A reflection on the use of A3 architecture overview in designing Wave Energy Converters

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***Abstract*— this paper is a reflective paper on what we learned through the course called Systems Engineering Modeling and Analysis (SEMA). Through the course, we applied modeling in an incremental product development process. The paper uses examples and reflection on the application of model based systems engineering in the company CorPower Ocean. They are working on a new product development of a wave converter, called Wave Energy Converter (WEC). The framework used through the course is the CAFCR+ model. The teams iterated through the different views of the model several times by the help of time-boxes and flip-overs. Through a 10-week post assignment, the models were elaborated further and we ended up with four A3s; one for the overview of the system, one for the installation operation, one for the maintenance operation and one that illustrates part of the maintenance operation in more detail. Stakeholders at CorPower Ocean use these A3s as a communication and discussion tool.**

Keywords—model based systems engineering, modeling, CAFCR+, A3

I. Introduction

The principal objectives of modeling are to maintain the communication with and between the stakeholders, make it easier to give reasons about the system requirements, support the decisions making and provide understanding, knowledge and overview of the system that is addressed [5]. Cernosek and Naiburg state *the value of modelling is to better understand the situation, to craft a better system, to build and design a system architecture and to create visualization of the implementation* [1].

This reflective paper discusses how models can be used as a communication and discussion tool between stakeholders and how models can contribute to reach design decisions for the system-of-interest.

The system-of-interest through this paper is the Wave Energy Converter (WEC), a product developed by CorPower Ocean. CorPower Ocean was founded in 2009 and has since been developing a new type of wave energy converter with a unique design. They are now *standing on the brink of a major breakthrough in terms of redefining the efficiency of wave energy generation [2]*.

As a company of young age, they have not yet incorporated systems engineering in their company, but they are aware of the great potential of what it could bring to them. They have therefor this fall hired a part-time student from the three-year systems engineering industrial master offered by the University College of South East Norway (HSN).One of the main tasks of the student will be to maintain the communication between the stakeholders and provide overview of the system; the modeling approach was therefore of great interest to the company.

Often in complex projects, the engineers and stakeholders have a tendency to stay indistinct and vague because of the complexity. This often causes people to delay design choices out of fear instead of making conscious decisions. The project was in the system design phase for a half-size model, which is a phase with many uncertainties and many options adding to the complexity. This became clearer later when we increased our insight in the system and the company.

From an outside perspective, it seems that they have used much time focusing on the converter itself, while investing little in an explicit holistic view of the system. They are now facing problems and difficult design decisions, such as how to install and maintain the WEC. If the design team keeps staying vague and leaving too many design options open, then the insight of these operations can become restricted and the problems may stay hidden [5]. A countermeasure is to make the problems more tangible and explicit. The aim of this paper is therefore to show how models can contribute to make problems more tangible and explicit to help in developing a holistic perspective of the system-of-interest.

A student in Industrial Economics, part time student working at CorPower Ocean, and the teacher of the course wrote this paper. The paper is based on the work for the course on this real case at CorPower Ocean.

II. Case description

During the SEMA course and the following 10-week assignment, the students in the team had to model a system with some actual challenging problems. The team did not know the system and its problems in advance of the course. The part-time student still had to start working in CorPower Ocean. The team therefore identified the problems throughout the five-day course.

This case study focuses on the installation and maintenance operation of the WEC. The operations have not been tested or launched and are still on the conceptual level.

Figure 1 shows a WEC, which is a buoy of about 4 meters in diameters with inside the buoy the actual converter. The converter transforms vertical oscillations into rotational movements, which in turn are transformed into electricity. A mooring system keeps the buoy in place. The Power Take-Off (PTO) can be removed from the buoy to gain access. The WEC has a total mass of 15 tons.

