INTERNATIONAL DESIGN CONFERENCE - DESIGN 2004
Dubrovnik, May 18 - 21, 2004.

DESIGN 2004

KNOWLEDGE AND DATA REUSE IN SHIP SYSTEM DESIGN AND ENGINEERING

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Keywords: reuse, knowledge, data, shipbuilding, engineering design

1. Introduction

Most modern day ships are developed as engineered-to-order, one-off products, requiring a substantial design, engineering and production effort. Pushed by fierce competition shipbuilders continuously have to find ways to reduce their product development time and costs. The option considered in this project, is to increase the degree of knowledge and data reuse in ship design and engineering. In this paper, with engineering is meant, all required design activities between contract design and production, like detailed arrangement design, detailed structural design and production design (this corresponds with the common conception of 'engineering' in the Dutch linguistic area).

In the present situation, there is some reuse of knowledge and data in ship design. During pre-design and concept design, the use of reference vessels as a basis for a new design is widely applied and a substantial part of the pre-design work is based on statistical data of previous designed ships (e.g.: weight estimation, resistance prediction). During the engineering (detailed design) stage, reuse of knowledge and data is done more ad-hoc. Some engineers use documentation of previous projects as an example or try to find information and data they can copy, but at most shipyards, this reuse process is not systematic and the extent and success mainly depends on efforts of the various employees. Although some shipyards successfully offer standardised ships (the ultimate degree of product data reuse), most yards do not go any further than standardisation at part level (bolts, valves, pipe-bulkhead penetrations, etc), as in most shipbuilding sectors a standard ship does not sufficiently satisfy client requirements.

The project is started with the identification of the possibilities and consequences of knowledge and data reuse in shipbuilding, in order to find the most effective way to reuse knowledge and data. In this paper a short overview of the possibilities and consequences of knowledge and data reuse in ship system design and engineering is given and two possible scenarios to implement reuse are evaluated.

2. Knowledge and data in ship system design and engineering

Before reuse of knowledge and data can be applied, it is necessary to know what kind of data and knowledge is available for reuse (for definitions of data and knowledge, see among others [Thoben, 1999]). The different types of data and knowledge used and generated in ship system design are identified with an analysis of the design and engineering process of a ship's black water system (BWS). 'Black water' is water coming from toilets and medical facilities and contains bacteria that can be harmful to the environment. In some areas, treatment of black water is thus required before discharge overboard is allowed. A BWS has the function to collect, store and treat black water.

The process analysis is based on interviews with a number of experienced designers of 'Schelde Naval Shipbuilding', a well-known Dutch designer and builder of naval vessels. In short, the steps required to design and engineer a BWS are:

- analyze requirements, rules and regulations;
- define system configuration (treatment type, transfer system type, etc);
- calculate capacities for black water treatment plant, storage tanks and discharge pumps;
- request proposals for system components;
- evaluate proposals and choose one;
- complete the BWS design;
- write system specification;
- draw system diagram, define pipe diameters;
- create detailed arrangement drawings of ship spaces;
- route pipes, cables and ducts through spaces involved;
- combine arrangement drawings and piping/cabling drawings;
- create all necessary production drawings.

Although feedback or iteration steps are not shown, this enumeration does give an idea of the way most common ship systems are developed.

Knowledge or data required and generated during these steps, can be divided in the following groups:

- *Domain knowledge:*
  All 'general' knowledge about a product domain, like documentation of previous projects, calculation rules, knowledge about possible solutions, etc. Domain knowledge can be explicit as well as implicit;
- *Rules, requirement and regulations:*
  All rules, requirements and regulations a product has to obey or to fulfill. Ranging from owner's requirements till legislation of national authorities or requirements coming from other parts of the design process, like maximum system dimensions or weight. Part of it overlaps with domain knowledge and product data. Rules, requirement and regulations are usually present in an explicit form.
- *Product data:*
  All technical and financial data concerning a product under design, like results of calculations, drawings, specifications, etc. Type of appearance: explicit;
- *Design rationale and intent:*
  The 'how' and 'why' behind a design. For example: required steps to design a product, reasons behind decisions, etc. Rationale and intent are only seldom available in an explicit form.

