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DESIGN METHOD FOR MODULAR CUSTOMISED PRODUCT FAMILIES TO CONSIDER DIFFERENT USE STRATEGIES

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1. Introduction

The increasing awareness of life cycle costs has focused the acquisition process of customised investment products towards total costs employed during the whole lifetime. Investment products, typically production machines, may be described as:

- Moderate or high initial investment (over 1 m€)
- Long expected life-time (20 years or more)
- Pre-determined performance and/or characteristics
- Operation is automated or semi-automated including lot of instrumentation.

Different acquisition strategy approaches may be identified with investment product purchase process, like; pure acquisition cost, life cycle cost and life cycle cost performance approach.
The purchase price provides an easy evaluation and selection method between different suppliers, but it is seldom as such sufficient criteria for the profitability or usability over the lifetime. When the equipment shall generate income for years, the operation costs and product performance form the key elements for profitability. Life Cycle Cost Assessment and product end-of-life strategy provide approaches for product design, while taking into account total impacts during design, manufacturing, operation, service and disposal. However, when the operation phase of the product is dominant, more detailed analysis of the use stage is needed.
The design parameters shall be determined so, that they have significant relationship to at least one life cycle parameter. As example, typical parameters include product output characteristics, like power output, operating speed, transmitted torque and force. In addition to product characteristics as design parameters, another viewpoint to design is the operational performance. Thus this is not directly included in Life Cycle Assessment, it is specifically with investment products an important factor for generating the income and presents the base for trade-off between initial acquisition cost and costs accumulated during the product usage.
Product manufacturer has to take into account several phases during the product use; installation, commissioning, warranty and operation. The benefits for the owner and the manufacturer during the operation stage are identical; short installation and commissioning time, low repair and maintenance costs and low downtime. Another aspect for product design is the type of use and maintenance policy. Product features should be designed based on use case analysis taking into consideration the satisfaction of customer requirements and product costs [Shun, 2001].
The objective of this paper is to introduce different use and maintenance policies of an investment product and suggest a method for conceptual design for combining maintenance policies and modular customised product family. That method is visualised by using a matrix. This research is made in the

leading globally operating crane manufacturer KCI Konecranes and especially in Very Large Cranes business unit.

2. Product end-of-life strategies

Product life cycle assessment is the financial and environmental impact investigation over the whole lifetime of the product. The assessment includes raw material acquisition, bulk processing of raw materials, product and packaging manufacturing, product usage (service), retirement (recycle, remanufacture, reuse) and final disposal. Rose [2000] has presented four end-of-life scenarios and guidelines to designers how to improve product life cycle assessment balance. Ishii [1998] has introduced that product positioning into different categories may be done according to the duration of the technology cycle and product lifetime. The product end-of-life scenario, duration of the technology cycle and product lifetime may be used as high-level guidelines, which design elements may be followed during development and design [Niemann, 2003].

When the usage period of the product is very long user selects mainly the product based on attributes and features during the usage stage. Customers have shown growing attention on the other end-of-life stages.

Profitability, the rate of the product utilisation and payback time of the production machines have become more critical in today's highly competitive manufacturing industry. The indirect costs (maintenance, unavailability) during the product lifetime has a great importance on profitability.

As the operational (total) performance is achieved with the combination of technical and availability performance. Technical performance may be described with product attributes characterised by output figures, but in case of human operated machines the product properties (utilisation comfort, maintainability) have an important role on operational performance.

2.1 Maintenance systems

Product users try to utilise the best performance out of the investment. Different types of industry and the stage of maturity in business have impacts how maintenance is organised. The type of maintenance system has an impact on how product features may be utilised during usage stage. Among harbour crane operators following user group types may be recognised:

- In-house maintenance organisation, which is capable to perform almost all maintenance and service activities. The personnel have knowledge on mechanical, electrical and electronics, have adequate tools, instruments and sufficient workshop facilities for repairs. Company is generally self-contained with spare parts. The maintenance organisation may have a dedicated IT-system for collecting equipment usage data and scheduling maintenance activities. Typically this user type is well above the average size and mature in business. The organisation may be as a result of historical development (e.g. communal authority) or in-house maintenance has been chosen as one key strategic value for the business. In-house organisation has a strong impact during product purchase. Preference is put on solutions and components similar to existing products. Constructions should be maintainable, adjustable and non-integrated.

- Partly outsourced maintenance systems may be seen as a dominant today. Transform from in-house organisations to outsourced has been going on for more than a decade, mainly due to concentration to key businesses. Outsourcing has first taken place for laborious regular maintenance activities and larger repairs as turnkey deliveries. In-house recourses have been dedicated for equipment specific trouble shooting and repair of control systems and drives (frequency converters, motors, machinery).
- Partly outsourced organisations are more adaptive during purchase process, preference is on proven solutions and components, but the product manufacturer has greater possibilities toto use own solutions. Robust, redundant systems are preferred, maintainability is not an issue. Integrated solutions are accepted in case the recovery from failure is not sacrificed.

