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PROBLEMS AND CHANCES IN INDUSTRIAL MECHATRONIC PRODUCT DEVELOPMENT

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ABSTRACT

This paper presents insights into two different mechatronic development processes in automotive industry. Both processes were leading to successful products, meaning that the developed systems are in production at reasonable cost. During both processes a series of prominent problems could be observed; the solution for these problems found in the development processes are sometimes not in line with recommended procedures in literature concerning mechatronic product development. Therefore the problems and the solutions were analyzed in detail by means of retrospection of involved design engineers. The basis for this analysis was a model of mechatronic product development which combines the core elements from multiple sources. During the analysis it became apparent that many publications, which research mechatronic product development, focus on the commonalities between the disciplines. In contrast, this paper is focusing on the differences between the disciplines. The focus on the differences is not intended to indicate that collaboration between the disciplines is not feasible or sensible. Instead, the chances listed in the last part of this paper are meant as measures to overcome the differences and by doing so to achieve a higher, more effective level of collaboration between the disciplines. Obviously, this list of chances is preliminary and is only based on the speculation of two design researchers. The main objective of this paper is to highlight fields of action for academic research in mechatronic product development.

Keywords: Mechatronics, Product Development Processes, Knowledge, Innovation

1 RESEARCH APPROACH

The conclusions presented in this paper are based on a retrospective analysis of actively participating individuals, an extensive literature review, and logical deduction. Actively participating individuals are understood as persons who are an integral part of the organization and who carry their own responsibilities for a part of the company core processes. In design research, the merit of participant observation is generally agreed upon. Very often, participant observation is carried out by design engineers who primarily work as design researchers. These participants were able and will be able to investigate interesting characteristics of design. However, some phenomena are hidden to such individuals. Design researchers in Germany are typically mechanical designers who research design during their dissertation. Later on, they participate in the processes which they analyzed before as design engineers or product development managers. This situation allows educated design researchers to reflect design processes as actively participating individuals. The two authors followed this common route. Accordingly, the results presented in this paper should be weighted as results of qualitative, exploratory research.

2 MECHATRONIC PRODUCT DEVELOPMENT

Mechatronic is regarded as an interdisciplinary approach that integrates mechanical, electronic, and software parts in one product. Its main characteristic is to consider these aspects as one system or in one model. However, “mechatronic” seems to have become some kind of buzz word, since most products nowadays consist of mechanical and electronic parts as well as software to some extent. And many approaches and methods for mechatronic product development do not differ qualitatively from “classic” product development and the basic principles are adequate for mechatronic product development, too. Nevertheless, often enough theses approaches do not consider specific aspects of mechatronic product development. These problems and chances are discussed in this contribution. We try to focus on merely “mechatronic” problems, though many of these aspects can be related to any complex development (which nowadays is mechatronic or multidisciplinary).

A good example is the (functional) structuring of a concept and the later integration into one product. Some approaches in mechatronic product development are content with a functional structure of the product and assigning single functions to either mechanics, electronics, or software. And the integration just looks at the integration of either these three disciplines or single components. But both the structuring as well as the integration have to happen on different dimensions: functionally, within one discipline, between the disciplines, component or system based – and all of this on different levels of detail of the whole product.

In order to get a better picture of mechatronic products, it seems to be appropriate to differentiate different levels of integrated mechatronic products (figure 1).

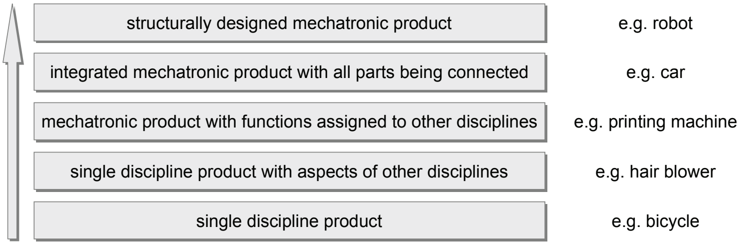

Figure 1: Levels of mechatronic products

The diagram does not only differentiate various kinds of mechatronic products, it also shows the development of products over time. E.g. a car was a purely mechanical product some time ago. Quite early it integrated some aspects of electronics, such as lights, ignition, etc. Not long ago, functions have been assigned to other disciplines, e.g. the electronic throttle, electronic transmission control, etc. Nowadays, the multitude of control units is interconnected throughout the whole car, e.g. engine control, chassis management, and navigation. And you can see trends that mechatronics will shape the overall structure and shape of a car in the near future, such as hybrid technologies.

