Refactoring Early Ship Design Methodologies

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ABSTRACT: Within the SHIPLYS project, one of the key goals is to increase efficiency, speed and reliability of early design processes. Over decades, a wealth of different methodological approaches have been conceived and applied. Such methodologies to a large extent rely explicitly or implicitly on the then-current computational capabilities and the set of objectives to be accomplished. With new or more powerful computing and processing techniques continuously becoming available, streamlining or refactoring of such methodologies appears to be a useful exercise in order to take best advantage and to accomplish the project's goals. It seems appealing to accelerate and improve such design processes by increasing the degree of automation. However, as with most creative tasks it is of high importance to enable design engineers to stay in full control of such improved processes and to apply expert knowledge and experience to drive design decisions.

In order to satisfy these requirements, a review of existing design process models for ship design has been carried out to produce an up-to-date formal model representation of such models, creating a ship lifecycle process model (with particular focus on early design) as the foundation of various design support and design management functions with the intention to support design engineers in various design stages. The paper provides an outline of the resulting model scope and structure and how it was created, reviewed, refactored and refined using a graphical modelling environment.

1 INTRODUCTION

European stakeholders in the maritime business face a strong competition world-wide. Especially small and medium-sized enterprises (SMEs) struggle to provide a sufficient number of well-trained and experienced experts as well as to have access to a wide range of tools to perform sophisticated calculations that would help to increase the reliability of design decisions and accuracy of cost estimation. The SHIPLYS project (Bharadwadj, 2017) tries to address this need by enabling designers to enhance the conceptual design phase with rapid virtual prototyping (RVP), production planning and simulation (PS) and life-cycle assessment (LCA) capabilities in a cost-effective way. Given the constraints of human resources at SMEs, such an approach would benefit substantially from a guided design process. To accomplish this goal, early design processes need to be formalized, documented and supported by software tools as much as reasonably possible without impeding creative actions, possibilities and responsibilities of design engineers.

Conceptual design at SME shipyards and design offices - as performed today - is a creative process involving numerous implicit assumptions combined with a limited amount of digital documentation. Therefore, it is difficult to assess and document the actual progress made during design process at any given point in time. Furthermore, different tools are used for different subtasks and/or design stages. Due to the nature and origin of many such tools, integration and consistent evaluation of result data turns out to be a challenge, limiting further detail investigation or evaluation of additional design options during the time-constrained bid phase.

Current concept designs created by SMEs can be improved concerning time effort, functional quality and documentation by

- Establishing a formal description of all design activities documented as an Activity Model,
- Providing a design process monitoring function that provides guidance and enables management of the design process based on the formal description of the design activities,
- Specifying tools that can support or perform individual or a set of activities (under assistance of designer),

- Identifying missing links between available tools,
- Using RVP, PS and LCA techniques to enhance the design results.

By combining some or all of these measures it is expected to enable SMEs to create designs more rapidly which also result in improved performance, are based on more reliable estimates and cater for better risk management.

A prerequisite of this concept is the existence of an Activity Model. Investigations of existing models have been performed and a suitable model has been chosen from the applicable ISO 10303 standard parts.

1.1 *ISO10303 Application Activity Model*

ISO 10303 is an international standard whose development was started around 1984 as an effort to develop a suite of data exchange standards and tooling methods for the computer-interpretable representation of product information and for the exchange of product data (ISO10303-1, 1994). The objective is to provide a standard reference capable of describing products throughout their life cycle. This mechanism is suitable not only for data exchange, but also as a basis for implementing and sharing product databases, as well as archiving. The standard is organized into a large collection of normative parts, grouped by type of content and target application domain.

The most visible and relevant parts are numbered 2*nn* which form the group of Application Protocols (AP). APs focus on the domain-specific definition of exchangeable data models. Among this family of APs, a number of parts exist which are focused on or relevant for shipbuilding related application:

- AP215 – Ship arrangement (ISO 10303-215, 2004),
- AP216 – Ship moulded forms (ISO 10303-216, 2003),
- AP217 – Ship piping (ISO 10303-217, 2001), superseded by AP227,
- AP218 – Ship structures (ISO 10303-218, 2004),
- AP227 – Plant spatial configuration (ISO 10303-227, 2005).