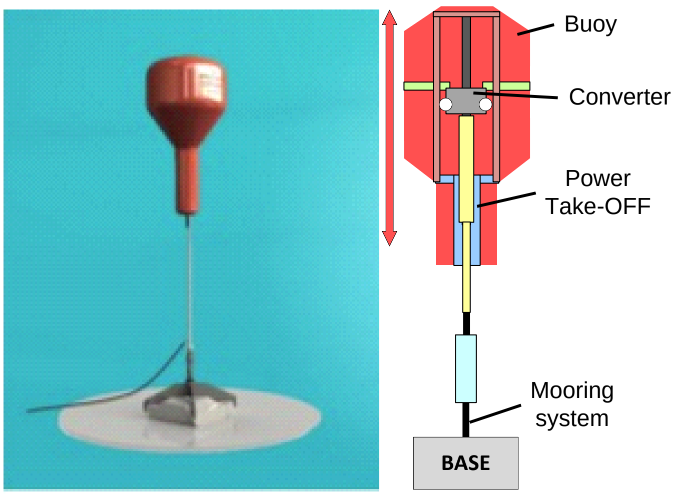

Fig. 1. FIllustration of the WEC

CorPower Ocean plans in 2016 a first time ocean deployment. They are now developing the transportation and installation systems of the WEC. The transport has multiple phases: on land, into the water, in water, to the right location. They are also developing the maintenance operation especially regarding how they should retrieve it from the water when it arrives at the dock and how they should retrieve the PTO from the buoy.

Through this paper we do not aim to arrive at a final solution, we hope that the visualization by using models will shed light on the many concerns and challenges that CorPower Ocean should address before the first time ocean deployment, in order for it to be most successful.

III. RESEARCH METHODOLOGY

The modeling and analysis methods and techniques used and reflected on were researched by applying them in the classroom. The teacher guided the students through the modeling approach during five days. The students formed teams that performed the tasks and discussed them. The team elaborated the results in a10-week post-course assignment after the five days course.

CAFCR+

The CAFCR+ model was used as framework [7]. The framework provided guidance for what to model and it helped to get a broader view. This enabled the teams to not only focus on the system-of-interest itself, but also on other important surrounding aspects.

Figure 2 illustrates the views that are included in the CAFCR+ framework. The *Customer Objectives* and *Application* views made the teams resonate on *who* are the customer, *what* does the customer want to achieve and *how* does the customer achieve these objectives. In the *functional* view, the system- of-interest is seen as a black box. Here the system requirements were described, which included the functionality, interfaces, restrictions and boundaries and the quantified characteristics of the system.

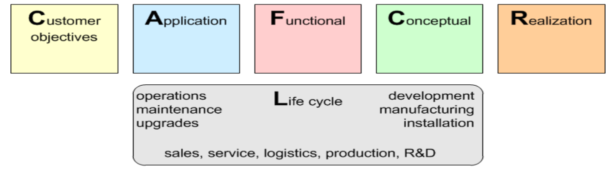

Fig. 2. Views in the CAFCR+ framework.

With the *conceptual* and *realization* view the teams described the *how* of the system. The *life cycle* view enabled them to get a holistic perspective of the system as this view wants to describe the *what* and *how* of the system through the entire life cycle from creation up to disposal. This view was especially helpful for the system-of-interest addressed in this paper, as CorPower Ocean had not considered the production and maintenance operations in the same extent as the product itself.

Flip-overs and time-boxes

A short theoretical foundation was introduced before each step of the modeling approach. Then we made several fast iterations over the different views throughout the course. We also zoomed in and out of the different views. To make the discussions and drawing easier and faster we used flip-overs. The use of flip-overs was a good tool as it allowed us to sketch and not focus on making the diagrams or figures perfect. It therefore prevented us from drawing and discussing unnecessary details. We also used the flip-overs as memory, since we fixed the flip-overs to the wall. In that way, we could always look at what we had discussed and modelled in the earlier session. Each team gave at the end of each session a presentation, regarding the discoveries and concerns. All the teams agreed that the use of flip-overs made it easier to present the discoveries, but also to get feedback.

The iterations of the CAFCR+ model were performed through 10 sessions where different sub - models were used in each session [8, 9, 10].

The 10 sessions made us iterate three times over the views, but this could not have been possible without the use of time-boxes. The team wanted to finish each view before continuing into the next, the teacher prevented this by giving us a limited duration to use on each view. The duration varied from 15 minutes to one hour for each task throughout the whole course. This prevented us to focus on unnecessary details and to dive too deep into each view.