Systems theory differentiates steps or levels in the emergence of systems (figure 2). These steps can be assigned to the levels of mechatronic products. While the current focus, as mentioned above, seems to be on the structuring of functions and the assignment of them to mechanics, electronics, and software, more aspects of mechatronics can be explained with this comparison.

- Mechatronics permits process orientation, i.e. the connection of and communication between remote parts of the product just like some kind of nervous system (again e.g. the connection of engine management incl. electronic throttle, chassis management incl. dynamic stability control and navigation or a motor start stop automatic considering various aspects of the car).
- Mechatronics permits reflection in the meaning of self-diagnosis of the system (e.g. broken light bulbs or failures in the engine due to wear), adaptation to the driver’s profile, prognosis of coming driving situations, or the occupant detection system described later on.
- Mechatronics permits the generation of new functions on a completely new systems level, such as traffic management by communication between cars.

All in all, mechatronics is not only the assignment of specific functions to another discipline; it is also the generation of completely new functions, which are not possible without mechatronics (e.g. a dynamic stability control system). These points are summarized in figure 2.

Complexity is defined as the interconnectedness and the degree of organization of a system. It also refers to the exceeding of the capacities to connect all of the elements, i.e. that not all possible connections of the system’s elements can be regarded or realized. Instead decisions and selections have to be made, which in the end correspond to the above described levels of systems’ organization.

Mechatronics can be understood as a measure to deal with complexity in the meaning that it combines and automatically handles possible states of the product or the product’s elements. E.g. the occupant detection system automatically reduces the possibilities of the car’s behavior depending on whether someone is in the car or not; a connection of chassis management and engine management reduces the possible independent states of the elements due to their mutual dependence.

This is a systems theory view regarding the product's purpose and function (behavior). From the viewpoint of the engineer, of product development, technology, and the functions within the product (functionality), the complexity increases. It increases, because the product developer has to regard more possible connections of the elements ("what shall the airbag do if there is no passenger in the seat?", "what shall the engine do if the chassis management wants to reduce the wheel torque?").

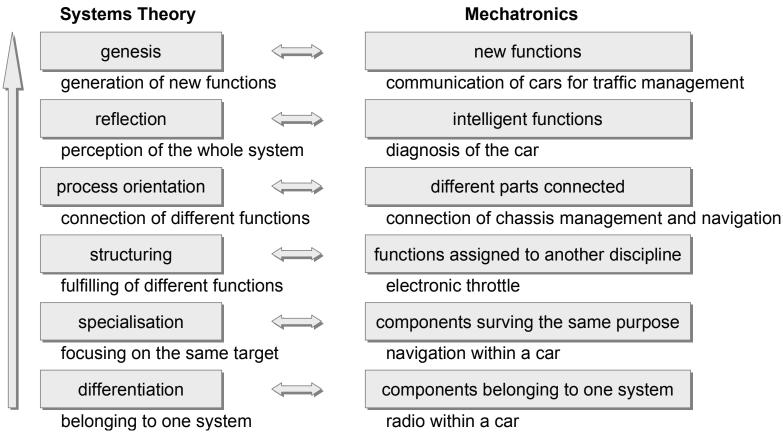

Figure 2: Systems Theory and Mechatronics

The complexity increases to a qualitatively different amount, where it is – hypothetically – not possible to overview and understand the whole product. This leads to the main question of mechatronic product development and this contribution:

Can mechatronic product development use the same methods and follow the same processes as "classic mechanical" product development or are other approaches necessary due to the increased complexity?

Of course, the same methods and processes can be used. But the question is, whether other approaches are necessary in addition. These additional approaches might refer to the complexity of very large product development processes rather than to mechatronics solely, but mechatronic product development processes of a large scale show the problems and chances very well. Instead of answering this question, we would like to start a discussion on this topic and show potentials and risks, which have to be answered.

Some ideas, in which direction such new approaches could go, i.e. where the focus should be on, are shown in figure 3.

