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MODULARISATION IN ONE-OF-A-KIND PRODUCT ENVIRONMENT, AN INDUSTRIAL CASE

Hannu Oja

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1 Introduction

This paper relates to the early phase of the product development process, in which the product requirements are evaluated and product concept is generated. The application area is customised, one-of-a-kind product environment.

A crane manufacturer, which has the market share between 5 to 10%, has positioned itself as "technically high-end and adaptive for customisation". It has launched a project for developing a new container crane generation. Thus the main goals with the development were to improve significantly the crane performance, reduce delivery time and costs; new alternatives for product management were also searched for.

The engineering process of a customised product focuses on high optimisation of structures and components for lighter weight and smaller direct product costs. Modularisation was expected to provide new approach to product management, engineering process and improve business profitability while maintaining the flexibility for customisation

The product requirements for concept generation was evaluated with various methods; statistically and by stakeholders' aspects. The product modularisation is followed by concept selection and affected by technical and strategic aspects. The engineering process has an important role in reducing the lead-time from order to start of manufacturing and therefor need for development of product data management has been recognised.

2 Development project objectives

Container crane annual market volume has been influenced by global economics. The number of crane orders and manufacturers between years 1997-2001 is shown on Table 1 [8].

Table 1. Container crane orders and manufacturers

Year	1997	1998	1999	2000	2001
Number of crane orders	127	150	126	198	217
Number of manufacturers	17	22	21	21	18

Simultaneously the market share of the three biggest manufacturers has increased from 35% to 65 % and clear concentration and trend towards more standardised products has occurred.

The biggest manufacturers concentrate on larger projects, particularly in, which the number of cranes is at least four and preferably according to manufacturer's standard design. Outside this segment there still exist markets for specialised manufacturer, in case they can provide more customisation, quality and added value with the product.

Despite the specialised market segment the customers are prepared to pay only some premium for customised products, typically about 8-10 % more compared to standard solution. The market prices with container cranes have had a decreasing tendency due to hard competition. According to cost split on Figure 1 the direct materialised product costs are about 42 % of the total project costs and hard to reduce due to optimised design.

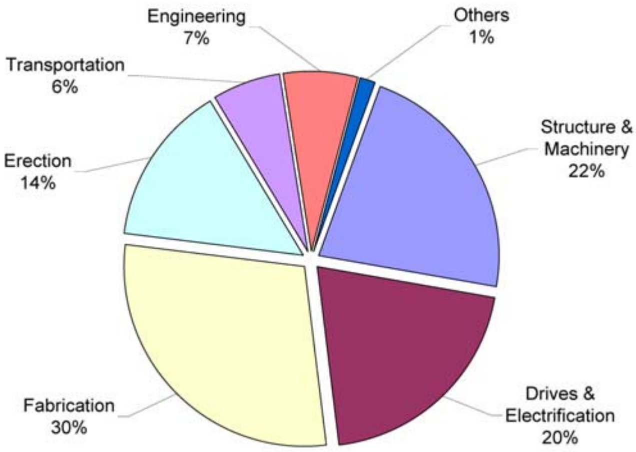

Figure 1. Cost structure of a typical project

A container crane project, starting from customer's investment evaluation and ending to commissioning, can take three to four years. Once the purchase order has been signed, the delivery time varies between 12 to 20 months. At that stage, when the customer finally makes his decision, the delivery time plays an important role. Primarily the customer is interested to get the equipment in operation as soon as possible, but also for the manufacturer a shorter delivery time can be seen as a possibility to reduce costs. By reducing the project duration, the interest on working capital and occupation of facilities can be reduced.

The development project targets were set to improve competitiveness and profitability on customised market segment within projects, which consists of one to four cranes. The product segmentation as such will not maintain competitiveness because the added value for the customer is finally measured by productivity. The new product should be significantly better in this respect compared to previous or competitors' products. Other specific goals were a significant indirect cost reduction and shortening of the lead-time from order to start of manufacturing (engineering process), which both were anticipated to be influenced by modularisation [1], [5].

3 Product requirements evaluation

An investment product has the purpose of providing services for the owner's customers. The products are always tailored to fit into customer's facilities and also often by other requirements. Very seldom an off-the-shelf solution is accepted as such.