Besides the difference in type, knowledge and data also comes in a number of different forms. Knowledge can be explicit as well as implicit [Nonaka, 1995] and can be captured or stored in many different forms [adapted from Kerssens-van Drongelen, e.a., 1996]:

- brainware: knowledge and data in people's heads (experience, ideas);
- mediaware: text, drawings, photo's, movies, sound fragments etc.;
- physiware: prototypes, mock-ups, etc.;
- digiware: electronic files, virtual models, databases, etc.

All knowledge and data used and generated in the design and engineering process can in theory be reused in some way. The usefulness, consequences and benefits however will differ. Reuse of explicit knowledge and product data for example, often results in a regurgitation of the past, whereas reuse of domain knowledge and 'rationale and intent' results in an application of the past [Duffy, S.M., 1995].

3. Reusing knowledge and data in ship system design and engineering

Knowledge and data reuse is not something that can be done in a single way. To comprehend the wide range of possibilities associated with knowledge and data reuse, a classification can help. By looking at 'what' is reused, a classification based on the different knowledge and data types and their possible appearance form can be made. This largely corresponds with the division made in section 2. A classification based on 'how' to reuse has been adapted form a classification made by Prieto-Díaz in [Prieto-Díaz, 1993]:

- *Scope*:
  - vertical: within a domain;

    - horizontal: across several domains;
- *Mode*:
    - planned: systematic;
    - ad-hoc: opportunistic;
- *Intention*:
    - black box: reuse as-is;
    - white-box: modifications possible before reuse;
- *Technique*:
    - generative: generating new products based on previous acquired knowledge and data;
    - compositional: composing new products out of knowledge and data developed for previous products.

In Dutch shipbuilding it is common for yards to concentrate on designing and building a limited number of ship types. This indicates a need for vertical, generative/compositional reuse. To maintain the utmost flexibility, while reusing knowledge and data, white-box reuse is preferred.

In order to materialize the concept of knowledge and data reuse and to get a better idea of the consequences, problems and benefits, a number of possible scenarios to implement knowledge and data reuse in ship system design and engineering have been set up. Two possible scenarios are:

- *Standardisation at system level*:
  Standardise systems that are common for all ships within a product family. The standardised common systems form a product platform, which could be (re-)used in every product of the product family. The product platform is complemented with a number of one-off designed modules, to provide the required variation and to fulfil all design requirements. Notice the difference between a ship with a number of standardised systems and a standard ship. This type of reuse is an example of systematic, vertical, compositional reuse and mainly aims at reusing product data. In many different industries the concept of product families and product platforms is common practice. Most cars, planes or consumer electronics are for example based on a product platform;
- *Support or automate the engineering process with a generative product configurator*:
  Supporting or automating the engineering process could for example be done with Knowledge Based Engineering techniques (KBE). KBE-tools are frequently used in the automobile, or aircraft construction industry to design and evaluate many alternatives in a short period of time. As long as all required knowledge can be made explicit (including domain knowledge and rationale) and can be converted to rules, this kind of system could:
    - guide an engineer trough the design process;
    - execute the calculations (based input of the engineer, calculation rules);
    - set-up possible system configurations (based on a component library, results of calculations, converted rationale, 'rules, regulations and requirements')
    - pick the most suitable components (component library, rationale)
    - advise the designer about the generated solutions based on rationalised previous experiences and domain knowledge (e.g.: configuration 2 is less effective in tropical waters)
    - generate design documents like proposals, system specifications and an initial system diagrams.

  This type of reuse can be classified as systematic, vertical, generative reuse and aims at reusing 'domain knowledge', 'rationale' and 'rules, requirements and regulations'.

There are of course many other possibilities, but it goes beyond the scope of this paper to treat all scenarios.

Before taking a closer look at the consequences of implementing one of these scenarios, it is important to consider the fact, that 'design and engineering' is only a small part of the overall ship development process. About 70% of the construction costs of a ship come from material and third party labour costs. The other 30 % are costs for man-hours made by the shipyard. Only 20% of these shipyard man-hour costs can be allocated to design and engineering [Aalbers, A., 2003]. This makes it clear that to draw well-founded conclusions about the consequences of reusing knowledge and data and to find the best way to do so, not only the consequences for 'design and engineering', but the effects for the overall shipbuilding process have to be considered. Reusing knowledge could for example have a positive effect at 'engineering and design', but if this positive effect is undone by an increase in purchase and production costs, it would not make sense to implement reuse.

