NordDesign 2004 – Product Design in Changing Environment
18-20 August 2004, Tampere, Finland

TOWARDS A FRAMEWORK FOR INTEGRATED INFORMATION MANAGEMENT IN MECHATRONIC PRODUCT DEVELOPMENT

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Mechatronic, information management, integration, system

Abstract

Information management at companies devoted to mechatronic product development is a cumbersome task due to the complexity of product definitions and supporting system architectures. The technology domains constituting mechatronics usually have their own courses of actions, culture and supporting information systems, thus making the environment in mechatronic development heterogeneous. This research work contributes to a framework applicable when adopting an integrated approach to information management. The framework approaches the area by distinguishing between organisation, process, system and information aspects of information management. Special emphasis is put on integration aspects on the system an information level.

1 Introduction

Large companies devoted to mechatronic product development typically have a variety of computer systems for administration of the evolving product definition. The arrangement of these systems frequently constitutes complex architectures that lack in integration. In order to achieve effective and efficient collaborative development it is fundamental to develop and implement information solutions that support inter-domain communication and that supply engineers with correct data throughout the development process, thus calling for tighter integration.

This work makes a theoretical contribution to mechatronic information management by delivering inputs to a framework of how information systems shall be deployed and developed in organisations devoted to mechatronic development. The framework is based on theories of product development as well as observations in industry and represents an analytical approach. The work adopts a holistic approach and distinguishes between four different views related to the management of information in mechatronic companies - organisation, process, information and system - as proposed by [Svensson03].

The remainder of this paper is structured as follows. Section 2 introduces related research work. Section 3 delivers a theoretical approach to information management in heterogeneous environments. Section 4 discusses issues associated to application of the framework. Finally, the work is concluded in Section 5.

2 Related work

Svensson [Svensson03] has performed work in the area of integrated information management in support of mechatronic product development. He proposes the overall point of departure for this work – Engineering Information Management (EIM), by recognising the four views of organisations, processes, information and systems. This subdivision show significant similarities with activities prescribed for the development of standardized information exchange protocols of ISO [ISO98]. Kruchten's [Kruchten95] 4+1 View Model of (Software) Architecture also show noteworthy similarities with the views of EIM. The work presented in this paper brings Svensson's approach further in providing a holistic perspective on integration by concurrently treating all four views of EIM. It also provides detailed considerations, for the company in focus, regarding information and system integration.

Information model integration plays an important role in EIM. Information related to the electrical and mechanical product definition is extensively modelled in the ISO10303 standard (STEP) [ISO94] and can be utilized for further research, but the dimensions of software and mechatronics are not explicitly covered.

PLM vendors [MatrixOne04] [EDSPLM04] [PTC04] have offered off the shelf integrations between information systems over the last couple of years. However, these integrations are often only to a limited extent adaptable and lack in performance and functionality.

A substantial contribution in the area of system integration is that of Crnkovic et al [Crnkovic*etal*03], where they provide an overall framework for Product Lifecycle Management (PLM) and Software Configuration Management (SCM). Their book is supposed to officiate as an implementation and integration handbook, however it turns out to be more of an outline of what PLM and SCM are about and how the two disciplines differ.

He et al [He*etal*03] and Gao et al [Gao*etal*03] have proposed detailed information system architectures and implemented solutions integrating PLM and Enterprise Resource Planning (ERP) systems. These contributions are system oriented and focus peer-to-peer integration of commercially available tools. Unfortunately, these approaches delimitate organisational and process aspects.

On a more theoretical level, some work presenting integrated frameworks for information management has been presented by industry. Grabowski et al [Grabowski*etal*03] describes a few examples of frameworks for engineering collaboration. However, they are not aiming at the complex of problems associated to mechatronic products. Instead, they are targeting cross-cultural aspects for engineering collaboration in the extended enterprise.

3 Framework

Management of information in modern product development is a cumbersome task due to the multiplicity of involved roles, processes, information systems and managed types of product data. As software and electronics have entered the scenes of product development, the situation has become even more complex as more people with a broader scope of competences are forced to work together on one single technically multifaceted product. This framework focuses integration aspects in such developing organisations with respect to the product development domain [Svensson03].

