user requirements* (e.g. accuracy and speed).

MORE ACCURATE AND RELIABLE CO-SIMULATIONS

Work Package Metrics:

- WP number 4
- 21.3% of total budget
- 1 350 000 NOK in 2024

WP Leader:

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Description

The *energy-conservation-based co-simulation method* (ECCO) monitors the flow of energies between models, estimates co-simulation errors reliably, and chooses optimal co-simulation step sizes to control efficiency and accuracy. It poses no additional requirements on the models (such as re-stepping or interface derivatives) and can be used for any power bond connection between models. As such, it presents a promising choice for an easy-to-use and robust co-simulation algorithm. Here, we aim to extend the theory of energy-based co-simulation algorithms to make them more useful and more powerful.

Status

The first half of 2024 was fully devoted to producing publications and fulfilling deliveries:

Submission The paper *Energy Conservation and Co-simulation: Background and Challenges* [2] was written, submitted, and accepted for publication with the International Conference on Bond Graph Modelling and Simulation, San Diego, California (1–3 July 2024).

Manuscript The manuscript *Error estimation and step size control with minimal subsystem interfaces* has been completed and will now be submitted to the journal *Mathematics and Computers in Simulation*. It aims to provide practical guidance on how to estimate and control co-simulation errors with a focus on minimal model and user requirements.

Submission Though not directly related to WP4, the manuscript *Adding higher-level semantics to Functional Mock-up Units for easer, faster, and more robust co-simulation connections* was revised and re-submitted to the Springer journal *Software and Systems Modeling* and is currently under re-review.

Progress of current activities

Planned
Actual

Publication: Energy Conservation and Co-simulation: Background and Challenges (D4.0)

Publication: Error estimation and step size control with minimal subsystem interfaces (D4.1)

Publication: Optimal multi-rate step size control (D4.2)

Publication: Energy-conserving input corrections (D4.3)

Implementation: libcosim demon-

MORE ACCURATE AND RELIABLE CO-SIMULATIONS

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strator (D4.4)

Plans for next period

The WP4 budget for 2024 is to a large extent exhausted, but if budgetary constraints allow results obtained for the work on stability and energy-conserving input corrections on one hand, and multi-rate step size control, on the other hand, will form the basis for at least two more WP4 manuscripts. In addition, libcosim implementations are planned to continue again with testing different multi-rate schemes as well as energy-conserving input corrections.

TESTING AND VERIFICATION

Work Package Metrics:

- WP number 5
- 13.1% of total budget
- 950 000 NOK in 2024

WP Leader:

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DNV Group Research and Development
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Description

The assurance of complex systems and operations based on simulation models requires established trust in chosen simulation technologies. Here, we will develop and implement a case study for testing and demonstration of the methodology developed in WP1–WP4. We will also develop efficient methods for independent verification of the fitness of given component models and simulation configurations.

All the aforementioned work packages will provide input to a joint case study specified in this work package, e.g. a marine operation where a load is transferred between two floating platforms, one of which is a ship that carries the lifting crane. This case involves all the project's research areas, as it requires a shared sea environment for the floaters, multiple frames of reference (global, ship bodies, payload), and centres on a quintessential tightly coupled system (ship and crane), all of which pose a significant challenge to co-simulation stability and accuracy. To keep the required models manageable it is planned to implement minimal sub-models as a first stage. When these sub-models work satisfactorily they will be collected into the final use-case model.

Status

The total status is provided as description list with the start year as part of the descriptor. The list will be updated throughout the project.

2022. Assurance of Simulation Models Training
A basic training on the DNV-RP-0513 'Assurance of Simulation Models' was provided, basic versions of the system conceptual model and the conceptual models of the most important component models were established. The importance of qualification of conceptual models as part of the quality assurance of models is evident.

2022-2023. Contributions to OSP Conference
Contributions to the OSP conference about testing and verification were provided to the OSP conferences of Nov. 2022 and Nov. 2023.