3.1 Consequences of reusing knowledge and data by system standardisation

System standardisation involves fixing of: system capacity, configuration, 'make and type' of the components and preferably also part of the arrangement of the main components, like the position of a treatment plant in the engine room. The main consequences of standardisation at system level are:

- *Design and engineering*:
  As main positive effect, a decrease in engineering hours and lead-time is expected. No information needs to be searched and investigated, fewer calculations have to be made, no proposals need to be requested, no system specification has to be written and part of the drawing work can be reused. Furthermore, number of changes, re-work and idle time during engineering is expected to decrease because exact and final information is available at the beginning of the design process. Another positive effect is the expected decrease in errors.
  Negative consequences are of course also present. The effort required to design and engineer a standardised solution will be substantially higher than the effort required to design and engineer a one-off. 'Freedom of design' for designers and engineers will decrease, because part of the overall solution is already fixed (including interfaces with other systems/spaces). Designers will have to find new ways to express their creativity and there is a chance that competence and skills deteriorate, as several tasks are not executed on a regular base. Another risk of standardisation is to miss significant innovations by sticking to a standard design for too long (usually for convenience reasons) and if any errors remain unfound the consequences will be worse than with a one-off design.
- *Production*:
  Overall construction costs and lead-time are expected to decrease. Improved quality of engineering work will result in a reduction of problems, mistakes and re-work during production. Learning effects and the fact that capturing, storage and reuse of production rationale (best practices) is relatively easy provides possibilities for further improvements in the production process. There is a (small) risk that production employees will lose certain skills as they get used to assemble only a limited number of system types.
- *Saleability*:
  With respect to saleability, main positive aspects are the decrease in overall costs and lead-time, the fact that a solution can be sold as a 'proven' solution and the possible advantages for after-sales services. The negative consequences however should not be underestimated. A standardised system could be sub-optimal compared to a one-off with respect to weight, dimensions or exploitation costs (e.g. when the system capacity is higher than actually required) and standardisation can make it hard to satisfy certain specific customer requirements.
- *Purchase*:
  Although the time and effort required to purchase system components can decrease and system standardisation offers possibilities for frame-, or long-term contracts, it also possible that standardisation increases the purchase costs. Initial acquisition costs of a standardised system could be higher than the costs of a one-off solution (a component with a higher capacity is usually more expensive) and standardisation could negatively affect 'freedom of negotiation' of the purchase department.
- *Suppliers*:
  Standardisation of a system not only has consequences for the shipyard, but also for component suppliers. To make standardisation feasible, components should be deliverable without major changes for a reasonable period of time. Advantageous for a supplier is the fact that the same system can be sold more often, resulting in a decrease of average engineering effort and risk per delivered system.

3.2 Consequences of reusing knowledge through support/automation of engineering

Consequences of implementing an engineering support/automation tool are:

- *Design and engineering*:
  Engineering costs and lead-time is expected to decrease, because the time required to find all relevant information is reduced (necessary domain knowledge, 'rules and regulations' and design rationale is captured in the program). Implementing changes is made easier, more alternatives can be designed and evaluated in the same amount of time and the final engineering result is expected to be better (less errors, better system). Another advantage is the fact that the company gets less reliant on the experience and knowledge of individual employees, because knowledge is captured and stored in an explicit way.
  To capture and store all required knowledge asks for a substantial effort and because knowledge is subject to change, frequent maintenance of the support/automation tool will be necessary. A risk of such a tool is that employees lose their job satisfaction and sense of responsibility, as the computer does most of the 'intellectual' work.
- *Production*:
  A decrease in number of errors in engineering work will result in fewer problems, mistakes and re-work during production. The possibilities for learning effects or reuse of 'production rationale' will be limited, as a wide variety of different configurations can still appear.
- *Saleability*:
  No negative consequences are to be expected, as the same options as in one-off design are still possible. Positive for the saleability is of course the expected decrease in production costs and lead-time.
- *Purchase*:
  The consequences depend on the settings of the configurator. If the program configures only one solution, a decrease in 'freedom of negotiation' is possible. As long as the program configures multiple solutions, no consequences for purchase are to be expected.
- *Suppliers*:
  To set up a component library, suppliers have to provide product data before any requests are made, or contracts are signed and suppliers should take care of keeping their product data up-to-date.