Post-course assignment

After the course, we conducted a 10-week post-course assignment. Through the assignment, we elaborated the most relevant models, and we searched for answers to the main questions, uncertainties, and unknowns. The team chose to use A3 architecture overview in the post-course assignment. An A3 report is a 29.7 x 42.0 cm piece of paper outlined in several structured sections. The exact structure depends upon the type of A3 and the needs of the situation. An A3 is a simple way to capture data and information and to visually communicate information [12]. The idea behind using A3 in this paper is that the format is large enough to support multiple views. It also forces the creators to focus only on essential information due to the limitations in size [11,12]. At the end, four A3s presented the result.

IV. THE FIRST ITERATION

Through the first iteration the team had time boxes of 15 minutes to scan each view in the CAFCR+ model [8][9][10]. Instead of starting at the top we worked upwards by asking why questions. What we discovered was that many of the questions that popped-up relate to the views in the earlier steps. The time-boxes did not allow us to answer these questions now; they later iterations will address them. The quick scan over all views was especially helpful for us, as we did not have a lot of insight about the system beforehand. This enabled us to get an overview of the system in a short amount of time.

V. STORY TELLING AS A WAY TO DISCOVER CRITICAL ISSUES

After the first iteration, the team was introduced to storytelling. A good story can foster understanding of an underlying issue and engage stakeholders in the development of system design [4]. A story can make the use or implementation of the system alive and it should entirely address the problem area. A story will function as a way to create relevant discussions [5].

To create a good story there are several points of attention. It is first important to define the stakeholder in the story and from which view we are telling the story. It is also easier for the people to "feel" the story if the character is described by name, age, duration, title and so forth. The writer will have to define the scope of the story; is it a specific event or an umbrella? It is also important to communicate what are the difficulties and challenges. Finally, the story has to be understandable and it should only take a few minutes to read it. A good advice is to use sketches or cartoons so the reader can more easily visualize the story [5].

In this story, we meet Bob, a 54-year-old maintainer working for CorPower Ocean. Bob needs to maintain a WEC and the story follow his workday from leaving his house in the morning until he is finished with the maintenance operation. The story portrays the many challenges Bob faces through his day at work and his frustrations regarding the maintenance operation.

To fulfill the important quality, described in the previous section, of reliability of the system, the maintenance and installation operation are critical aspects to address. This is what the story wants to visualize. The story tells about the concerns and challenges regarding, mostly, the maintenance operation, but we also realized that many of the same problems would appear during the installation operation.

Regarding the credibility level of the model it is important to know that the story takes place in an imaginary world and can therefor differ from how the system and persons can act and react in the real world. The ones telling the story will also be subjective to their own thoughts regarding what can be the underlying issues in the problem domain.

Storytelling still allowed us to "experience" how it was to work with the system and it made it easier for us to collaborate effectively. We also felt that it was easy to use the story as a way to get feedback regarding the problems from the other teams in the course.

VI. A VARIETY OF SUB-METHODS FOR EACH VIEW

Several sub-methods were presented for each view in the CAFCR+ model throughout the course. Not all the sub–methods will be presented. The paper only includes the sub-methods from each view that address the two operations and that have been helpful to create the resulting four A3s. Another remark is that the order that the sub-methods are presented in below will not necessarily be consistent with the order that was used during the course and the assignment.

A. Functional view – SMART key performance parameters

A use case describes how a user uses the system to achieve a goal [5]. Use cases are a valuable tool as they facilitate analysis and design, and verification and testing. It is especially useful to see what the limits of the system when describing worst-case use cases. The use case can therefore describe in which situations the limits occurs. Note that this notion of use case is significantly broader than current usage in SysML, where many designers only describe functionality.

Use cases are helpful in order to give quantitative descriptions of the system, especially for performance [6]. Even though the story telling described earlier is not a use case we identified many boundaries in the system. The team was therefore able to define 10 SMART key performance parameters for the maintenance operation.

That a performance key parameter is SMART, means that the parameters have to be Specific (quantified), Measurable (verifiable), Achievable, Realistic, and Time-bounded.