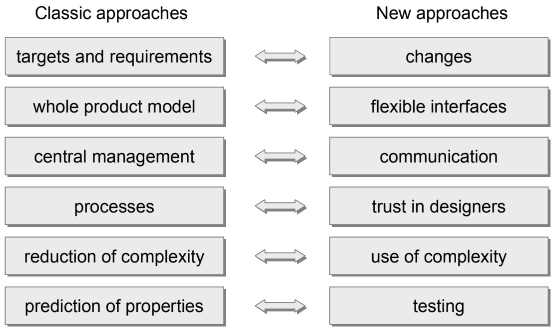

Figure 3: Classic and new approaches in mechatronic product development

These shall not be discussed here in detail, they are addressed in the chapter "problems and chances".

3 EXEMPLARY MECHATRONIC PRODUCT DEVELOPMENT PROCESSES

In this section, the two mechatronic product development processes are briefly characterized in order to allow an insight into most important components of the product development system, e. g. the product to be developed, the industry, the organization.

3.1 Integration of a occupant detection system for car seats

Occupant Detection Systems are designed to classify the occupant seated in the front passenger seat for potential airbag suppression [1]. One possible setup consists of a pressure sensor, bladder assembly, belt tension sensor, and an electronics control unit (ECU). This setup is shown in figure 4.

Figure 4: Passenger Occupant Detection System (PODS)[1]

The sensing system detects loading force on the front passenger seat and classifies the seat as empty or the occupant as an adult or infant/child. The ECU processes the sensor data and provides a deployment-allowed output to the vehicle's sensing and diagnostic module when a defined threshold is met. Such systems help to reduce the potential for airbag-induced injury, allow airbag suppression when seat is empty, allow airbag suppression when occupant is below a defined threshold, allow airbag suppression for children as defined by the advanced airbag regulation FMVSS 208, and allows airbag deployment when 5th percentile female and larger adults are present [1]. In the example process such a system was integrated for the first time into the passenger seat of a premium class vehicle. One of the authors was the responsible project manager for the integration of this mechatronic device into the seat.

3.2 Development of functions for engine management

An engine management system (EMS) is the most complex part in a car. It covers the governing and control of all functions of the engines, such as electronic throttle, which is a complex interpretation of the driver's demand for torque, charge, fuel mixture generation, ignition and combustion, exhaust gas treatment, auxiliary equipment, heat management, acoustics, etc. Many functions can only be handled by intelligent steering algorithms and many innovations are only due to software algorithms. The EMS has to cover the main functions as well as system functions, diagnosis, security functions, etc. The engine control is strongly connected to the transmission control and a lot of other control units of different departments, e.g. chassis management, combined instrument, fuel tank control, etc (figure 5).

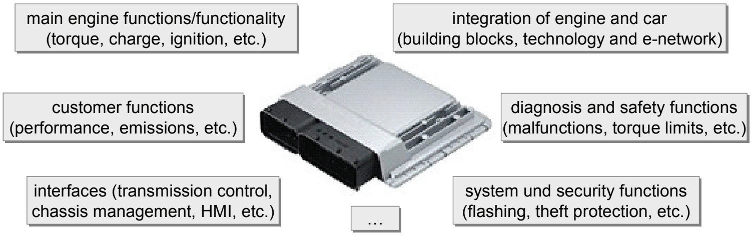

Figure 5: Engine control unit

Engines try to follow a building set approach, i.e. the same engines are used in different cars. The engine control also makes use of building blocks, using the same algorithms for different engines in different cars – as long as it is conform to the engine technology. The adaptation of an engine to a certain car happens via parameters or application data (or sometimes through learning algorithms). Thus, the engine control software can be divided into functions and data. To get an impression, there are around a thousand functions and over 15.000 parameters in each engine control unit.

The development process of an engine control is strongly driven by changes, i.e. an existing engine control (or existing functions, see building blocks) are used as a basis for the new engine and adapted by both a requirement specification and change requests. Still the focus is on the latter, which allow late changes in requirements, innovations, and reaction to difficulties in the mechanics, but aggravate the generation of a consistent functional model. Many different organization units contribute functions to the engine control; especially crosslinks are extremely difficult to control. The process is also characterized by time pressure, since software development and application comes last in the process; as well as by high complexity due to variants, since many of the possible variants of a car are finalized by specific data.

The integration of suppliers, who make the hardware of the control unit and parts of the software, as well as the division of functions/data and software code/hardware aggravates the process, too. Due to the large scale of the process and the organization, there is not one strict process, but different process approaches such as requirements management, change management, data management, implementation planning and monitoring, testing, etc. Thus, project management activities are spread over the organization. Furthermore, testing, verification and evaluation play a prominent part in the process. This is partly strongly combined with the “synthesis” of the development, but many activities can also be done by Hardware in the Loop, Software in the Loop, etc.