According to the ISO 10303 documentation rules, any AP document is expected to provide a common set of sections and annexes. For purposes of this investigation the most relevant section is found in each respective Annex F, which contains the Application Activity Model (AAM). Due to the full synchronisation between the shipbuilding related APs (which was accomplished by establishing a "Ship Common Model") all activity models in the "Ship" series of standards link well together and can be seen as subsets of a complete activity model for vessels.

1.2 *IDEF0*

All shipbuilding-related APs documents use the IDEF0 modelling method to describe the activity functional model (AFWAL, 1981). This process modelling methodology evolved from business process modelling projects. Its focus is on ease of use, enabling domain experts with no or little background knowledge in data or process modelling to describe complex processes without major formal training. For this reason, IDEF0 has been chosen as one popular method for description of AAMs in ISO 10303 to define the functional scope of the standards.

Every activity is drawn as a rectangle, identified by a unique id and a descriptive name (Figure 1). IDEF0 activities are interacting by means of *flows* which can represent data items, physical items or triggers. These flows are characterised either as *inputs* (incoming data/material/interim products), *outputs* (outgoing data/material/products), *controls* (rules, constraints, triggers) and *mechanisms* (executing entities such as resources, facilities, algorithms). Inputs are marked as incoming arrows from left, outputs as outgoing arrows to the right, controls as incoming arrows from top and mechanism as arrows from bottom.

Activities are organised to create a hierarchy. An activity can be structured into other sub-activities. The top activity is usually called A0 or A1. Sub-activities will be identified by adding the number of sub-activity to the parent activity identification, e.g. A1 will be divided into A11 to A13. Sub-activities can inherit the flow connection arrows (input, output, control, mechanism) from their parent activity.

The ISO 10303 Application Activity Model for ships ("Ship AAM") provides a detailed and comprehensive description of the top-most process "Perform ship lifecycle", which is the root activity (A0) in IDEF0 description. It is further refined by splitting it into sub-activities:

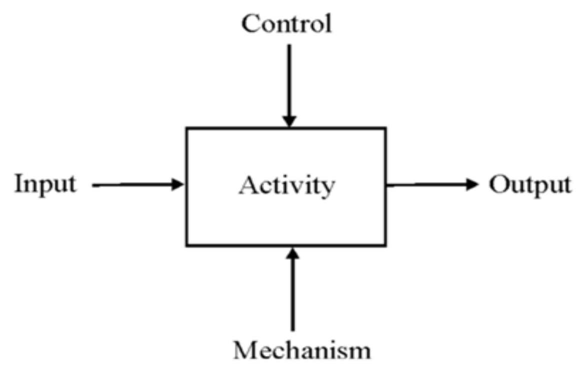

Figure 1: IDEF0 activity representation

- A1 – Specify ship
- A2 – Complete and approve ship design
- A3 – Produce and inspect a ship
- A4 – Operate and maintain a ship
- A5 – Decommission and disassemble

This refinement continues through several levels, representing the hierarchy/break-down of activities. Many of these activities are linked by several flows such as “ship product model data”, “contract” or “feedback”, which denote information or physical items moved between activities. Most relevant for the early design phase is activity A12 – “Prepare bid” which can be subdivided into approximately 60 leaf-node activities (a leaf node activity representing the most detailed level). The highest level of detail is provided by activities such as “Evaluate weights of outfitting and accommodation”.

As the Ship AAM describes the whole life cycle of a ship, a subset has to be selected to fit the early design scope. For this reason no *detailed* design activities are considered to be in scope (some specific exceptions, e.g. for production planning, apply). Furthermore all activities that are related to carry out production, operation, and maintenance or decommissioning are not in the scope. It should be noted that the formal representation of such out-of-scope activities are still of interest for processing in some related tools (e.g. for purposes of LCA) that are being developed within SHIPLYS.

