Module Property Analysis in the Assembly Process

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ABSTRACT
Property analysis of modules in a modular product can support the decrease of lead-time to customers (TTC) by shortening the time needed for control and/or testing to verify product specifications. It is argued that verification of product specifications on complete product level, product property analysis (PPA), should be shifted towards verification on a modular level, module property analysis (MPA). To decrease TTC successfully the MPA should be integrated into the activities of the module assembly workshop, using flexible MPA fixtures enabling efficient adaptation to changes necessary for new products and properties. It is also postulated that the resulting property of a modularised product can be described as the sum of the property transfers and receives between modules.

INTRODUCTION
The need today for a decreased lead-time to customer (TTC) is essential to remaining competitive. At the same time, the development of new products has to increase and be steadily ongoing in an iterative process, fulfilling new needs in the changing market. Several authors have discussed the importance of a short TTC. Three benefits of launching a product ahead of the competitors are suggested by [Preston & Reinertsen 1991]. Firstly the market share increases, secondly the product's sales life is extended, and thirdly a higher profit margin is achievable due to pricing freedom. For many companies the solution to remaining competitive is an implementation of a modularised product assortment. Modularisation is here referred to as a "decomposition of a product into building blocks (modules) with specified interfaces, driven by company specific reasons" [Erixon 1998], and implementation implies that modularisation is realized and fully understood throughout the company.

A modularisation of the product assortment has proven to decrease TTC as a result of parallel activities in module assembly [Erixon 1998], see Figure 1. Modules can be assembled in separate assembly workshops and supplied to the main flow for the final assembly into a finished product. The decreased TTC is due to the parallel assembly instead of assembling the product part by part on a serial assembly line.

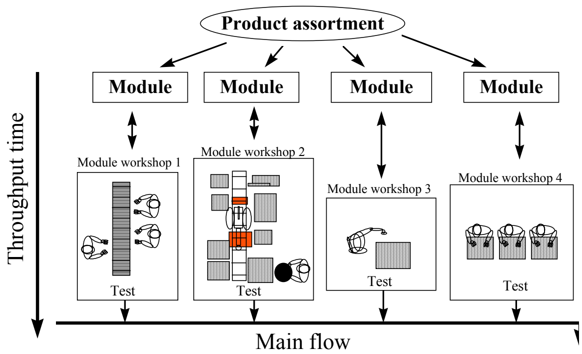

Figure 1: Parallel activities in the module assembly [Erixon 1998].

Parallel activities require specifications of interfaces that in turn allow parallelism both in product development and manufacturing [Stake 2000] and, at the same time, concurrent processing of independent blocks will reduce the cycling time dramatically [Baldwin & Clark 2000].

New challenges for property analysis intense modular products

Although a modularised product assortment has several benefits, the implementation confronts companies with new challenges, especially for companies with products that can be considered property analysis intense. Intense implies that the property analyses are time demanding, expensive, difficult to perform or difficult to evaluate. One example is ABB Power Technology Products/Components which assemble 1100 high voltage transformer components annually. To ensure that there are absolutely no defects every component is property analysed during assembly which takes time and money. Thereby, the products can be considered property analysis intense. Another example is Remote Control Sweden AB assembling pneumatic, electric and hydraulic valve actuators. Remote Control Sweden AB competes in the global market for high quality products, selling over 25 000 products annually. Quality is assured through several property analyses on all products at part level, sub-assembly level and product level.

Experiences from case studies show that the process of PPA extends the TTC. This is due to transportation of the product to the PPA workshop, the set-up time in fixtures, evaluation of the analysed result, and adjustment of possible defects. For example, the valve actuators at Remote Control Sweden AB are analysed using water and a pump. The valve actuator is mounted in a pressure analysis fixture where water is pumped into the valve actuator at the specified working pressure. At ABB Power Technology Products/Components it is necessary to disassemble some of the product variants after the PPA to enable packing and shipment, which further extends TTC. Sepson AB, producer of hydraulic winches for civil and military use, has to disassemble the tested winch after the PPA in order to detect any defects, which further extends the TTC.

The train couplers of Dellner Couplers AB must comply with a large variety of standards, authorities and regulations [Kenger 2002]. At the same time, the needs from different customers vary which is also the case at Sepson AB and ABB Power Technology Products/Components. The operators performing the property analysis have two choices. One, to trade-off between the standards and the customers' need in order to accelerate the property analysis and to make it more economically feasible or, two, to handle all possible standards and customer needs even if they sometimes overlap, resulting in extended TTC and increased costs.

In a changeover from product property analysis (PPA) into module property analysis (MPA) a company will encounter new challenges. The *first* challenge is how to derive the properties of modules from verifications of the finished product, and how to generate properties of products from verifications on a modular level. That is, module property analysis (MPA) has to be derived from product property analysis (PPA), and the product properties should be generated from the results of MPA. The *second* challenge is to integrate MPA into the activities in the module assembly workshops in such a way that TTC will be decreased. The *third* challenge is to find a balance between the needs of the product and the properties to analyse, without making too many trade-offs.