4 A MODEL OF MECHATRONIC PRODUCT DEVELOPMENT

4.1 Origin and justification of the model

Future mechatronic products can be characterized by the following features: multifunctionality, reliability, adaptability to changing conditions, flexibility, and simplified service. This multitude of requirements requires specific processes. For mechatronic system development, a process model called V-model is generally the recommended one. The V-model is a graphical representation of the system development lifecycle. It was adopted by Germany federal administration to regulate a software development processes in 1997. After considerable adoption and modification, the V-model has been suggested by VDI Guideline 2206 as a “Design methodology for mechatronic systems” [2], [3]. Several researchers report current endeavors to apply and optimize this methodology for the product development of different mechatronic systems [4], [5], [6], [7]. Nowadays, the V-model has become a standard process model for mechatronic system development in many industrial companies.

One of the shortcomings of the V-model is the fact that the life-cycle of physical products is not visible. This may be caused by the fact that the V-model was adopted from software development; for pure software products the production process and the life-cycle of the physical product (DVD/CD and Booklet, etc.) presents no challenge. However, for physical mechatronic products the life-cycle is extremely important. Another shortcoming of the V-model is the fact that it is not appropriate for modeling the time sequence of a mechatronic product development process. The V-model primarily presents a logical structure of the mechatronic product development process, but cannot be used to show and analyze the schedule of a project. It is just a model, which shows the different levels of product development. Most authors agree that iterations within the V-model are necessary and that it is even necessary to run through several cycles of V-models. The V-model is generally understood as the central model of the interdisciplinary mechatronic product development processes. Complex models of product development processes often are confused with schedules. However, many authors [8], [9], [10] point out that product development is never a sequential process. Product development of conventional and mechatronic products is always characterized by iterations and jumps between certain stages as well as parallel and simultaneous activities on all levels of the V-model. The V-model as a process map shows the way from requirements to a market-ready product on a logical level. However, in analogy to a map of a landscape it cannot tell you where you are or where you should be at a certain time. The "process map" V-model needs to be accompanied by project plans showing phases and milestones. Stania&Stetter [11] propose a combination of a project plan and a process map. During the retrospective analysis of industrial product development processes it became apparent that a number of very important aspects of industrial product development are not reflected in the different models of design, product development, and mechatronic development. Time to market is a major challenge in today competitive product development. Consequently, successful product development requires a conscious and rigorous project management in order to arrive at with the right product at the right time. Current product development and serial projects are characterized by an extremely large number of changes caused by product development flaws but also chances of surrounding conditions or customer expectations. Furthermore, today's products can be ordered in a large number of variants. This may be the main challenge for product development. Companies can only face the competition if they are able to apply the state of the art methods and tools of configuration management. Based on these considerations the model in section 4.2 was developed.

4.2 Description of the model of mechatronic product development

Figure 6 presents a model of mechatronic product development which is proposed for the sake of an in depth discussion of the most prominent aspects of mechatronic product development.