The bidding and supplier selection process depends on the buyer's experience with the product. Typically three different alternative procedures are involved:

- Buyer hires a consultant to write the product specification and advice during the selection.

- Buyer has a strong technical section in the company, which writes the specification and advice during the selection. In-house organisations (technical and maintenance) have very good knowledge on the equipment that the company already has. The specification reflect these experiences
- Buyer invites the suppliers offer their best suitable product for the purpose and makes the selection accordingly

Consultants have joined a lot of various projects and their specifications reflect the past designs and experiences met during the times. The tendency within the specifications is to set very strict and detailed requirements even on component level and leave very few alternatives for the suppliers.

Customer’s main interest with specifications is naturally to ensure that the product fits into its purpose. The main characteristics are typically defined and deviations are not accepted. More detailed requirements are based on good experiences with existing products, but also to put all suppliers more comparable with their offers. Finally, when the order is addressed to one supplier, the product is by no means completely defined – lot of iterations will happen as well as additions and changes to original specification. At this stage the supplier has possibilities to affect with his preference.

The progress of the purchase process sets the supplier’s specification into two stages: first it shall meet most of the customer requirements to stay in competition and second to be modified to fit better with suppliers product strategy. Thus the changes will come anyway, the product structure and engineering process shall be flexible to adapt these.

The owner and the operator can be different and therefore their interests are different. Once the owner highlights the return on investment, the operator‘s main focus is on product performance, productivity and operational costs. Finally the product user, driver, has only minor influence on product selection thus he makes the work with it.

3.1 Product attributes

Product attributes are product parameters, which the designer can directly influence by his design activity [1]. For a customised crane, the main structural attributes, dimensions, capacity, speeds and accelerations are defined per project for the design basis. If the design is based on case-by-case attributes the final products may vary a lot. A product concept, which applies modularisation, uses predetermined attributes or attribute ranges. A container crane as such is not a serial product, in which size ranges could be applied with main attributes, but they may be categorised by reviewing realised projects in the past.

The statistical product attributes evaluation can be approached from published annual crane order statistics [8]. Thus the customer defines the crane dimensions; some clustering of the main design attributes may be done.

Statistics of vessels in service and new-builds may be used to complete analysis for the definition of attributes. As seen on Figure 2, the container vessels in service can be clustered into three groups, namely Panamax, Post Panamax and Super Post Panamax. The development of the vessel width follows change of the sea routes and directly affects on the most important attribute of the crane - the boom outreach dimension.

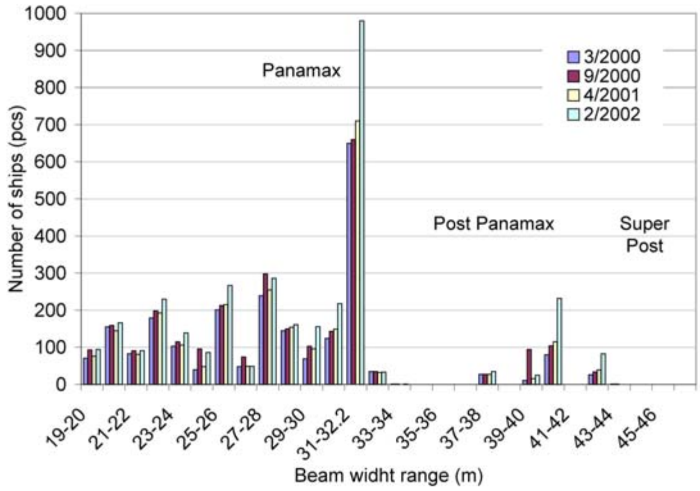

Figure 2. Container vessels in service and new-builds during 1998-2001 [4]

Market statistics provide one approach to product requirements and should be carefully evaluated before utilisation. The information can be organised and analysed for evaluating design attributes. However the data is always historical and may not forecast the future. Supplementary information may be reached by analysing the trends on transportation means and interviewing customers.

3.2 Product properties

By its nature the product properties of investment equipment are in many cases indirect for their owners and origin. In case of very complicated products, the final measurable results are the equipment performance e.g. moves per over time period and total costs activated. Once the terminal operators charging is based on handled containers, the financial interest is on the life cycle costs, e.g. costs activated per container move.

It is very difficult to point out a single product requirement, which provides the best impact on owner’s final interest – it is more a combination of numerous product features and characteristics. However, the product price has still remained one of the key factors for supplier selection at least among customers, which look forward for short-term payback rather than life cycle costs.

