Joshua Sutherland (37-146879) Supervisor: Prof. Aoyama (青山先生) 2016年1月27日(水)

# Knowledge Management and System-Level Design Tools utilizing OPM and Modelica for a Student Solar-Boat Project

## Master's Thesis Abstract



| Keywords: | Knowledge management, Systems-Level Design, Alternative designs, Object Process Methodology (OPM), Modelica |
|---|---|



## 1 Problems with Student Solar-Boat Project

Every year the Department of Systems Innovation enters into the Lake Biwa SolarBoat challenge, which involves students designing, building, testing and racing a solar powered autonomous boat. In (Sutherland, Kamiyama, Aoyama, & Oizumi, 2015) I described the SolarBoat 2014 project including problems encountered. V-Model Views proposed by (Scheithauer & Forsberg, 2013) and Knowledge growth curves as shown in Figure 1 were used to assess the potential causes and solutions of problems of the project. Assuming the SolarBoat project follows a standard series of lifecycle stages it is possible to map these identified problems to a stage as shown in Table 1, where in addition some high level solutions are proposed to the problems.

| Lifecycle Stage: | 2014 problem | Proposed solutions |
|---|---|---|
| LS1: Clarify | Slow to acquire initial knowledge. | Provide knowledge in models |
| LS2: Concept development | Unclear of the design target. | Complete trade-off analysis of multiple designs using models to simulate performance. |
| LS3: System-Level Design | Little exploration of alternatives or their predicted outcomes. | |
| LS4: Detail Design | Little prediction of performance. | |
| LS5: Production, Test and Refinement | Based on trial and error. | |
| LS6: Race | Lost race due to faults which could have been predicted with modeling. | |
| LS7: Knowledge transfer | | |

**Table 1 SolarBoat 2014 lifecycle stages with identified problems and potential solutions of the 2014 project**

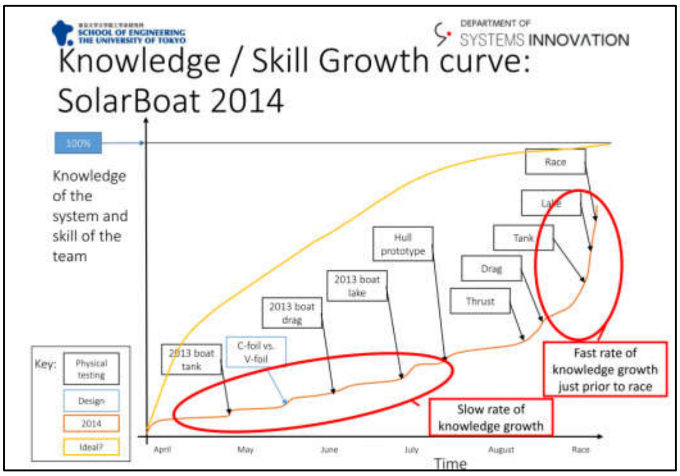



**Figure 1 Knowledge growth curve for SolarBoat project presented in (Sutherland et al., 2015)**

## 2 Requirements for the Proposed Solutions

However these proposed solutions need further breaking down such that something concrete can be defined and built, and acknowledgement of the problems and difficulties must be made.

### 2.1 Provide knowledge in models

Some basic requirements include:

- Avoid tacit knowledge
- Avoid document-based knowledge
- Ability to understand and modify

Some problems and difficulties:

- Selecting appropriate modelling languages
- Integration of multiple modelling languages together
- Keeping said models updated

### 2.2 System-Level Design – Complete trade-off analysis using models

Some basic requirements include:

- All alternatives assessed using the same approach
- Scalable to the size of the size of the project
- Transparent to why an alternative was chosen
- Easy to introduce alternative designs (as shown in Figure 2 there are many different SolarBoat physical architectures)

Some problems and difficulties:

- How to synthesize an assessment procedure? What assessment criteria is important to all designs?

- How to synthesize alternative designs?
- How to predict each designs performance?
- How to analyze the performance based on the assessment procedure?

**Figure 2 Alternative SolarBoat physical architectures**

### 2.3 Thesis scope

As such aim this thesis becomes to propose tools and methodologies to help students:

- Manage project knowledge
- Explore concept designs

## Literature Review

### 2.4 Trade studies

The International Council of Systems Engineering (INCOSE) provides by way of (INCOSE, 2015) a 10-stage decision management process which is intended for trade studies. Two examples of the implementation of this process are provided in the literature (Cilli & Parnell, 2014) and (Edwards et al., 2015) for a fictional UAV and US Army ground fighting vehicle respectively. In both cases there is the need to decompose high-level objectives into lower-level measures and define a Systems Architecture on which subsystems can be varied.