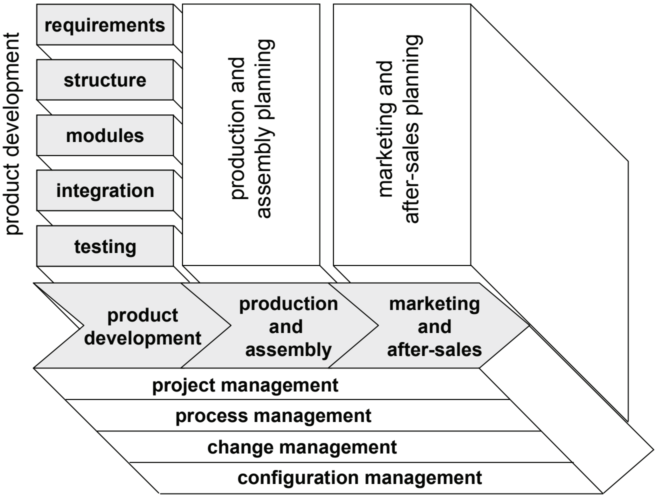

Figure 6: Model of mechatronic product development

The core of the model is the core process of producing companies consisting of product development, production and assembly, as well as marketing and after-sales. Four groups of activities are important in every phase of this core process. The essential activities of the project management concern the planning and control of all schedules as well as the assignment of resources. The most important aspects of project management concern people, time, and money. The logical relationships of the product and the process are dealt with in "process management". Process management is often also referred to as Systems Engineering and can be defined as guidance for the functional design of complex systems, which is based on certain thinking models and principles [12]. Change Management is the process of requesting, determining attainability, planning, implementing, and evaluation of changes to a system. It has two main goals: supporting the processing of changes and enabling traceability of changes [13]. In order to allow this traceability often a version management is part of the change management. This aspect becomes increasingly important in mechatronic product development. The term "configuration management" is meant as an extension of variant management. Possible variants of a product have to be consciously configured so that each possible product variant (configuration) will fulfill the functional and physical requirements throughout its life, including compatible and working configurations during the design process. These possible configurations have to be considered during all phases of the core process of producing companies.

For the phase "product development" necessary activities can be summarized using five notions. These notions have a sensible sequence, but should not be understood as a process as iterations and jumps between activities under different notions are frequently necessary. The notion "requirements" summarizes activities which aim to translate customer wishes and expectations into appropriate requirements as well as to manage these requirements. Activities which focus on establishing functional and physical structures of the product and process are subsumed under the notion "structure". The notion "modules" summarizes activities with the objective to develop smaller subsystems of the product commonly referred to as modules. Activities which deal with interfaces and information, energy and matter flows trough different modules are subsumed under the notion "integration". The notion "testing" summarizes a number of activities which have to be planned, carried out and controlled during all phases of the core process. The activities in testing focus on virtual and physical analyses of the product and process performance. These activities are necessary to assure the functionality and quality of the product and processes.

The phases "production and assembly" as well as "marketing and after-sales" are not analyzed in this paper in detail. Consequently no groups of activities are defined and displayed in this model. This is not meant to indicate that such groups of activities are not sensible in these phases of the core process. These phases are not the focus of this paper, a definition of groups of activities is left to further research, though they are probably similar.

5 Problems and chances concerning mechatronic product development

In this section problems and chances concerning mechatronic product development are discussed in detail. The structure of the section is according to the model of mechatronic product development shown in figure 6.

5.1 Problems and chances concerning project management

The notion "project management" summarizes activities which concern the planning and control of all schedules as well as the assignment of resources. In the analyzed mechatronic product development systems it became apparent that the time-lines are very different in the different disciplines. Time-lines are mostly developed by recalculation from a set start of production date. This recalculation procedure is especially apparent in the product development of physical systems. The start of production date is set by the management on the basis of experience and market necessities. Interestingly the schedules of project management are only to a comparably small degree influenced by synthesis activities like direct geometry development or code generation. On the contrary, the schedules are largely depending on analysis and production preparation tasks. Typical analysis tasks that have a major influence on schedules are endurance testing or homologation testing. Production preparation tasks which influence schedules are preproduction series and the procurement of production tools and assembly systems. Due to the different nature of the modules the time spans in different disciplines differ greatly. Additionally it has a major influence if modules have to be produced specifically in the product to be developed or if standard modules can be used unchanged or adapted.

The synchronization of the different disciplines is consequently a major challenge for project management of mechatronic products. The top level product development plans are frequently not applicable to certain modules. Top level product development plans are usually driven by analysis and production preparation activities (prototype phases, homologation, procurement of tools, etc.). Software development is in some instance independent of production preparation because the duplication of software is nearly not time-consuming. Currently such disciplines are not represented appropriately in the top level project management. These disciplines apply discipline-specific procedures to plan and control their part of the project. Unless these different procedures and schedules are thoroughly coordinated and synchronized, substantial difficulties will inevitably disrupt the overall project. The highest chances for success were detected in the project if regular cross-discipline synchronization meetings were attended by the project managers, were launched early, and were carried out throughout the process. On the one hand, these synchronization meetings allowed the participants of the certain disciplines to understand to procedures and necessities of the other disciplines up to a certain degree. On the other hand, project managers were able to discuss their project plans and to obtain an overall picture of the status of the project. Further research should focus on easily applicable procedures to plan, control, and assure complex and integrated techniques for the development of complex mechatronic systems.