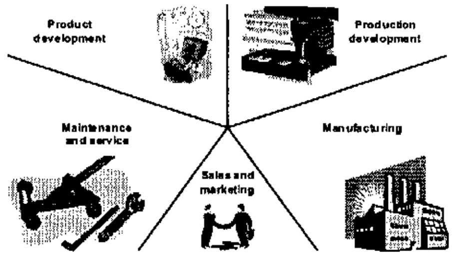

Figure 1 **Activity domains**

3.1 Different views of engineering information management

This section briefly describes the four views of Engineering Information Management (EIM) proposed by Svensson [Svensson03] – organisation, process, information and system.

Organisation

Development organisations are typically structured in accordance with the activity domains, see Figure 1, implying a so called line organisation. For well defined development projects, dedicated teams and project working methods are commonly deployed. When needed, cross domain competences are compiled within such projects, thus implementing the concept of concurrent engineering.
Companies developing mechatronic products often have, in their role of Original Equipment Manufacturers (OEM), interfaces to other organisations such as component and subsystems suppliers and service and maintenance partners. This environment, often referred to as the extended enterprise, calls for an effective and adaptable mechanism for exchange of knowledge, information and data.

Process

There exist many generic proposals for describing, prescribing and structuring the activities performed in the product development process. However, mainstream authors tend to look upon development with a traditional mechanic outlook, rather than accentuating cross-disciplinary issues. Examples of such are *Engineering Design* [Pahl&Beitz96], *Product Design* [Otto&Wood01], *Product Design and Development* [Ulrich&Eppinger04]. With a somewhat sweeping render, we state that these methodologies' description of the development process is divided into three phases. First, a phase dedicated to clarification of the task and settlement of requirements. Secondly, a phase of system-level structuring of the design into meaningful units and finally, a phase of detailed design where solutions are finalised in technical terms.
Few systematic approaches explicitly arrange all activities in mechatronic product development. An early approach towards describing the phenomenon of mechatronic development was made by Buur [Buur90]. He argues the importance of early phases, thus calling for sub-processes directed towards a development of functional descriptions, technology assignment, conceptual design, et cetera. Shakeri [Shakeri98] brings Burr's ideas further with a detailed methodology targeting abstract (early) views of mechatronics.
Systems Engineering claim to be in position of an interdisciplinary approach [INCOSE00] for product development, thus facilitating technology independent procedures for development. As Systems Engineering covers the product's entire lifecycle, it is more than promising as a fundament for process design in mechatronic product development. An instance of the generic Systems Engineering process is proposed in the book *Systems Engineering* [Stevens*etal*98].

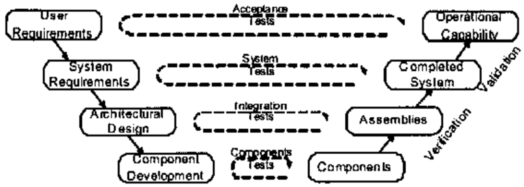

Figure 2 The V-model [Stevens*etal*98]

The authors divide the development process into a partitioned requirements phase, an architectural phase and a component development phase, see Figure 2. Emphasis is set on verification and validation of solutions. For mechatronics, the model can be used by separating domain specific activities in the detailed design phase [Hallin*etal*04], thus recognising software, mechanical and electronic architectural design and component development processes. Synchronising these sub-processes might be a complex commission as demands for rapid development increase. However, it is important to realise that these sub-processes must implement a technology adapted configuration and change management that is compatible with system level dittos.
Direct industrial implementations of the generic product development processes mentioned above are rare. Instead, stage-gate processes are popular in industry [Fagerström04] [Mesihovic*etal*04], often used to facilitate means for quality execution, support of project managers, and serving as a general roadmap for the development activities.