All container terminals follow their container-handling rate at quay level. Reference figures have a great importance for terminals due to usage as part of their marketing for shipping lines. Typical average figure is the number of moves per hour. Thus the productivity figures are important, they seldom give comparable information on real crane performance, because the container handling rate depends also on the terminal type and the efficiency of the yard operations.

A detailed study [6] among different terminal types was done by observing and video recording cranes in operation. Time usage was categorised into machinery on-time and positioning time. The summary of the study is shown on Table 2.

Table 2. Crane cycle time distribution [6]

	Europe 1	Europe 2	Europe 3	USA 1	USA 2
Machinery on-time (%)	41	47	57	50	52
Positioning time (%)	59	53	43	50	48
Productivity (moves/h)	27	45	25	58	55

The conclusion from the study was that regardless of the terminal location or type, about half of the cycle time was spent on actual machinery on-time and half was almost idle – time used for the last half meter for positioning the container or lifting device. Accordingly the new product features to be developed should attack the idle time in purpose to improve the load handling and by that the crane performance.

3.3 Product's stakeholders requirements

Within a crane project, the buyer's aspects vary. Three main customer groups and terminal types may be categorised, namely: private, global stevedoring and communal terminals. In each case the stakeholders and their requirements for the product vary as well the operative organisation varies. Principal differences on weighing product properties and purchase options may be presented as:

As an owner of the equipment the private terminal has a great interest on product performance due to competition. The latest technology, if it provides reliable high throughput capacity, is attractive and provides the best return on investment. Product life cycle costs are more and more considered and the equipment price is not the main criteria for selecting the supplier. The response for traffic changes in terminal makes the delivery time of the product critical.

Global stevedores have typically large projects, even greenfields or combined purchases for several terminals. Due to global operations, product harmonisation for training, spare parts and maintenance has a significant importance. Purchase prices are naturally lower due to volume. Preference is on proven conventional technology, because in many cases these terminals hire crane drivers and outsource maintenance. Long range business planning and the power of routing the traffic reduce the importance of the delivery time.

Communal terminals are requested for public tenders and in many cases the bid with the lowest price is chosen. Conventional technology is typical, mainly due to in-house maintenance organisation and drivers. Delivery time is not critical, due to long range planning and established facilities.

4 Concept development and modularisation

A manufacturer, which has positioned itself on customised market segment, cannot offer a standardised product line. In such a case the company will align itself with the competitors having larger volumes and without the economics of scale the higher product costs will ruin profitability.

A small, niche market share demands that the product shall be flexible to adapt different requirements. On the global crane market, there exist three product types according to their trolley construction, categorised as rope towed, semi-rope and full machinery trolleys. Customer preference depends either on the quay strength or geographical tradition.

The target for the new product development was that the same basic crane structure should be suitable for all different trolley types. The guideline was argued to provide reasonable volume for modularisation, while combining different types of product [3]. Alternative concepts and designs were analysed in detail as well as considering applicable manufacturing and erection aspects. Modularisation was considered simultaneously with concepts and finally the concept selection was greatly influenced by modularisation.

The project cost structure indicates that the direct product costs may not be significantly reduced by the new concept. Combined effect of the new design and revised design criteria was approximated to bring 3-5 % reduction. Greater expectations were set on indirect product costs like engineering, erection and transportation. These cost items were aimed to be attacked by modularisation and reduction was approximated to be at least another 5%.

4.1 Product modularisation

Drivers for modularisation have been introduced in several papers. An approach is presented [2], which divide module drivers into two, namely functional and strategic aspects. Both aspects shall be taken into consideration while grouping solutions into modules. Within industry, the relative importance between these two aspects may vary. In this particular case the strategic aspects become more dominant.

Strategic aspects came from the company's business plan and the way the business is driven. A customised product project involves a lot of engineering work and it has become critical for the lead-time. Thus the product specifications are broad, in practise the product details are not described very well. Typical situation with a project is that the details become more accurate during the engineering process. Challenging task for the engineering is to produce rapidly all relevant information what for purchasing long delivery time materials and components and still maintain control with modifications.