Using the selected subset of the Ship AAM as a starting point, a comprehensive review of the early ship design process has been performed.

2 SHIP DESIGN REVIEWED

Since the creation of the applicable ISO 10303 parts design methods have been further developed and new approaches have evolved. As an example, sophisticated numerical methods have gained wide acceptance and are increasingly applied. Correspondingly, a revision or update of the model deemed necessary to ensure representing the current state of design processes. The approach to update the Activity Model can be described as follows:

- The subset of the Activity Model that fits the scope of early design phase has been determined.
- The Activity Model subset has been reviewed concerning its accuracy and applicability, identifying any omissions or limitations.
- An investigation concerning necessary changes due to technological progress over the years and modern approaches such as LCA has been performed and modifications were applied.
- The flows in the Activity Model, which originally differ in their level of abstraction from very general (ship operations, owner requirements, …) to fairly specific data items (trim, freeboard, …) have been mapped to more fine-grained data entities (utilising the ISO 10303 ship model entity definitions to the largest extent possible).

In order to broaden the coverage of the early design scope to include some production planning work, some activities in the Ship AAM originating from the detail design scope have been reutilised and adopted.

Special attention has been given to the definition of LCA-related activities in early design. While some of these aspects are usually present in most early design results, the goal here is to provide a reasonable complete input for LCA tools.

Another important task is concerned with extending the Ship AAM in such a way that preparation of retrofitting and conversion projects can be covered as well.

2.1 *Modelling methodology*

While IDEF0 has its clear benefits, it also has its weaknesses and peculiarities (IDEF, 2017). Most importantly, while the connectivity between activities seems to imply a sequence, it is not – and should not be considered as – a strict definition of a firmly defined process flow.

Apart for such modelling considerations, the review process had to deal with some other issues. First of all, it seems that modelling support for this methodology has not advanced in pace with other software modelling technology. Maintaining graphical models by use of specialised graphical editor is sufficient for documentation purposes, but it would be desirable to have access to better tools supporting advanced modelling rules and validation of models in particular.

Some properties of IDEF0 models allow for ambiguities and imprecision. For example, the consolidation of flows from different levels of activities leads to perceived dependencies which are not reflecting the actual situation. For a reasonably complete description a better degree of traceability of individual flows would be desirable. This is of particular importance if design guidance is supposed to include data flow analysis, as will be discussed below.

As a result, a modification of the modelling methodology has been applied focussing on a combination of improving tool support and arriving at a more refined activity model specification. For review and modification purposes it is indispensable to employ a representation that supports both graphical visualisation and modelling functionality. For machine-processing purposes a well-defined data storage format is needed at the same time.

A solution had to include the transformation of the Ship AAM in IDEF0 representation into a machine- and human-readable representation.

2.1.1 *Graph-based modelling*

Our approach uses a generalised graph representation of the activity network to be investigated. It involves the use of an intentionally flexible graph format, GraphML (Brandes et.al., 2016), to capture a fully attributed activity model representation in a way suitable for both human interpretation as well as software-based processing. GraphML supports a layered representation that allows enhancing a fully generic graph network both in terms of visualisation and modelling properties by means of customisable node and edge attributes.

The solution implements an abstraction layer consisting of mappings between structural nodes representing activities and inputs/outputs/controls and mechanisms as well as edges representing the flows. Manual (i.e. interactive) modification and examination can be performed using a graph editor such as yEd (yWorks, 2017) where all applied changes automatically redefine the Activity Model. Figure 3 provides an example of the GraphML representation of the Activity Model. It shows the root activity A0 “Perform ship lifecycle” connected to input, output and control nodes that define external dependencies.

A GraphML data set consists of the generic graph description part and the layered attribution part. The modelling approach chosen is based on using specific attribution additions and conventions for adding IDEF0 compliant identifications and descriptions to graph entities.