- Totally outsourced maintenance system may bee seen on companies, which have focused on key business activities. The tendency is even towards low capital intensive operation, in which owning of the equipment is not attractive – only high utilisation and productivity. Products are purchased or leased with maintenance and detailed technical solutions or components are not under discussion during purchase negotiations, only characteristics and performance. Product manufacturer may choose the solutions, thus novelty designs have to be proven feasible. As the part of the responsibility and financial risk of operational performance is hold on the manufacturer the awareness of the product condition and failures are important. Designed and selected solutions should include supervision of operation to prevent miss-use, feedback of usage and condition for maintenance requirements and modular structure to enable latter upgradeability.

Among these three main types different combinations exist, but while creating product families for customised products at least these measures shall be taking into account.

2.2 Product maintenance policies

During the purchase process of an investment product the operative, maintenance and financial sections have presence and impact during negotiations. Each section has its own preferences and final product characteristics and attributes are a combination or compromise of different aspects. The actual product operating conditions follow rather the type of the usage policy than how the maintenance is organised. Analysis of equipment usage and maintenance shows different maintenance types like;

- Breakdown maintenance (operate to failure); the equipment is used as long as serious breakdowns occur and prevent operation. Maintenance is pure repair activities as emergency on-calls. Breakdowns occur during operation and cause a lot of downtime. Main focus on maintenance (repairs) is fast replacement of broken components. The maintenance costs are dominated by indirect (downtime) and direct repair and component costs. Technical solutions may not include adjustable or monitoring features.

- Preventive maintenance (scheduled); the equipment are maintained according to predetermined plan, either based on operating hours or calendar days. Maintenance activities include typically lubrication, change or adjustment of wearing parts and routine inspection of safety devices. The target of the maintenance activities is to lengthen product usage time by lubrication and adjustment of wearing components. Significant share of the maintenance costs consists of direct labour and consumables, resulting decrease on indirect costs. Technical solutions shall include means for re-lubrication and adjustments.

- Predictive maintenance (condition based monitoring). Decision of maintenance activities is based on equipment condition, which is measured or analysed either manually or automatically. Maintenance is performed when required, which cause a reduction of direct maintenance costs by avoiding unnecessary activities. Technical solutions shall include means for measurable condition detection, re-lubrication and adjustments.

- Proactive maintenance (maintained and diagnosed system with upgrading and/or conversion options). Maintenance activities are performed as predictive system, but in addition to that the technical solutions may include means for detection of sources of failures. Active monitoring and diagnostic system the operational performance may be improved by correcting root causes of failing components. The solutions shall be designed modular to enable later upgrade to improve performance and/or extend product lifetime.

The case analysis of maintenance systems and product maintenance policies give an indication how the customer requirements may be categorised and transferred into product specifications while creating product families. In addition to performance characteristics the analysis forwards the product designer's decisions to improve usage stage, while utilising modular product structure.

3. Design method for different usage maintenance strategies

3.1 Design disciplines

Large machines consist of different constructional (elementary) blocks, which are generally divided by professional disciplines. The grouping in this context is aimed to show that each block presents certain type of technology, which has its altering mechanics and lifecycle. Therefore the end-of-life strategy of each block is considered separately and not for the whole product as presented by Rose [2000] and Ishii [1998]. This partition is not modularisation.

Traditional partition of main constructional blocks of a machine by professional disciplines and their typical design approach may be presented as:

- Main frame, base e.g. supporting structure. The design is done for the total lifetime by assumed loads, cycles, environmental impacts etc. During the usage the actual conditions may differ from the design assumptions and faster degradation may occur. Typically these are environmental impacts (surface coating) and type of operation (unexpected type of use, overloading, collision). Main frame structures are seldom maintenance sensitive, thus need inspections and repair actions in case defects. Generally main frames are integrated due to customised requirements and modularity may be applied only during product configuration and design.
- Mechanisms, machinery, movable/working devices. The primary design principle is performance driven for predetermined lifetime. The real operating conditions may differ from design assumptions and therefore these constructional blocks are maintenance sensitive and may not reach the total lifetime of the product. Due to individual product design, the struggle between optimised versus modularised and integrated versus standard designs always exists. Application of size ranges and series is obvious on component level, but may be favourable also on mechanism level.
- Electrical system, power supply equipment and field devices. The design and selection is done for maximum and average loading combinations. The lifetime of this constructional group is not time related, thus influenced by environmental wear and maturity of electronics. In case of customised products, standardised design may be applied within equipment, but not between them. Application of modular components is obvious. Field devices (limit switches, sensors) are a great source of failures and malfunctioning. Whilst the diagnostic features of systems require more data acquisition equipment, the risk of sacrificing product availability exist.
- Control system, (controller + software). The design is application based and fitted for purpose. The system is tightly integrated with the equipment in purpose to realise functions. Accordingly the changes and upgrades may be difficult if modularity options have not considered.

In addition to these four main blocks, there exist components like consumables, means for access etc.