Once the manufacturing is outsourced from lower cost countries, it also requires comprehensive supervision. Thus the unique designs have been based on previous projects the different mistakes and problems repeat randomly project by project. Low volumes do not provide learning curve effect, but more constant assemblies and components may enable more robust process.

Functional aspects with grouping the technical solutions into modules within a customised product involve various elements. The main dimensions vary case by case, capacity and characteristics are variable and a lot of optional equipment may be provided. The modularisation of the new concept started by structuring the product attributes and features from earlier analysis by evaluating:

- which product blocks are fully customised (typically interface dimensions)
- which product blocks are customised but may be clustered or pre-sized based on market information
- which product blocks have consequences to another block(s)
- which variables exist with typical blocks
- what optional equipment exists with blocks

According to evaluation, the interfaces and content of each block were defined more detailed.

5 Modularisation impacts

Switch from optimised custom designs to modularised design causes changes to engineering process. While the customisation gives freedom for the designer to choose solutions and details, applying modularisation principles require a lot of attention and control for sizing variations and interfaces.

5.1 Product design

Modularisation involves utilising standardised or pre-designed solutions, which are generally designed to fit for certain attribute range. Designed ranges presume that the selection is done stepwise, which in case of steel structures is hard to accept by designers. Applying size ranges for various components like motors and gear reducers is normal, even it in many cases lead to over dimensioning. The design of structures is still considered to be optimised, most likely because the weight difference between optimised and pre-designed solutions can be easily calculated.

The crane main structure dimensions were defined for four different outreach ranges with predefined extensions. These sizes create the framework with different sub-modules. Standard modules define structural geometry, sections and suspension hinges, which provide commonality between ranges. Variable modules with pre-determined ranges were applied within sub-modules, where analysis show potential need for variations. These variable modules were designed with auxiliary equipment and fittings; e.g. crane height series were designed to match with stair rise module to eliminate brackets design case by case. Customised modules were applied for blocks having typically attributes, which have to meet customer specific dimensions. These modules were designed with standardised interfaces.

A special feature with machinery modularisation was that the mechanical, electrical and control systems were considered together and not separately. A crane is an embedded system, in which the mechanical design and functional properties are affected by the behaviour of electrical equipment and control software – and vice versa. Therefore a machinery module were structured and designed as a combined system. This organisation enables the early definition of key components still maintaining the flexibility for possible changes, because the interactions within the systems were defined and controlled. Machinery layouts were frozen including optional equipment to be selected case by case. Component selection was based on three capacity and speed ranges according to component size ranges to avoid case by case design.

5.2 Design work

One of the main targets with modularisation was to reduce design work in projects. The comparison of engineering work between reference project, modularisation project and first project after modularisation is shown on Figure 3. Thus the projects never are alike and not directly comparable as such due to various differences, an indication of modularisation effects may be seen.

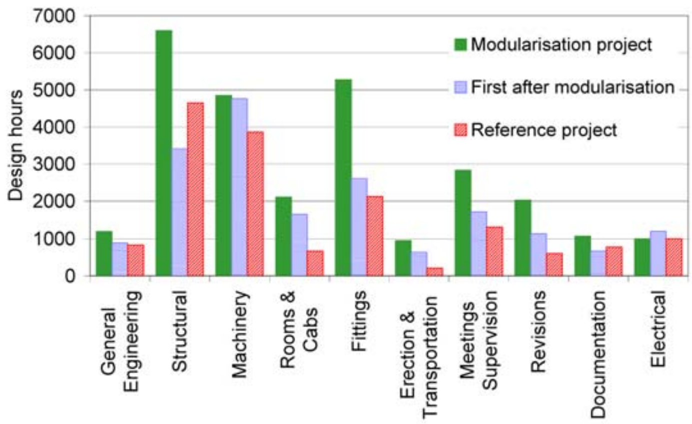

Figure 3. Design work content within projects

During the modularisation project, additional efforts have been directed to structural and fittings design. This seems to be logical while preparing interfaces and solutions to meet variables. The work reduction in first project after modularisation has realised within structural design, showing utilisation of pre-designed, standardised solutions. Significant reduction has realised on fittings design, thus not yet reached the reference project level. Almost equal machinery design work may be explained with different product types between modularisation and first following project.

5.3 Engineering Process

Once the project contract has been signed the actual product design can start. During the final negotiations the main content of the product is defined, however modifications to the original specification have been made. As the delivery time is critical, the product content should be defined fast and enable ordering of components and materials, which have the longest delivery time.