The team identified the following 10 SMART performance key parameters for retrieving the buoy from sea to do maintenance:

1. Maximum wave level < 6 meters
2. Wind speed < 17 m/s
3. Crane capacity of 80 tons
4. The crane shall have a dual function
    - one function must lift the buoy
    - the other function must hold the cable connecting the buoy and the mooring
5. Space between the buoys shall be at least 80 meters
6. There shall always be at least 2 persons operatingthe boat
7. The boat shall manage storage/equipment load of at least 160 tons

8. The boat shall be able to handle two buoys at the same time.
9. The maintenance time shall take maximum 3 hours
10. The crane shall have a lift height of minimum 16 meters above the deck.

More correct numbers, should replace the quantification of the parameters that we defined as these are only coarse estimates,. The accuracy and credibility level of the parameters are low. The list above is rather an indication of which parameters we have to consider and which are affecting the system when designing the installation and maintenance operation.

B. Customer objectives - Customers key drivers graph

Customer key drivers can capture the objectives of the customers. The value of using the key driver method is that the method relates key drivers to a long list of requirements. It will be easier to understand the customer and product requirements by finding these relations. [5]

The first step is to define the specific scope in relation to stakeholder or market segments. The second step is to obtain facts. We therefor began at the right hand sight and analyzed the requirements established for the system by asking why questions, see Figure 3. The scope in this example is safety regarding the maintenance operation. For the scope we found several requirements through the functional view. Two examples are: "the wind speed shall be less than 14 m/s" and "the space between the buoys shall be more than 80 meters". We then asked ourselves why we need these requirements.. The third step is to build a graph, which relates the drivers and requirements, it is important to know that one requirement can have several drivers.

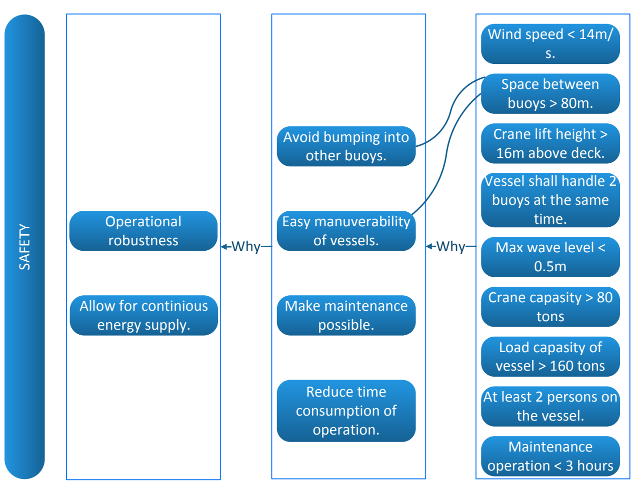

Fig. 3. Steps in the key driver graph

After asking why questions about the requirements we discovered, through several discussions, the derived application driver for the requirements mentioned above. This was to avoid bumping into other buoys as the bumping can crack the shell of the buoy. Another derived application driver was that the requirements discussed above may make it easier to maneuver the vessel. When we found the derived application drivers, we asked questions about why the derived application drivers are needed or important. The key driver identified for the two derived application drivers were operational robustness.

The last step in the method is to get feedback from the customers and iterate many times. We have not yet been able to obtain feedback for this method and have just performed it one time. The accuracy and credibility level for this model at this point is therefore not as high, as if the team had obtained feedback and iterated many times.

We still felt that the model helped us to emphasize later on the importance of the identified relation between the requirements and key drivers.

C. Application view – Context diagram

An application context diagram shows all the systems that can be operational in the application context [7]. The context diagram will define which actors that will interact with the system. This is shown by having a labeled box in the center representing the system, with no details, and put external boxes around it to show the actors interacting with it, see Figure 4.

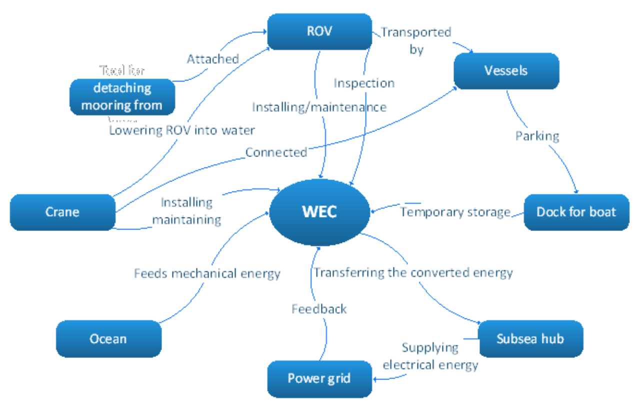

Fig. 4. Illustration of Context diagram

The context diagram is a method that is used to show how a system interacts with others at a very high level. It is important to understand that many systems that belong in the customer domain are not interfacing directly with the current product. In many cases, the interactions that the systems have with the product take place through human monitors. The diagram is a valuable tool in order to understand how the customer context diagram allocates the functions. [5]