3.2 Design views (DFX) in conceptual design

Ullrich and Eppinger [1999] have presented the conceptual design process with phases from identifying customer needs to refining specifications. This design process is applicable also for customised product development and design. Each considerable product concept should be created by a preliminary technical solution. The analysis of product usage and maintenance policies may be used as an approach to support the generation and selection of product concept. Early recognition of different usage and maintenance policies (customer requirements) may also be successfully applied for product family generation and basis for modularity [Riitahuhta 1999]. Different subsystem variations (modules) with predetermined interfaces may be specified simultaneously for particular project or customer.

3.3 Design for specification criteria (DSC)

Design for specification criteria is the basic approach for customised product. Predetermined specifications made by customer have detailed design criteria and component specifications and cause partial optimisation with design. The design is made for the worst case condition, which generally means overdesign for the purpose. Robust design is the best guarantee to reach demanded lifetime or even have extended lifetime. Technical systems shall be build up with independent components without integration, which provides easy replacement and repair. Components shall be the same type or model than existing equipment at customer's site to be supported by in-house maintenance and spare part stock.
Design for specification criteria lead to unique one-of-a-kind product and cannot be used for product modularisation or configuration purposes.

3.4 Design for fit to purpose (DFP)

Design for fit to purpose is application driven and is type of performance specification. Machine functions and requirements are defined with an addition of performance characteristics. Often customers' inquiry calls for manufacturer's standard off-the-shelf solutions. By allowing integration within functions the customer sees the benefit of technological development and system simplification providing better availability and performance by reducing the number of parts. Design optimisation is directed from component level to functional level.
Design for fit to purpose enables the basis for modular approach with product family creation.

3.5 Design for life cycle (DLC)

Design for life cycle approach covers the whole product life from manufacturing to retirement. The product designer's decisions are primarily directed for usage stage. Design parameters relating to the life cycle inventory and product operational performance should be considered. As the interest is to maximise the life cycle profitability of the investment, the cumulative costs shall be minimised and production made by invested product shall be maximised during the lifetime.
Design for life cycle may be applied on modular fit to purpose design with features to enable measurable condition monitoring of the system. The detection of roots of caused failures and/or performance deficiency enable to further develop life cycle profitability. These features require measurable data the information of machine behaviour. The information should be collected and stored. It should be analysed and screened to identify cause for the failure.

3.6 Design Method

Above it were presented four different modes for enhancement the design of investment products. These are

- Maintenance systems
- Maintenance policies
- Design disciplines
- Design views.

Authors have seen in the global crane business that those modes are becoming more important when companies are going towards Service Oriented Business paradigm. Similar phenomenon happens on other product areas e.g.

- energy production power plants
- welding gas supply
- buss industry.

Based on the research in the crane industry it is suggested the following method. In the method decided maintenance policies and maintenance systems can be applied by using presented design views in each disciplines. Table 1.
The two latter design methods (DFP, DLC) may be combined for considering modularity features and provide an approach for creating a product family for a customised product. The analysis shows that machinery, electrical and control systems have impacts on each other depending on which design

strategy is followed. Structure (base) seems to follow more specification criteria and not bound to other blocks. While creating product family for a customised product these three main blocks cannot be developed separately, if modular approach for product configuration is targeted. Further on, the higher level features cannot be type of add-ons due to deep integration of different systems.
The applicable design methods for different constructional blocks within four main technical disciple (S: structure/base, M: machinery, E: electrical, C: control) are shown.

Table 1. Method to select design strategy

	Breakdown maintenance		Preventive maintenance		Predictive maintenance		Proactive maintenance	
In-house maintenance	^{S} DSC	^{M} DSC	^{S} DSC	^{M} DSC	^{S} DSC	^{M} DFP	^{S} DFP	^{M} DLC
	^{E} DSC	^{C} DSC	^{E} DSC	^{C} DSC	^{E} DFP	^{C} DFP	^{E} DLC	^{C} DLC
Partly outsourced maintenance	^{S} DSC	^{M} DSC	^{S} DSC	^{M} DFP	^{S} DSC	^{M} DFP	^{S} DFP	^{M} DLC
	^{E} DSC	^{C} DSC	^{E} DSC	^{C} DSC	^{E} DSC	^{C} DFP	^{E} DLC	^{C} DLC
Totally outsourced maintenance	^{S} DSC	^{M} DFP	^{S} DSC	^{M} DFP	^{S} DFP	^{M} DFP	^{S} DFP	^{M} DLC
	^{E} DFP	^{C} DFP	^{E} DFP	^{C} DFP	^{E} DFP	^{C} DLC	^{E} DLC	^{C} DLC

4. Conclusions

Large machine systems consist of multiple subsystems or constructional elements. Each system may have a different end-of-life strategy, which is influenced by usage and maintenance policy. Early recognition of customer behaviour on product usage and maintenance may assist to configure product for better fit to purpose. A design method for conceptual design phase is presented in this paper. The study has shown that modern customised products consist of multiple embedded systems and product can not be divided into constructional modules within one technical discipline. Integration and interaction of mechanical, electrical and control systems within multiple subsystems cause that modularisation shall be considered by different measures covering different technical disciple aspects. Future research is needed to study models and tools for concept generation, selection and product configuration for such products.

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