MODULE PROPERTY ANALYSIS

Benefits from controlling and testing on a module level, i.e. MPA, have been discussed by many authors, e.g. [Erixon 1998] and [Robinson et. al. 1990]. In the AIP (Assembly Initiated Production) concept TTC only consists of the final assembly of modules, and shipment [Onori & Karlsson 2000]. In order to achieve the shortest possible TTC the properties of every separate module have to be known and verified beforehand, as well as the resulting properties of the assembled product. Otherwise, the property analysis has to be performed after the final assembly extending TTC. Thus, the AIP concept underlines the benefits of performing MPA.

Theory of Module Property Analysis

When performing MPA the interface relations with other modules have to be considered, as well as the property transformation of the actual module. [Baldwin & Clark 2000] argues: "To evaluate a module without embedding it in a prototype system requires detailed knowledge about what the module contributes to the whole, as well as how different modules interact". An interface may be seen as the connecting system created between two or more modules. [Erixon 1998] describes six different interface relations between modules: Attachment, Transfer, Control & Communication, Spatial, Field, and Environmental. Interface connections can also be looked upon as "property carriers". The property carriers transfer and/or receive properties to and from other modules, and to and from the connecting environment. The transformation, transfer and receive may be described as follows, see Figure 2:

- A module transforms and/or forwards received properties, within the *Module System*.
- The transformation and/or forwarding of properties result in a transfer and/or receive to and from the module. The transfer and/or receive takes place within the *Modular Product System*.
- Transfer and/or receive also takes place to and from the *Environment System*. The environment system may be seen as the surroundings that affect the modular product system and the module system, e.g. train carriages on both sides of coupler, vehicle connected to the winch wire or human users.

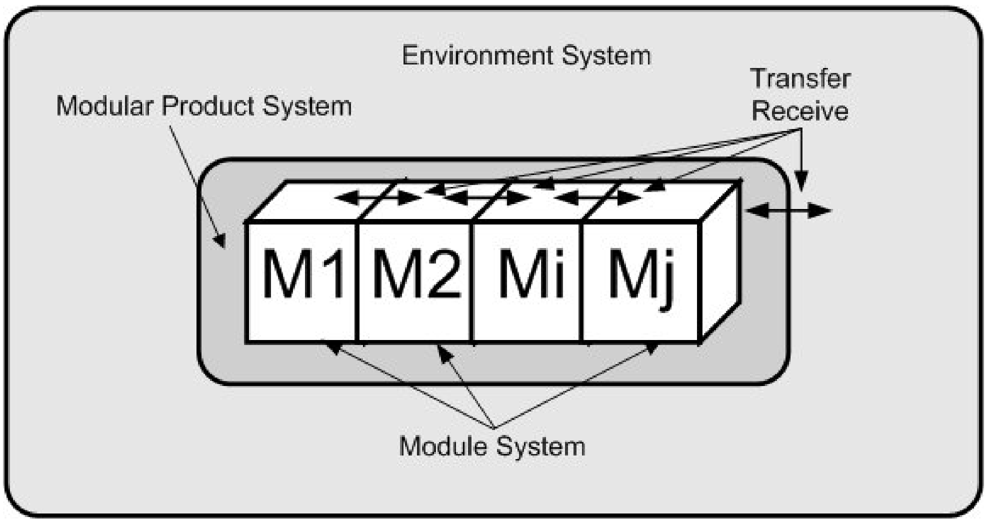

Figure 2: Schematic way of looking at a modular product with different systems, M1, M2, Mi, and Mj denotes modules in a product build up by j modules.

The transfer and/or receive between modules results from the environment system, the modular product system, and the module system. Thus, if the total transfer and receive system is known the complete product properties are known. Thus, a product analysis on module level (MPA) will equal what the modules are capable of transferring and receiving between each other. Based on this it is postulated that the resulting property of a modularised product is the sum of the receiving (R) and the transferring (T) between the total numbers of interfaces (including the environment interface).

Equation 1: *The resulting property of a Modularised Product* $= \sum_{m=1}^{n} R_{\mathrm{Im}} + \sum_{m=1}^{n} T_{\mathrm{Im}}$

A modularised product with *j* modules and *n* interfaces may have several property carriers which results in a transfer and/or receive system of properties between all the modules. In Figure 3 interface I_m on the detached module M_i transfer (T) and receive (R) properties to and from interface $I_{n\text{-IMi}}$ on $M_{j\text{-}1}$ modules, where,
n = maximum number of interfaces (including environment)
j = maximum number of modules
IM_i = all the interfaces on module i
$\Leftrightarrow$ = transferring and receiving of properties.