The context diagram was a valuable tool to understand how the WEC will interact with the systems that will be present in an installation and maintenance operation. It also helped us to see which systems will not only interact with the WEC, but also with each other.

The diagram shown in the figure 4 is only showing a limited number of interconnects; the accuracy level is low. The reason for deciding not to display even more interconnects in this diagram is that it would become complex and difficult to read. When making the A3 we used this diagram as an overview when making the work flow sequence of the two operations.

D. Conceptual and realization view – functional model

A functional model visualizes the functions within the system. The model is used as a way to identify the functions and by this be able to single out opportunities and needs.

In the A3s, a functional flow diagram for each of the operations is used. The flow diagram shows the sequence of functions that the system has to conduct to be able to deliver the capabilities to the user. In the A3s, the flow diagram is still at the system level with the top-level functions that the system has to perform. CorPower Ocean will have to iterate the A3s many times. The aim is that the functional flow diagram will be decomposed little by little to a level where they can identify specific parts or components that can provide the required functions. The parts are then defined and become part of the systems architecture.

To be able to identify the opportunities and concerns of the system in a more effective we decided to draw the workflow into a cartoon. We had a positive experience with this approach, as we were able to visualize and provide more details on each step than by using text. We also believed it was easier to get feedback by doing this as it might provide the stakeholders better understanding of the workflow. We also expect that the cartoons will make it easier for them to point out what they would have done differently and provide for additional concerns or thoughts with the cartoons.

It is important for the architect to always improve the understanding of the problem and the solution and quantification is an important factor to enable this [5]. Even though the quantification will be more precise as the project evolves, it is important at the beginning to quantify in order to get a hold of the problem. The quantification, will at the beginning, be mainly based on assumptions. This will still be helpful in order to identify where the largest uncertainties are and which measurements may be made to refine the assumed numbers [5].

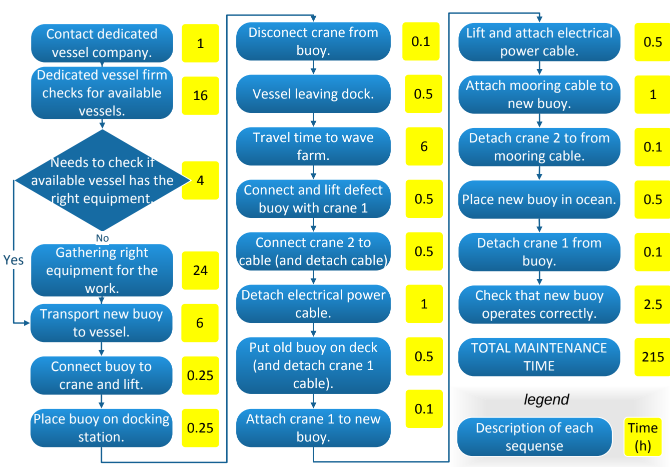

Fig. 5. Technical budget

To quantify the workflow diagram we used a technical budget. The technical budget show how much time the user will use for each sequence of the two operations. The team has only assumed the times a, but they will be further elaborated by CorPower Ocean. In the A3 the technical budget shown in figure 5 will be refined into a timeline.

VII. CASE RESULT

Four A3s present the case result. The first one is a system A3 mainly based on the functional, conceptual and realization view of the first iteration. The purpose of this A3 is to show the key functions of the WEC. The second A3 is an overview of the installation operation. The main model used here is a functional workflow diagram, both in text and as cartoon. The installation A3 also presents the main concerns regarding the operation. Once the system will be tested, a timeline will represent the technical budget. The third A3 is somewhat similar to the second A3, however, instead of focusing on the installation operation it shows the maintenance operation. The last A3 presents a more detailed workflow from some parts of the maintenance operation. This is a very complex sequence and we felt that a more detailed workflow was necessary.