Information

This work has adopted the viewpoint of Fagerström [Fagerström04], where information is regarded as data in a meaningful context, implying that this section deals with information management and not data handling in terms of bytes and bits. In representing information generated in mechatronic product development, two different techniques can be distinguished. First, an information model based approach that capture the syntax and semantics of product data in a context, thus defining important concepts and their relations. Secondly, a document centric approach that by means of containers hold raw contextless data. Information model based data representation is typically implemented by means of object-orientation with data stored in central database systems, whereas document-oriented approaches rely on fileservers or traditional document archives. During many years, best practice has been to combine the two approaches thus representing products by means of documents and metadata in information models. Recently the trend in industry has turned in favour of model-centric approaches, thus recognising the importance of defining high quality information models for representation of product data. Abstractions of the product itself are commonly used to specify a pattern for such information models, often referred to as product models [Duffy&Andreasen95] [Isaksson*etal*00]. An example of a generic product model for mechanical design is the Chromosome model [Andreasen92], which abstracts the product into processes, functions, organs and parts. In product modelling for software artefacts there has been less work done and no models have, so far, been presented [Crnkovic*etal*03]. However, it has been shown that there exist product models that are applicable for mechatronic products [Hallin*etal*03] and that such models, by means of functional modelling, capture the tracelink from hardware to software design artefacts, thus supporting a consistent representation of mechatronic product. In designing an information model it is fundamental to analyse the development process [ISO98] as a thorough process analysis delivers significant information requirements.
In addition to the prerequisites set by the process and the product, seven aspects of the product definition have been found to be of special interest. These aspects need to be taken

care of in order to facilitate an effective and efficient information management in support of product development [Hamer&Leopoeter96] [DHBrown01], see Table 1.

For mechatronic products, the interface aspect between hardware and software is utterly important to define, in addition to a consistent version and effectivity management.
A significant set of information models for a wide range of industrial applications are defined in ISO 10303 [ISO94], the STEP-standard. The aim of STEP is to provide a neutral mechanism for data exchange, defined independently from any particular information system. However, STEP has also been shown to be very useful as a basis for product modelling in general [Phelps98][Hallin*etal*03]. One shortcoming of STEP in a mechatronic product context is that it mainly deals with electronics and mechanics, omitting the phenomenon of software.

Table 1 Seven aspects of product data management

#	Aspect	Description
1	Hierarchy	Division of objects in superiors and subordinates
2	Variants	Grouping of objects that share many, but not all characteristics
3	Interfaces	Defines how objects interrelate within a product representation
4	Views	Visualizations of particular subsets of the product representation
5	Versions	The altering process of an object is recorded through versioning
6	Status	Deals with the maturity of an object as it evolves in the product development process
7	Effectivity	The identification of the valid use of an object

System

In modern product design, information system tends to play an increasingly important role, which has resulted in the introduction of systems that contribute to the product development throughout the product lifecycle. However, the number of adopted systems has in many companies run out of control, typically due to constant addition of new tools in conjunction with the lack of distinct policies for system introduction. In mechatronic development, some of the most commonly used data management tools are PDM (Product Data Management), SCM (Software Configuration Management), SE (System Engineering) applications, ERP (Enterprise Resource Planning) and CAD (Computer Aided Design) systems. In addition to these, there are complementary information nodes that contribute with services such as data warehousing, web services et cetera. Although these systems support the process in different phases and by different means they all contribute to the definition of the final mechatronic product.
Information systems are generally connected to the company intranet as illustrated in Figure 3, but more seldom tightly integrated. The most common scenario is that information, at certain gates, is transferred between systems, either manually or semi-automatically by means of import and export procedures. Depending on present company stakeholders, the information systems may be accessed by different people having different roles in the organisation, resulting in a distributed utilisation throughout the enterprise. System engineers work in specialized SE tools for requirements management, functional modelling, trade-off analysis, et cetera. Software engineers work in SCM systems, hardware engineers in PDM