The lead-time to manufacturing may be evaluated by two factors; (1) time from order to launch of material purchase data and (2) time from order to launch of manufacturing drawings to contractors. The comparison between projects is shown on Figure 4.

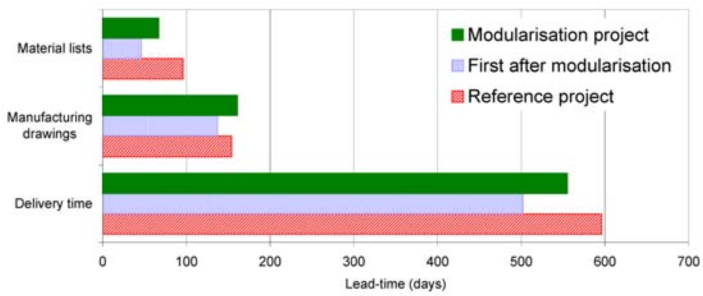

Figure 4. Lead-time comparison between projects

The decreasing tendency of delivery time may be seen, but also that after the modularisation project the lead-times have been reduced.

5.4 Product data management

One-of-a-kind product environment with low volume may not justify a computerised product configurator at once. Due to large range of customised attributes and variables, comprehensive pre-designed product module library and selection rules cannot be created reasonably. The content and utilisation of product data may be approached by their purpose during the engineering process.

Offering is the starting point for new projects. Actually the product concept and most of the details are defined for the cost estimation, which create the basis for the design in case the contract realises. As the sales process causes changes to the content of the offer, consequences and the accuracy of the estimate is critical. The data generated during offering includes the weight and/or cost of different structural blocks, machinery components, manufacturing, erection and transportation concepts.

The task of the product design is to generate manufacturing documents; material lists, drawings and instructions. The applicability of previous designs in customised environment is limited due to one-of-a-kind approach through the engineering. Generally all documentation is created for each project, thus similarity between projects exists.

The accuracy of the cost estimation may be improved by utilising feedback from past solutions and the structure of cost estimation must follow the product modules in which the variables can be evaluated. The outlined new organisation collects the content of modules, variables and options into module binders added with information for cost estimation and design. Frozen dimensions and sections for structures are described with the possibility for plate thickness optimisation case by case. Machinery assemblies in ranges are defined in mechanical and electrical component level with frozen interface dimensions. In case of coming new optional equipment, the binders are completed accordingly. The organisation and applicability of manual binders are further tested and may be later converted to an electronic system.

The identification system for mechanical drawings was modified also. Thus the identification was already build to support product blocks, a unique set of drawings were generated for each project in the past. The system was modified so that hierarchically below each main customised product blocks standard identification sub-blocks were introduced. This organisation enable the utilisation of previous designs as such and still maintains the higher level variations e.g. customisation. The customisation may be created with so-called customised blocks, which have standard interfaces but variable attributes.

6 Conclusions

This paper describes an approach for concept generation and modularisation in industrial customised product environment. Different aspects and methods are introduced for collecting customer requirements and selecting product concept and modularisation principles. Thus different products vary by their application and customers, some generalisation among customised products may be seen. In this paper it is presented that the application of modularisation is a strategic business decision and modularisation was found an important factor for selecting the product concept.

Product modularisation was structured by clustered characteristics from various surveys. Different types of modules were applied within functional product blocks; standard modules to provide commonality between ranges, variable modules for pre-determined ranges and customised modules for customer specific dimensions. A specific feature with creating machinery modules was that mechanical, electrical and control system were combined together to enable better control and design of product properties.

Modularisation impacts for engineering process are investigated and reduction of design work and lead-time were found compared to reference project. Modularisation requires utilisation of product data management and an approach to supportive PDM-system for one-of-a-kind product is presented.

The methods and findings are applicable within the environment and product presented in this paper, but further research should be directed for better quantitative and qualitative evaluation of impacts.

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Corresponding author:
Hannu Oja
Tampere University of Technology
Konecranes VLC corporation
P.O.Box 666, FIN-05801 Hyvinkää
Finland
Tel: +358 20 4271640
Fax: +358 20 4272599
E-mail: hannu.oja@konecranes.com
URL: http://www.konecranes.com