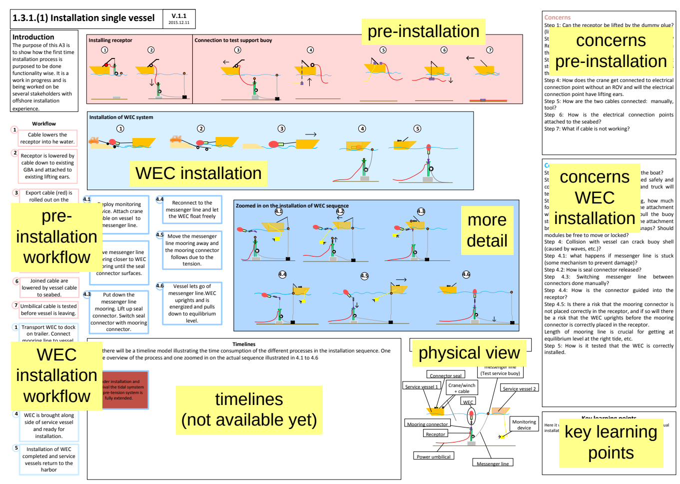

Fig. 6. The installation A3 as in use at CorPower Ocean

Figure 6 shows an example of an A3 architecture overview for the installation of the WEC. The A3 visualizes the pre-installation and the WEC installation in schematic form as “cartoon”. The installation workflow is further abstracted in a stepwise diagram. Later a timeline will be added to show the duration of all installation steps. A physical view shows all relevant components for installation. The “concern” boxes at the right hand side list concerns that popped-up while creating and discussing the installation. Finally, there is space to capture main learning points.

Even though the functional workflow diagram is mainly present in two of the A3s, it is important to emphasize that the content in the A3 has been identified through the other models as well. The workflow illustrates how several of the elements identified in the context diagram are interacting with each other. The SMART key performance parameters identified many of the concerns. The key drivers are also important regarding the design suggestion of the two operations. The modeling approach has been used as a baseline and been elaborated further to get to the result. It has also helped the team to get a holistic view of the whole systems.

CorPower Ocean has received the A3s and its content very positively. They think that the A3s can bring new interesting questions and that they give a fast and detailed presentation of the system. One of the employees wants to use the A3s at a conference where people will ask question of the technology and it`s operation. This shows that modelling is especially helpful when the system is presented to new stakeholders.. They also said that the workflow models can be used as an informative roughly illustration of the work process to installation and service personal at sight. The feedbacks, especially the last comment, show that modeling can provide understanding, knowledge and overview of the addressed system.

One of the managers is now using the installation and maintenance A3s in meetings with other stakeholders about the choice of preferred site. This can underpin the statements of Cernosek and Naiburg [1] that modeling brings value as a way to better understand the situation and that it creates a visualization of the implementation. This also shows that the modeling approach can contribute in reaching design decisions for the system-of-interest. We therefore dare to say that the A3s, based on the feedback from CorPower Ocean, are successful and that the functional workflows that have evolved through this modelling approach can, on a high level, been seen as realistic since they are now being used in decisions meetings.

VIII. FINAL REFLEFCTIONS AND FURTHER WORK

The installation and maintenance A3s are still at a high level. Many iterations of the workflow will be required to bring the workflow to a more detailed level in order to identify and select specific elements.

We also want to emphasize how crucial it is to quantify. Even though CorPower Ocean have some uncertainties regarding the installation and maintenance operation they should make a thorough technical budget as this will make the discussion more precise. Finally, they will have to find possible solutions to the identified concerns and concerns that may be discovered in the future.

The aim of this paper was to show how models can contribute to make problems more tangible and clearer regarding the holistic perspective of the system-of-interest. The use of the modeling approach that resulted in the four A3s can in many ways confirm this. A detailed visualization of the system and the two operations addressed are described systematically. This has at a certain extent enabled CorPower Ocean to get a more distinct view of the system.

ACKNOWLEDGMENT

CorPower Ocean has provided the team with many documents and pieces of information that have been crucial for the team to work with the system. CorPower Ocean has also shown great trust by providing this information to a person outside of the company.

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