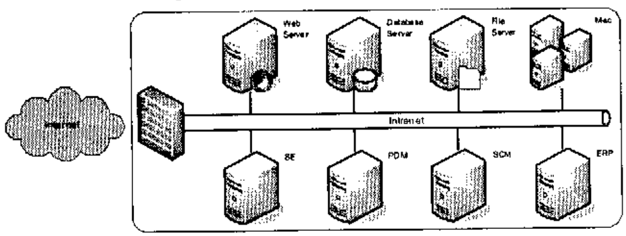

Figure 3 Heterogeneous system environment

and production in ERP, thus creating an environment where information is scattered around different domain specific data sources. This situation has raised the need for a unifying approach to data management in product development joining the generated information into a whole. Several contributions have been made in the area but the final answers are still far a way from being found. Svensson [Svensson03] has investigated the possibilities for integrating PDM with RM (Requirements Management – specialisation of SE) and ERP systems by exploring different scenarios where RM and ERP data is stored in PDM systems and vice versa. Crnkovic et al [Crnkovic*etal*03] have analyzed the similarities and differences of PDM and SCM systems and proposed methods for integration. However, proposals for peer-to-peer integration are most often possible, but tend to increase the systems architectural complexity.

3.2 Integration issues

A company's business in terms of the products offered, integral technologies, defined processes and historical background set prerequisites for information system deployment. No company's existing system topography or information requirements are another alike. Still, while adapting an overall strategy towards system integration, there are a few important aspects to consider.

Integration of information management has traditionally taken place only on the organisational and process levels due to the absence of efficient and all-embracing information models and system integrations [Crnkovic*etal*03]. In order to increase the incentives for collaborative working methods, it is of great importance to study approaches for integration on the system and information level. From a holistic perspective, two different integration methods can be distinguished. Firstly, system level integration where information systems are integrated by connecting interfaces or integrated by product data import/export procedures. Secondly, information level integration where systems are integrated by means of one all-embracing information model or by means of domain specific models based on a common information core. In order to maintain information consistency in information integration it is necessary to integrate systems that manage common sets of information, see Figure 4.

Although integration may support the collaborative aspects of information management, it implies an increased architectural complexity, which may decrease flexibility in maintaining and upgrading information systems.

Most available commercial systems offer some kind of integration functionality. The offered solutions span from open application programming interfaces to particularly dedicated applications for system integration. Examples of the latter are PTC's Windchill Enterprise System Integration module [PTC04] and UGS PLM Solution's Teamcenter Integrator [EDSPLM04], which both integrate their application suites and provide extended means for integration with other legacy or commercial information systems. These kinds of applications are normally configurable by means of seamless information transfer or event-triggered information transfer.

An approach towards open information systems solutions often means adapting standard-based information schemata. The already mentioned ISO 10303 offers explicit methods for the structuring of information to facilitate data exchange between systems.

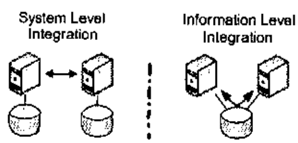

Figure 4 Integration at different levels

Implementing STEP methodologies into the company's information strategy and systems will most likely increase the freedom of action in terms of an ability to engage new information systems and decrease complexity in further system integration. STEP constructs can be utilized to enable data import/export features. Most PDM and CAD applications offer at least basic features in that direction. Webasto, a German automotive industry supplier [Göllnitz*etal*01], provides an example of an intense event-based data exchange utilizing STEP schemata. At Webasto, two major PDM systems were integrated for a continuous export of structures and CAD-data from one system to the other. In this case, STEP was shown to be a very feasible fundament for integration.

4 Adopting an integrated information management

This section discusses issues associated with adoption of an integrated approach to information management based on the theoretical framework of section 3. The point of departure is large companies devoted to mechatronic product development, typically active in the automotive, consumer electronics, aerospace and defence industries. The framework is designed for companies with settled organisational structures and a product portfolio including mechatronic artefacts. From an information management perspective, such companies typically have experienced serious difficulties in managing information in a consistent manner due to a great number of processes, tools and managed types of information, et cetera. The overall information system architecture is commonly disordered and lacks in integration, raising demands on manual operations.

In building and maintaining integrated information environments, it is crucial to adopt a holistic approach where all four engineering information management views are considered. As illustrated in Figure 5 the views may be used as means for abstracting a company in terms of information management thus recognising four different abstraction levels. When introducing an integrated information management approach changes shall be made on all levels, implying a combination of top-down and bottom-up approaches. It is obvious that the organisational aspects of information management is more critical in early stage of a company's life then the design of perfect information systems architecture. Nevertheless, a sufficiently defined information model is often the main contributor to efficient information management. When implementing a new EIM system it is important to address the organisational setting answering questions such as: What does the company's organisation look like? To what extent are suppliers and customers affected? What are the overall business processes' requirements on information management?