By comparing the SolarBoat project to the first five stages of the INCOSE Decision Management Process and reflecting on what was required by (Cilli & Parnell, 2014) and (Edwards et al., 2015) to pass each stage results in Table 2, where requirements and issues to be addressed are listed. Further it is recognized that some kind of language and/or method is needed to develop objectives and measures while numerical simulation is required for analysis of the performance of the SolarBoat alternatives.

### 2.5 Modeling languages

#### 2.5.1 Systems modeling languages

SysML and Object-Process Methodology (OPM) are quite different approaches to the modeling of systems. Where SysML has nine different diagram types, OPM only has one. Further it has been found by (Grobshtein, Perelman, Safra, & Dori, 2007) that while SysML is good at handling detail OPM is better for enabling a holistic understanding of the system and its environment. As such OPM was selected as the systems modeling language.

#### 2.5.2 Multi domain numerical modeling languages

To model a SolarBoat the modelling language must support the electrical, mechanical and structural components all of which are associated with it. This makes Modelica a good candidate, further its highly modular and hierarchical models potentially make it fit well with OPM.

| **Decision stage:** | **Requirements for SolarBoat project** | **Issues needing to be addressed** | **Modeling approach** |
|---|---|---|---|
| 1 Frame decision and tailor process | Define the decision to make | How to define Concept Design and Systems-Level design | |
| 2 Develop objectives and measures | Identify Functional Architecture | No requirements document to work from | Systems modeling |
| | Identify how to assess | What can be simulated? | |
| 3 Generate creative alternatives | Systems Architecture | No provided Systems Architecture | |
| | Populate the Systems Architecture with subsystem alternatives | Too many alternatives? | Multi domain numerical simulation |
| 4 Assess alternatives via deterministic analysis | Build numerical model | Unsure what to model | |
| | Simulate to determine each alternatives performance | Each alternative needs to be assessed in the same way | |
| 5 Synthesize results | Compare the simulation results of the alternatives | Extract a range of simulation results and compare | |

**Table 2 Reviewing the first five stages of the INCOSE Decision Management Process if they were applied to SolarBoat project**

#### 2.5.3 Language integration

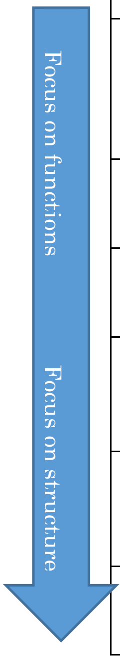
Table 3 shows the current state of literature integrating systems modeling with numerical, indicating no literature has been found linking OPM to Modelica.

| | | **Numerical modeling languages:** | |
|---|---|---|---|
| | | **Modelica** | **MATLAB/Simulink** |
| **Systems Modeling** | **OPM** | No literature found | (Bolshchikov, Renick, Mazor, Somekh, & Dori, 2011) |
| | **SysML** | (OMG, 2010) | (Qamar, During, & Wikander, 2009) |

**Table 3 A review of literature linking systems modeling languages to numerical modeling**

## 3 Usage of OPM and Modelica for Knowledge Management and System-Level Design

As such to make use of this some definitions are required for the types of models for use and which language they will be modeled in. This is displayed in Table 4.




| Model type: | Definition: | OPM | Modelica |
|---|---|---|---|
| Functional Architecture | Process and operand description of the system for modeling. | Y | N |
| System Architecture | Assignment of objects to processes. | Y | N |
| Formal Structure | Direct connection of objects. | Y | Y |
| Connectors | Defines how the object is connected to other objects. | Y | Y |
| Alternative | A fully specified definition of the item for modeling. | N | Y |
| Simulation result | Time series object attribute values. | N | Y |

**Table 4 Definitions of the types of models needing to be created at various levels of the OPM and Modelica assessment hierarchy**

However as hierarchy is commonly used to handle complexity as such a hierarchy is defined from a process which is considered important for simulation. This hierarchy is described in Table 5.

| Hierarchy level: | Definition: | Example: |
|---|---|---|
| Assessment Scenario (Level 1) | A process which is considered appropriate to use to compare alternative designs with. | Driving forward in good weather. |
| System of Interest (Level 2) | The System of Interest which enables the Assessment Scenario process to be completed. | SolarBoat. |
| Subsystem (Level 3) | Subsystems which make up the System of Interest. | Solar to Electrical subsystem. |
| Subsystem Component (Level 4) | Components which make up the Subsystem. | Electrical to Rotation component (i.e. a motor). |

**Table 5 Definitions and examples of items for modeling from the OPM and Modelica assessment hierarchy**

Which can then be combined into a diagram with types of models and how they can be represent different level of hierarchy. As shown in Figure 3 and Figure 4.