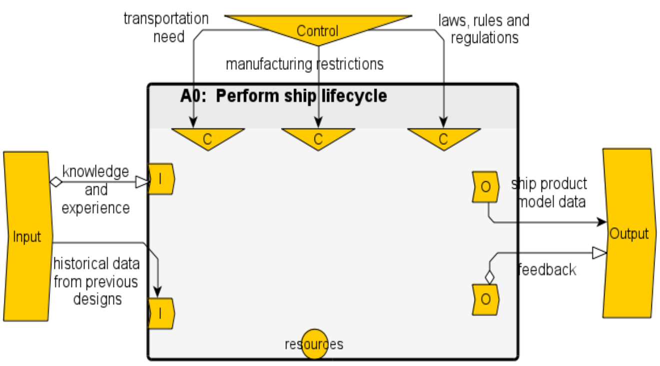

Figure 3: Top-Level activity A0 of the Ship AAM

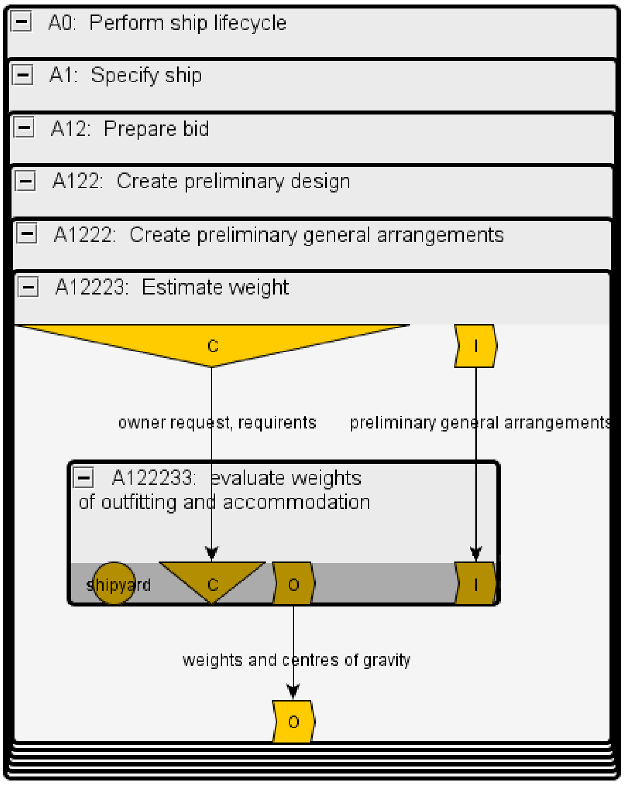

Figure 2: Activity neighborhood view

Since the GraphML format allows for hierarchical graphs, modifications can be performed either in the multi-layered full model or in single layer (one parent activity subdivided in its direct sub-activities) templates. When modifying the full model, an additional relationship-view allows easy orientation, as shown in Figure 2.

In order to better support the activity model review while interacting with domain experts, it was important to maintain the “easy-of-use” features of IDEF0 as much as possible. For this purpose some documentation generation functions have been provided. They allow extraction of fully browsable documentation which is a convenient tool during model reviews (Figure 4).

The first model review step involved the definition of the necessary subset of activities, mostly from A12 - “Prepare bid” but also some activities concerning production preparation e.g. from A2 to be considered for production planning, life cycle analysis and retrofit planning. Some additional activities had to be defined as part of this step. Consequently, the selection of activities implies the selection of a subset of flows as well.

As mentioned, one of the review tasks involves the determination of the detailed content of flows, leading to individual data collections which define the transferred entities independent of the actual flow from one activity to another. In this step it turns out that multiple flows involve identical data collections, a relevant input for any data flow analysis.