5.2 Problems and chances concerning process management

The main objective of process management (or systems engineering) is to provide a guidance concerning the logical relationships within complex systems. It is a major challenge during the development of mechatronic products to keep the overview over the functional and physical relationships between modules of different disciplines. The ever increasing complexity of mechatronic products was elucidated in section 2. The consequence for process management is twofold: on the one hand it gets more and more difficult for process management to keep the overview, on the other hand the necessity for an effective process management is stronger than ever. Besides project management a coordination and synchronization of the functional and physical content of a product is needed in mechatronic product development. The main question is to what degree this coordination and synchronization is sensible. In the current industrial mechatronic product development rather chaotic processes can be observed which still lead to successful products. This kind of chaos becomes apparent if different disciplines and departments use different definitions and notions for the same items or if no single person has an overview over the functionality even of sub-modules; if different disciplines and departments carry out the same activity with different tools and procedures and even with a different outcome; and if extensive product and process changes in late phases are necessary in order to arrive at with a function product. Still, the question if no chaos at all would be feasible and sensible is valid. The complexity of mechatronic products renders a full planning and control of all functional and physical aspects impossible. The analyzed product development processes make clear that a complete planning of all possible aspects is an illusion. The only possibility to approach this essential question seems to be a combination of different measures:

- Integrators and integrating departments, i. e. persons with the main responsibility to keep the overview over the functional and physical product architecture and to guide the specialist in the development of complex mechatronic systems can be established. These persons represent the process management and are also some kind of project managers.
- Direct communication between the disciplines can be fostered. During the discussion of detailed questions the knowledge of integrators might be too superficial to acknowledge the essential points and to convey the right information in the right manner. Communication over discipline borders is necessary during all phases of the core process. It is an illusion to believe that this communication will take place automatically when it is needed. Communication platforms such as regularly meetings or communities of practice have to be installed and monitored in order to get the communication going.
- A certain degree of chaos has to be accepted and measures have to be taken which allow a stable process in a chaotic environment. Such measures are frequent milestones with product and process performance reviews and the application of certain degree of redundancy in the development process. Furthermore, stable processes in chaotic environments can be achieved if all individuals know the main objectives, understand the essential activities in the process, and identify themselves with the company targets or if they have one clear reference product. In this regard also a certain amount of trust which allows information sharing [14] without formal procedures is necessary. Product developers in the different disciplines need to accept responsibility for the overall product performance.

5.3 Problems and chances concerning change management

The notion “change management” describes the process of requesting, determining attainability, planning, implementing, and evaluation of changes to a system. Usually traceability of chances is required and a version management is consequently integral part of the change management. It is one central insight of the analysis of the mechatronic product development processes that the flexibility towards changes is very different in the disciplines. This fact is probably caused by the different amounts of resources and risks connected with certain changes. In mechanical engineering large changes are usually very difficult as the procurement of the production equipment and the homologation processes require large time spans. Smaller changes which can be realized by small changes in the production tools and do not influence the homologation are possible throughout the product life-cycle in flexible companies. In the automotive industry sometimes lead times of few weeks are possible for smaller changes in mechanical engineering. The situation in electronic hardware is different. Especially the elaborate testing procedures, e.g. for electromagnetic compatibility, prevent even small changes in short time spans. In the example product development processes the electronic hardware proved to be the least flexible module of a mechatronic product. For software engineering the situation is again totally different. Theoretically software can be changed very quickly. However, this possibility is connected with high risk. Even small failures can have large effects and are often caused by the interaction of different software elements in improbable use cases. In the last years of mechatronic product development a series of product failures was caused by premature software. Therefore elaborate testing procedures for the release of software have been defined in order to assure a certain maturity. These procedures reduce the flexibility of software engineering. Still, in the analyzed mechatronic product development processes the software proved to be the most flexible module of a mechatronic systems.

It is the difference between these flexibilities that makes mechatronic product development difficult. Nevertheless, this difference in flexibility between the disciplines presents both a problem and a chance. Problems occur if the different levels of flexibility are not covered by a rather static change management. A change management needs to distinguish between the change possibilities and change risks in the different disciplines. The difference in flexibility also presents one of the most prominent advantages of mechatronic products. If this flexibility is used in a sensible manner, chances can be transferred to more flexible modules. This offers the possibility to reduce lead times, cost, and change risks. More specific, it is quite easy to change software very quickly, which is used to react to problems in the mechanics, finalize the behavior of the mechanic product, or to implement still necessary functions. This easiness to implement new functions is often misused to implement new functions arising from e.g. market demands, which by then cannot run through a complete development process with requirements management, concept phase, testing, etc.