The basis for process analysis can either be driven by the situation as-is or driven by an idea of how things should be. If a sufficiently detailed process is defined, the main issue is to implement or purchase an information system that supports this process. Whereas if the understanding of how to work is less settled, focus shall be put on defining a process, preferably based on some standard or recognised working procedure. When an initial organisational environment is present, the process, system and information levels shall be addressed, see Figure 5, in a top-down approach. It is fundamental to map out the process before details at the system and information level are addressed, recognising the activities supported by the EIM system.

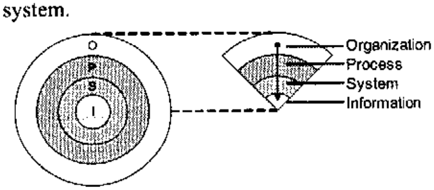

Figure 5 **Abstractions of engineering information management**

For mechatronics, adoption of the V-model's basic principles is recommended, where the management of design artefacts on a system level is performed according to a shared process. The fine-grained component design processes shall be allowed to diverge between product development sub-domains such as electrical, mechanical and software design.

For successful integration of information management systems, a common semantic structure is fundamental implying the need for integration on an information level. Common concepts and a mutual understanding between the product development activity domains are of particular importance for mechatronic information management. A shared product model implemented in a common information model increases the precision of tasks such as version, configuration and change management in heterogeneous environments. The purpose of information integration is further to bring engineering domains closer to each other by enabling the use of a common information backbone, thus sharing and jointly maintaining the product definitions. The best way to obtain this type of backbone would be to develop an all-embracing information model that covered every aspect relevant to every activity domain in all lifecycle phases. However, such an approach is not feasible due to the complexity of information management in product development and due to the continuous change process. The second best approach is to divide the information model into different modules defining domain specific data and to collect all common information in a core module. This type of approach maintains the benefits of a single model, such as consistency and compatibility, and increases flexibility in the respective domains. Therefore, it is recommended to separate the model according to the specialized product development domains. When possible a standard solution shall be deployed in order to guarantee accessibility and compatibility as solution providers may cease to exist and new demands on integration may appear.

Commercial systems have a strong advantage over in-house developed systems due to their shared development and implementation costs. If such systems are possible to deploy without extensive customization, they are commonly preferred. A countless number of in-house development projects have failed in both cost, time and in implementing information management systems that satisfactorily fulfil company requirements, thus indicating the danger of such projects. A key enabler of some systems is the ability to integrate to other information systems in order to secure information. Once again, this calls for standard based solutions including communication protocols such as STEP. Although it is possible to integrate systems with a peer-to-peer approach, integration on the information level is recommended.

5 Conclusions and future work

The path towards an integrated approach for engineering information management, conveyed in previous sections is to be characterised as an overall roadmap that calls for certain considerations. It assembles the most critical viewpoints on information management for mechatronic product development, without prescribing narrow details. In that sense, the contribution of this work is to be regarded as a holistic framework rather than a delivery on implementation specifics. Some concluding remarks are nevertheless possible to extract.

- Implementing an integrated information management is facilitated by utilizing a systematic and primarily top-down approach. The organisation and overall business processes constitute the foundation for fine-grained process analysis, information modelling and system implementation. However, legacy systems, information models and processes also call for bottom-up approaches when designing new information architectures.

- On a product system level, mechatronic development is to be regarded as a shared activity of engineers with different technological origin. On a product component level, development is better of performed separately by the respective domains.
- The existence of system level representations and cross-domain integration at the different EIM abstraction levels are key enablers in maintaining consistency in the mechatronic product definition.
- The most applicable way to model information for mechatronic products is to develop domain specific models and to integrate such models by a core interface model defining common information concepts.

This paper represents an exposition of aspects on the implementation and introduction of EIM. It remains for the authors, as well for many others to continuously cross over the path of implementing the delivered ideas in real mechatronic companies.

Acknowledgements

This work was financed by Vinnova (Swedish Agency for Innovation Systems) whose support is gratefully acknowledged.

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