Since data collections are more or less descriptive definitions of transported data/material/triggers etc., a further mapping has to be performed. Every data collection has to be dissected and subdivided into parameters in a way that the combination of those parameters covers the full content of the parent data collections completely and concretely. Consequently, for every flow it has to be verified which subset of the parameters apply to the specific flow since likewise named flows in the Ship-AAM can represent different parameter entities (for example, "hydrostatics" can in one case include all hydrostatic "tables" for every draft/loading condition and in another case refer just to the righting lever curve for a specific draft and loading condition).

Once the data entities to be handled during the design process are fully identified, an evaluation of data content and formats can be carried out.

2.1.2 *Data flow analysis and data state*

Early ship design is an iterative process in which several different, potentially interfering iteration loops are performed while carrying out a design. Those iteration loops should be identifiable based on the Activity Model. There are several types of iterations:

- *Explicit* iterations which are represented by cycles in the activity model graph. These iterations are typically modelled to reflect major design dependencies based on cyclic flows, e.g. in order to achieve compliance with rules and regulations. Therefore such iterations will usually be initiated based on the state of certain flows and decision criteria to be evaluated as part of the involved activities.

- *Implicit* iterations as a consequence of data quality assessments. If certain data flow content is determined to be incomplete, preliminary or inconsistent with rules or requirements, any such condition may, at the designer's discretion, trigger (re-)execution of various prerequisite activities. Again, the state of flows will be an essential metric to control such iterations.

Explicit iterations are directly identified from the graph representation of the activity model by using appropriate cycle discovery algorithms. In some cases the Ship AAM reflects tight iteration loops by directly feeding back output flows to input flows. In other cases the iteration cycle may include a whole sequence of activities. (Note that for reasons of practicability and readability not all such iterations have been explicitly described in the Ship AAM.) Such iterations will require some sort of iteration control criteria which in our approach would be provided by associating some data state information with the flow content.

Implicit iterations can only be based on a dependency analysis of the underlying flows. If certain flow content needs to be re-established, a reverse dependency search will determine the set of predecessor activities that need to be re-executed. The key criterion in this search will be the requested data state for the set of flows feeding into these activities.

A12223

Path Name	A0—A1—A12—A122—A1222—A12223
Common Name	A12223
Aliases	Estimate weight
Description	This task is necessary for calculating the lightship weight and consists of the calculation of the hull steel weights, machinery weights and weights of outfitting and accommodation.
Activities	A122233, A122232, A122231, A122234
Inputs	preliminary general arrangements, preliminary machinery, structure and outfitting design
Controls	laws, rules and regulations,owner request, requirents, preliminary general arrangements
Outputs	weights and centres of gravity, feedback
Mechanisms	shipyard
Transitions	A122233→A122234, A12223→A122233, A122233→A12223, A122232→A122234, A12223→A122232, A12223→A122231, A122231→A122234, A122234→A12223, A122232→A12223, A122231→A12223

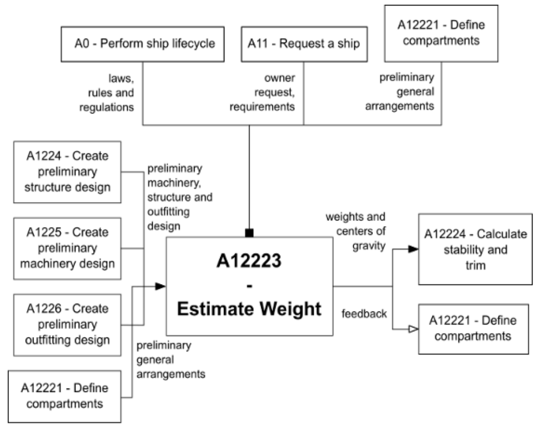

Figure 4: Browsable Activity documentation

In order to provide guidance for the design process all such iterations need to be detected. For this to happen, assessment of data *state* is an essential prerequisite. By date state we refer to properties that help describe the origin, method of creation, timestamp/actuality and other designer judgement information. With such properties maintained for every characteristic data entity it will be possible to evaluate the overall data state and to determine the need for re-evaluation and corresponding iterations.