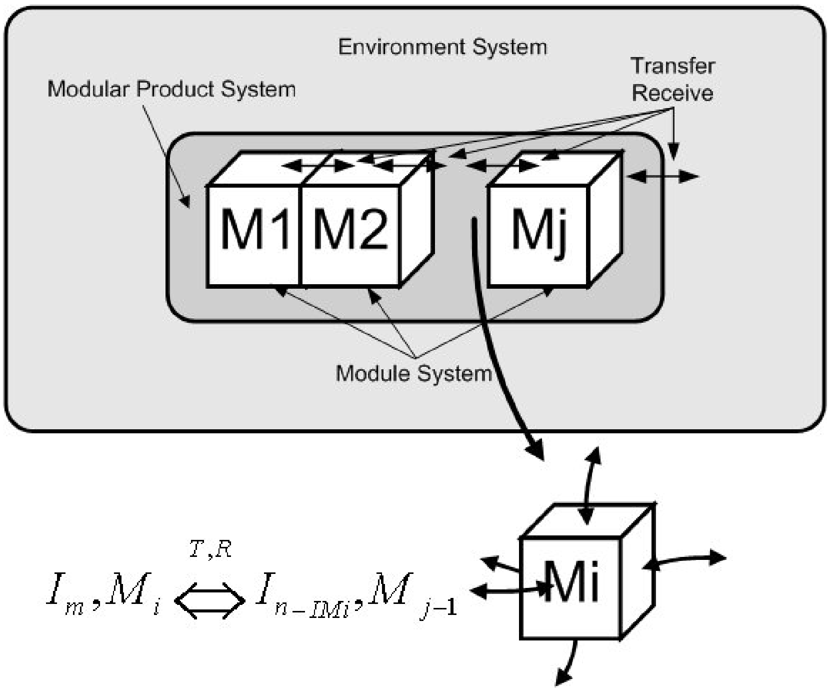

Figure 3: A module (Mi) detached from its context which transfer and receive properties within the modular product system and environment system, schematic.

A similar approach has been proposed by [Hubka & Eder 1988] using the *operand* concept instead of Environment System, *transformation* process instead of Module System and *receptors* and *effectors* instead of transfer and receive. The theory put forward in this section will be further developed in continued research.

MODULE PROPERTY ANALYSIS IN THE ASSEMBLY PROCESS

It is known that the number of product variants increase and new products are introduced on the market with shorter intervals, see for example [Ericsson & Erixon 1999] and [Womack et. al. 1990]. New product variants set new demands on the assembly system. [Andersson 2000] mentions three changes that the assembly system has to adopt: changes in shape, in assembly time, and in the number of parts. To adapt the assembly system to various needs, [Johansson 2002] discusses a modularised assembly system with standardised modules and interfaces as the solution. If a modularised assembly system is used, the fixtures have to fit into this modular approach. Even if a modularised approach is used for the assembly system and at the fixtures, the place in the assembly process for the property analyse workshop will have a major impact on the final TTC result. There are three options on where to place the property analyse workshop.

The *first option* is to perform PPA by locating the property analysis workshop at the end of the final assembly. In this case, the TTC is extended by the time the PPA takes, and operators are needed to perform the PPA. On an already assembled product it is more difficult and more expensive to adjust any defects that are detected. It can be ten times more expensive to repair a defect once a product is fully assembled than it is to repair the same defect at the point at which it occurs [Robinson et al. 1990]. In addition, heavy and/or bulky products are difficult to handle during PPA, and a separate workshop is needed.

The *second option* is to perform MPA separate from the module assembly, as an isolated operation. This requires MPA operators and a separate MPA workshop. If any defects are detected the module needs to be transported back to the module assembly workshop for adjustment which extends the TTC. Alternatively, any detected defects can be repaired at the MPA workshop that, in this case, requires repair equipment and spare parts. In addition, the MPA operator needs knowledge about the assembly sequence for the modules. In the end, this may result in a redundant set of module assembly workshops.

The *third option* is to integrate MPA in the module assembly workshop. If any defects are detected, the assembly operator can adjust the defects directly as they are detected using equipment and parts in the module assembly workshop. There is no need to transport the module to any MPA workshop, i.e. a decreased TTC, and, there is no need for more operators apart from the ones already working in the module assembly workshop. [Robinson et. al. 1990] discuss three different strategies for handling defects on an assembly line. These are line-stop strategy, which stops the line and repairs the defect on line; repair-shop strategy, which moves the defect part into a repair shop off line; or asynchronous strategy, which divides the assembly line in sub-lines with small repair buffers in-between. The on-line strategy is beneficial in the sense that the assembly operators become more aware of the defect causes and effects, leading to an overall reduction in the defect rate.

Given that defects occur, the third option seems to be the most beneficial, i.e. to perform MPA as an integrated part of the module assembly workshop.

CONCLUSION

A conclusion of the discussions and theories in this paper is that there is a need to perform MPA as an integrated part of the module assembly. To do this, fixtures to perform the MPA have to be a part of the module assembly workshop. In the use of the fixtures it has to be possible to analyse and to evaluate if the module fulfils needs from standards, authorities, customers, and the company. That is, to analyse the transfer and receive capacity of the modules. The MPA fixtures should be modularised in order to adapt to the changes in the assembly system and among the product variants. Further research including case studies is planned with the objective to develop and strengthen the theories of MPA.

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