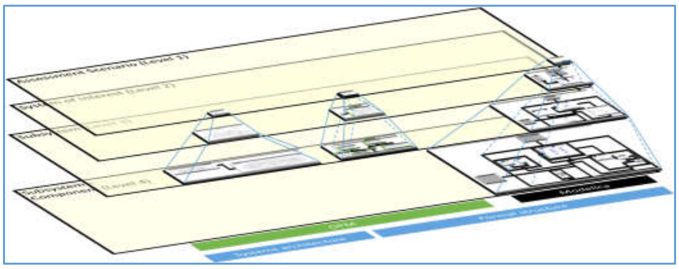


**Figure 4 Visual description of the assessment hierarchy.**

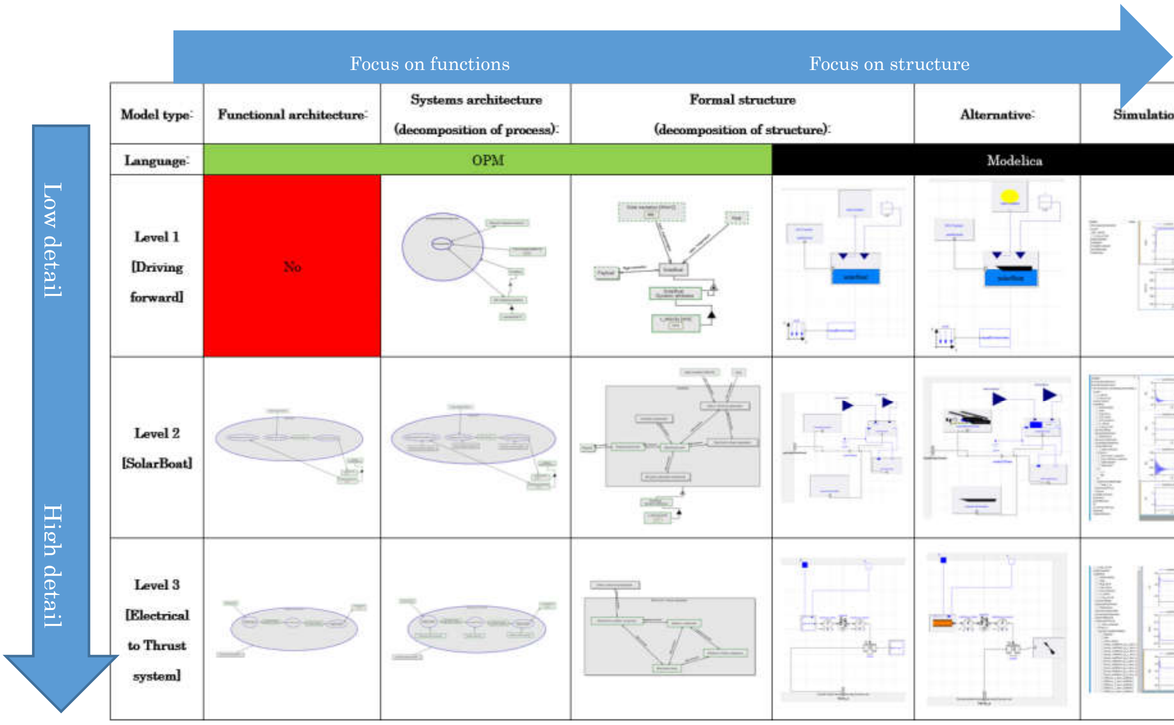



**Figure 3 Example diagrams of the models implemented in the range of languages for a three layer hierarchy**

By moving between positions on this hierarchy it is possible to functionally decompose the system and generate a series of formal models in Modelica which are applicable to model replacement, as shown in Figure 5.

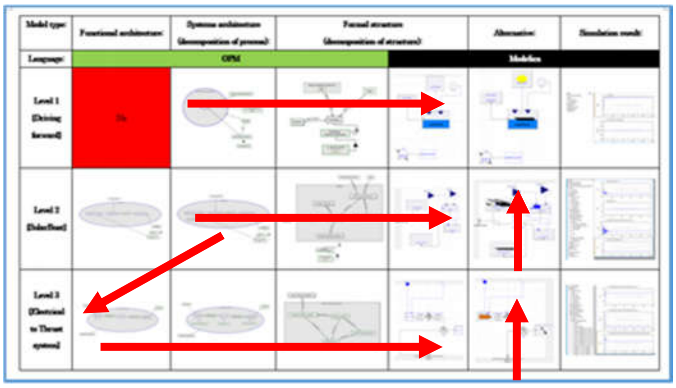


**Figure 5 Generating creative alternatives using the assessment hierarchy**

## 4 Example Usage

By using this approach a SolarBoat Formal Structure (Figure 6) was defined and implemented in Modelica for a range of Assessment Scenarios (e.g. average sunshine, poor sunshine). Using customer python software a range of SolarBoat alternative designs can then be automatically assessed for all the scenarios (Figure 7) and their performance results combined by way of Multi Objective Decision Analysis (MODA) (Figure 8).