Once re-evaluation of a flow has been found to be necessary or useful, a dependency analysis of the supporting feeding data flows will help to find the activities that need to be re-executed (or may get executed for the first time as a result of improved or more complete input).

2.1.3 *Data model definition*

Due to the relevance of data state for guiding the process execution, the activity model can only be put in full use if the corresponding data entity content is well defined. The Ship AAM was chosen as a starting point, since it has been defined in close relationship to the ISO 10303 definition standards. Therefore it is a logical step to express data definitions related to early ship design in terms of ISO 10303 data

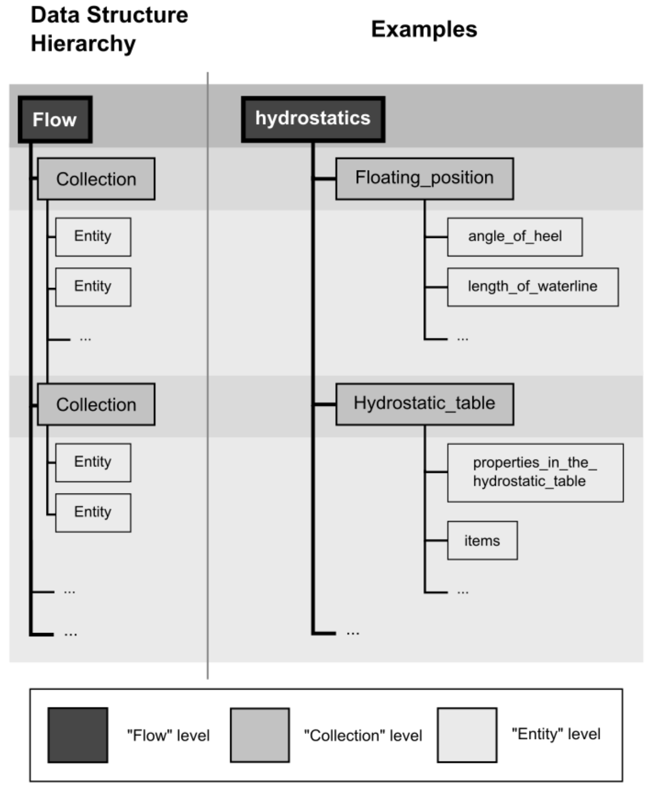

Figure 5: Mapping flows to data entities

entities definitions to the largest extent possible and to apply the same formal description methods to those data definitions that are additionally required to support the modifications and additions of the activity model. The shipbuilding related ISO 10303 standards provide a good coverage of data definitions applicable to the early design scope. Figure 5 exemplifies the relationship between flows and detailed data entities.

3 CONCLUSIONS AND OUTLOOK

The ISO Ship AAM can be considered to provide a well elaborated starting point for the definition of a detailed process flow model to be applied in the SHIPLYS design tools and surrounding framework. Since the publishing date of the relevant parts of ISO 10303, some modifications have become necessary, not least due to the wider availability of new or improved computational methods and the introduction of new design criteria and ship types.

The purpose of a revised activity model is to provide a formal underlying model to be used as guidance in design processes. In the SHIPLYS project, tools are created to supervise the design progress in early ship design scenarios.

The chosen approach to modify the Activity Model (software-based modelling approach) has the advantage of providing a machine-readable representation of the Activity Model which is an important feature for the intended purpose.

With the Activity Model being complete, accurate and up-to-date, the next steps within SHIPLYS will be

- to create a design process monitoring tool that is capable of documenting the progress of early ship design using the underlying activity model,
- to establish a software registry which administrates all available software tools. Registered software tools can be started within the context of the Design Process Monitoring Tool,
- to identify missing connectivity between registered tools that restrain the design progress within bid phase and potentially development of linking tools to close the gaps or to provide alternate means of providing such data,
- to develop and integrate tools for RVP, PS and LCA, and
- to carry out a proof of concept for three selected scenarios.

In conclusion, the selected approach for guiding early ship design processes seems to be promising - especially for SMEs with limited resources.

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