4. Evaluation and further work

To find the most effective way of reusing knowledge and data in ship system design, the consequences of the different scenarios need to be evaluated. One of the most important aspects in ship design is 'saleability'. In most sectors of the shipbuilding market, there is an overcapacity, which enables a potential customer to choose between a number of different yards. This makes it in most occasions very hard to sell a ship that does not completely comply with all customer requirements (i.e. a buyer's market). So whether the effect of (system) standardisation at saleability is tolerable, will depend on the product-market combination and on the magnitude of the advantages of reuse. Further research will be required to identify shipbuilding product-market combinations in which standardisation of systems is tolerable and to identify how big the advantages have to be in order to make system standardisation commercially feasible.

The second most important factor is probably 'purchase'. According to a number of shipbuilding specialists, reduction in costs obtained by negotiation can rise till 10%. Combined with the previous mentioned fact that about 70% of a ship is subcontracted, it is clear that small changes in the achievements of the purchase department can have considerable effects on the total costs of a ship. Further research is required to define the magnitude of the consequences of system standardisation at the purchase activities.

In contrary to standardisation, reuse by support/automation does not have these (possible) negative consequences. However, it is expected, that the decrease in engineering and production hours/lead-time, will be smaller than in the case of standardisation. Furthermore implementation costs could turn out to be higher for the support/automation scenario. Capturing and storing of all required knowledge

asks for a substantial effort, and creating a product configurator could ask for the acquisition of some additional software licenses.
Both scenarios not only influence internal processes, but there are also consequences for component suppliers. These consequences are hard to control for a single yard, but they do have to be taken into account before a decision between different scenarios is made.
Since a few years, not only the total construction costs, but also Life Cycle Costs, or even Total Ownership Costs are considered to be important aspects of ship design. In this light, not only the influence of knowledge and data reuse on the total production costs, but also on the Life Cycle Costs (LCC) need to be evaluated. The influence of reusing knowledge and data on a product's LCC can be split in a direct and an indirect effect. A direct effect for example occurs when a standardised system with a higher capacity than actually required is used, this usually directly results in higher product exploitation and maintenance costs. Indirect effects come for example from taking into account the maintenance costs of a support/automate tool, in the cost price of the ship. A product's cost price in turn directly influences a product's LCC. Further research is required to clarify the ratio between the consequences for the LCC for the different scenarios.
All in all, this qualitative analysis of the consequences gives some idea about the effects of reuse, but it is still hard to say which scenario would be the best choice to implement reuse in shipbuilding. In order to make the choice between the different scenarios easier, research is carried out to quantify the effects of scenarios for BWS design. The results of this quantitative approach will be transposed to other ship systems and to other reuse scenarios to define the most effective way of reusing knowledge in ship design and engineering. In the final stage of the project, tools will be created to practically implement knowledge and data reuse in shipbuilding.

References

Nonaka, I., H. Takeuchi, The knowledge creating company, Oxford University Press, 1995

Kerssens-van Drongelen, I.C., P.C. de Weerd-Nederhof, O.A.M. Fischer, "Describing the issues of knowledge management in R&D: towards a communication and analysis tool", Journal of R&D Management, vol. 26, no 3, 1996, pp 213-230

Duffy, S.M., A.H.B. Duffy, K.J. MacCallum, "A design reuse model", International Conference on Engineering Design, Praha, August 1995, pp. 490-495

Prieto-Diaz, "Software Reuse: Issues and Experiences", American Programmer, Vol. 6, No. 8,1993, pp. 10-18

Aalbers, A., "Production of complex ships", In: Design of Marine Systems 1, ed.: Boonstra, H., Technical University Delft, Delft, 2003

Thoben, K.D., P.M. Wognum, H.J. Pels, A.G. Büchner, J.B.M. Goossenaerts, M. Ranta, A.A.M. Ranka, W.M. Gibbons, I.C. Kerssens-van Drongelen, From product data to product data and knowledge management – Requirements and research perspective, 5th International conference on concurrent enterprising, The Hague, March 1999, pp 147-155

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