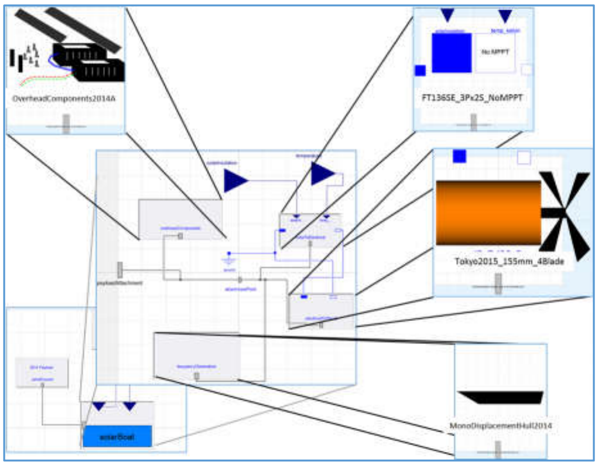



**Figure 6 SolarBoat Formal Structure (Level 2) being populated with subsystems (Level 3)**

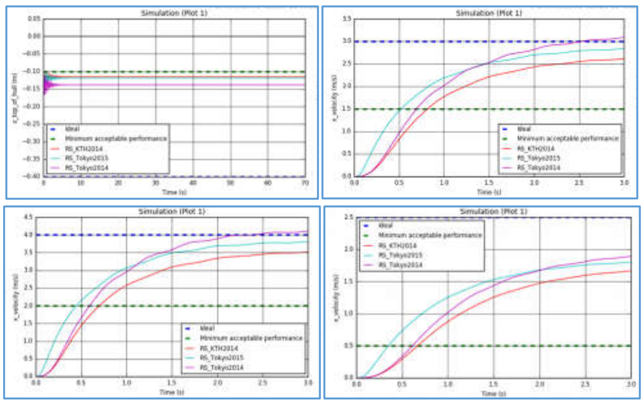


**Figure 7 Simulating five SolarBoats alternatives over 4 different Assessment Scenarios**

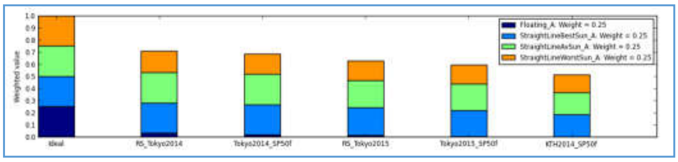


**Figure 8 Results from comparison of past boat designs and the replacement of the solar panel (0.64kg payload)**

## 5 Conclusions

In this thesis it has been attempted to show how Knowledge Management and System-Level Design can be accomplished by creating a design methodology incorporating:

- A defined framework for the mapping of conceptual modeling in OPM to numerical modeling in Modelica
- Utilization of the INCOSE Decision Management Process to formalize decision making
- Multi Objective Decision Analysis and design exploration
- Ensuring previous design knowledge embedded in the models which was previously either implicit or document-based
- A practical demonstration of model based design and Model Based Systems Engineering for educational purposes

The defined framework to enables the logical creation of conceptual models in OPM which are logically transferred to numerical models in Modelica by way of six model types were described (and their hierarchical decomposition for complexity management).

These models (and their hierarchical decomposition) are then incorporated into the INCOSE Decision Management Process, where the decomposition described here is used to create a structure on which alternative designs can be assessed in the same way.

## 6 References

Cilli, M. V., & Parnell, G. S. (2014). Systems engineering tradeoff study process framework. In 24th INCOSE Int'l Symposium, Las Vegas, NV.

Edwards, S., Cilli, M. V., Peterson, T., Zabat, M., Lawton, C., & Shelton, L. (2015). Whole Systems Trade Analysis. In 25th INCOSE Int'l Symposium, Seattle. Seattle, WA, USA.

Grobshtein, Y., Perelman, V., Safra, E., & Dori, D. (2007). Systems modeling languages: OPM versus SysML. In Systems Engineering and Modeling, 2007. ICSEM'07. International Conference on (pp. 102–109). IEEE.

INCOSE. (2015). Wiley: INCOSE Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities, 4th Edition - INCOSE.

Scheithauer, D., & Forsberg, K. (2013). V-Model Views. INCOSE International Symposium, 23(1), 502–516.

Sutherland, J., Kamiyama, H., Aoyama, K., & Oizumi, K. (2015). Systems Engineering and the V-Model: Lessons from an Autonomous Solar Powered Hydrofoil. Presented at the 12th International Marine Design Conference (IMDC), Tokyo Japan.