Understanding and updating PythonFMU
Related to the initial OSP project a Python package PythonFMU was made and published (see PythonFMU). For both OSP research and OSP projects it is important to be able to construct FMUs "on the fly", where PythonFMU should be a suitable tool. In addition, SEACo wants to test how model assurance work might be done while developing a model, where Python seems to be a suitable starting point. FMUs contain their published (interface) information in the modelDescription.xml file. The information in this file is also needed for model assurance, but also additional information should be addressed and included (e.g. Risk Analysis information) in what we call the *Design Contract*.

Unfortunately the PythonFMU package

TESTING AND VERIFICATION

Work Package Metrics:

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WP Leader:

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is currently rather unsupported, as their makers have moved on. In SEACo we are currently providing updates like support for units, support for compound variables (vectors) and extensions with respect to assurance activities. These additional features are supported through the package *component_model*, which will be published as open source package and as part of the SEACo project. Extended FMU building abstraction requires also additional changes to the PythonFMU package. Both updates to the PythonFMU package and the *component_model* package will be published Open Sources after the summer 2024.

pyCrane As decided in 2022, a crane FMU model has been designed for usage in the SEACo use cases and for permanent storage among the OSP basic models. A first attempt for designing the crane using symbolic computation and Lagrangians has turned out unsuccessful, as the model initialisation time grows exponentially with the number of crane booms and the required results which are to be reported back. A second approach using basic Newton Mechanics has proven successful. The crane model is developed based on the component_model package and packaged as FMU through PythonFMU. A first working version of the pyCrane FMU does now exist. More model testing will be performed through the rest of the year (crane on fixed support). The pyCrane package will be published Open Source after the summer 2024. It is expected that other partners can then use this to further test SEACo methods with respect to cranes mounted on a movable surface.

case_study To arrange single simulation experiments within OSP, the built-in scenario manager can be used. Unfortunately the user interface is rather cumbersome (more like a programming language) and its abilities are limited. A more user-friendly simulation experimentation tool, called *case_study* has therefore been developed. A first version of this python package will be released as Open Source before the summer. This includes also a first instance of a pyCrane FMU, called *MobileCrane*, together with a case study example of this crane. The package will later be further developed with respect to expected results, enabling automatic system model testing and the assurance that model changes do not break models.

Progress of current activities

Planned
Actual

PythonFMU updates: This is ongoing work which is basically open-ended. For the SEACo project most issues should be resolved. To be published 2024-Q3.

TESTING AND VERIFICATION

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component_model development: This is ongoing work which is basically open-ended. For the SEACo project the so-far needed features are implemented. To be published 2024-Q3.

pyCrane: The first FMU-packaged version of pyCrane will be released 2024-Q2. The fully configurable base package of pyCrane will be published 2024-Q3.

case_study: The first release is currently finalized and will be released 2024-Q2.

Plans for next period

The following activities are planned for the second half of 2024:

Testing of crane model in connection with vessel When the crane model is mounted on flexible/moving base, most of the SEACo issues (see WP2 to WP4) kick in and need to be resolved. That is also the reason why the crane was chosen in the first place as a use case. We are planning to experiment with that problem and its solution in steps from mounting the crane on a vessel with simple movement to including the crane in the full system, including e.g. also advanced environmental effects. The solutions suggested in the other work packages will thus be tested, scrutinised and verified. This activity is delayed due to the development of the experimentation platform *case_study* but we expect that this same tool will make the experimentation of the crane+vessel much more efficient.

Collaboration with Aukra Maritime As planned, the crane model shall also be used for industrial purposes. This will be tried out in collaboration with Aukra Maritime.

Follow-up of the other FMUs needed for the planned use case(s). The producers of the other FMUs have been appointed in the SEACo workshop September 2023. Some of these FMUs are already in use, but for others more-follow-up work is needed so that the planned minimal use cases can be implemented and used to test SEACo challenges and techniques. At least one system model (minimal use case) should be available for each WP during 2024.

Link to the PhD project There is already established good contact with the PhD project. The crane and its related use cases are identified as good starting point in relation to the PhD project. Since the actual PhD work will start up in the second half of 2024, the contact will then be taken up again through regular meetings. Concrete tasks must be agreed upon, but it is expected that the crane model (within the use case), the overall use case model and assurance activ-

TESTING AND VERIFICATION

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WP Leader:

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ities will play an important role. These will then be followed up within this work package.

Identification of efficient assurance methods For an assurance recommendation to have practical value, the employed methods must be efficient. There should never be doubt about the value the assurance activities add to a project. While this vision makes sense, it is hard to achieve in practice. As a continuous activity in the project we will add and test methods and tools which increase the efficiency of assurance methods. The ideas in this respect span from efficient/automatic testing to efficient model documentation. The assurance needs will put special focus on SEACo issues, as specified in the other work packages.

Identification of RP improvements The issues addressed in SEACo (see WP1-WP4) are important for co-simulation in general and especially of marine systems. DNV wishes to keep our RP-0513 updated with respect to important simulation issues. The updates should be twofold:

1. A checklist on how to identify SEACo issues in simulation models
2. A list of test methods to verify that the issues are properly addressed

Assistance in OSP implementations Assist in the implementation of dedicated algorithms for use in the SEACo project within OSP. This work has already begun and will be continued in 2024.

ACTIVITIES, COMMUNICATION, AND DISSEMINATION

This section lists all activities, communication and dissemination throughout the entire project period. Also, additional project information for the status report period, if any, is listed.

Additional resources:
SEACo project card
OptiStress project card
fmiCpp
OSP website
OSP conference 2022: Presentations
DNV-RP-0513
ViProMa website
Other publications
FhSim

Activities

2021

1 Sep.	Project start

2022

20 Jan.	Kick-off (online meeting)
7 Feb.	Advisory board meeting
3 Mar.	Presentation of DNV-RP-0513
11 Mar.	Steering committee meeting
22–23 Sep.	Physical workshop in Trondheim, lunch-to-lunch-meeting
31 Oct.	Steering committee meeting
15 Nov.	Annual OSP conference, held in Ålesund, hosted by SINTEF Ålesund

2023

22 Feb.	WP4 workshop in Trondheim
1 Aug.	KSP project OptiStress started
5–6. Sep.	SEACo workshop in Ålesund
(**13 Nov.**	Kick-off in OptiStress, Ålesund.)
14 Nov.	Annual OSP conference, held in Ålesund, hosted by GCE Blue Maritime

2024

14 Feb.	Steering committee meeting
24–25 Apr.	Project workshop in Trondheim

ACTIVITIES, COMMUNICATION, AND DISSEMINATION

This section lists all activities, communication and dissemination throughout the entire project period. Also, additional project information for the status report period, if any, is listed.

Additional resources:
SEACo project card
OptiStress project card
fmiCpp
OSP website
OSP conference 2022: Presentations
DNV-RP-0513
ViProMa website
Other publications
FhSim

Publications

2022

[3] Stian Skjong and Eilif Pedersen. "A distributed object-oriented simulator framework for marine power plants with weak power grids". In: *Journal of Marine Engineering & Technology* 0.0 (2022), pp. 1–13. DOI: 10.1080/20464177.2022.2120171. URL: https://doi.org/10.1080/20464177.2022.2120171.

2024

[1] Severin Sadjina et al. "Coordinate transformation techniques for improved co-simulation in the maritime industry". In: *Proceedings of the 6th International Conference on Maritime Autonomous Surface Ships*. ICMASS 2024 (Trondheim, Norway, Oct. 29–30, 2024). Manuscript submitted for publication. 2024.

[2] Severin Sadjina et al. "Energy conservation and co-simulation: Background and challenges". In: *Proceedings of the 2024 International Conference On Bond Graph Modeling And Simulation*. ICBGM'24 (San Diego, CA, USA, July 1–3, 2024). Manuscript submitted for publication. 2024.

Additional information

- Karl Gunnar Aarsæther (UiT), a former SINTEF employee, will contribute in WP1 from SINTEF's side.
- Stian Skjong is in paternity leave from 27 May to 30 September this year. Lars T. Kyllingstad will step in for him while he's away.

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