Similarly, a well designed change management workflow, has the potential to support the high amount of software changes (in a design paradigm that is based on changes), but leads to the danger that more and more – not necessary – software changes, because it can be done so easily.

5.4 Problems and chances concerning configuration management

The term “configuration management” names the process of configuring variants of a product in a manner so that each possible product variant (configuration) will fulfill the functional and physical requirements throughout its life. The challenges of configuration management of mechatronic products are rather similar to the configuration management of conventional products and are therefore not discussed in detail in this publication.

5.5 Problems and chances concerning requirements

The importance of an early clarification of requirements is frequently highlighted in literature [10]. However, in the analyzed product development processes only the most important requirements were communicated between the disciplines and were monitored throughout the process. No organization unit or single person which has a complete overview of the requirements of the mechatronic products could be identified. This is aggravated by the complex relationships between explicit and implicit requirements in different domains. A conscious cross-domain requirement management including requirement identification, requirement formulation, requirement tracking, and requirement monitoring could present a major change to optimize mechatronic products and to streamline mechatronic product development processes. In order to optimize the collection of requirement over time, a continuous feedback of change requests into requirements is necessary. Additionally, it is difficult to fix requirements in industrial companies with complex supply chains, if there is a change oriented development and the organization wants to keep its contractual requirements against involved supplier companies relatively open.

5.6 Problems and chances concerning structure

The main problem concerning structure is that a mechatronic system has to be structured in different dimensions. The structures have to cover the abstract functional structure, the structure of modules, the mechanical structure (geometry), the electronic structure (“systems”) in the meaning of a network, as well as the software structure (software functions). Ideally, these should be congruent, but in real live there are various reasons why they differ: Functions can be spread over various components and systems; the realization of components is based on the organizational structure of the company, which is grown over time; each structure has to be regarded independently in order to get an optimized system (and together in order to get an optimized product); functions are strongly interconnected and defined from different viewpoints or on different levels. While these problems could be solved by a clear functional structuring, other aspects make this approach unrealistic: The complexity of a mechatronic system hardly allows a complete modeling of the system; variants have to be considered; time pressure does not allow a design from scratch, the development is based on existing solutions and time consuming modeling cannot cope with quick changes in order to solve problems; the involved disciplines have a different thinking; many problems can only be solved by bypass solutions regarding the structure; regarding a technical system, functions from the customers' viewpoint and functionality from the technical viewpoint are not congruent, and this border is not clear. In the end, a complete and integrated modeling of complex mechatronic products is not practically possible (yet).

As an example, the main functionalities of an engine and thus its technical structure might be torque modeling, charge, fuel mixture generation, ignition, combustion and exhaust gas treatment. With the use of an engine, "functions" such as performance and driving behavior, consumption, emissions, acoustics, heat management, etc. are regarded, which are linked to many of the technical functions. The control units have to fit into the electrical and electronical system (with signals etc.). The mechanics is mainly interested in the thermodynamic cycle, geometrical integration, and endurance of the engine. And finally, different modules of the engine (e.g. cooling) or the drive train (e.g. the gear box) are developed in different departments.

5.7 Problems and chances concerning modules

Current mechatronic products are usually realized by means of a combination of modules. This strategy allows a large number of product variants with a relatively small number of modules which can be combined in different ways. Furthermore, modules allow a reduction of complexity which probably is a necessity for the product development of mechatronic systems. The problems concerning modules are strongly connected to the problems concerning structure (chapter 5.6). The main problems concerning modules are to define binding and stable interfaces, which often go beyond the borders of disciplines, and the fact that a modular design (due to variants, production etc.) is suboptimal compared to an integrated design. Further problems concerning modules are caused by modules which cannot be assigned to a single discipline. Prominent examples are modules containing complex sensors. Very often these modules are developed by the electronics departments but have to measure physical phenomena which are the core competency of the mechanical engineering. Such modules are mechatronic systems and require appropriate procedures and tools; such modules have to be identified and treated as mechatronic systems themselves.

5.8 Problems and chances concerning integration

The problems concerning integration are again closely linked to those concerning structuring, i.e. that the integration has to take place in different dimensions: functionally, geometrically, electronically and according to the software structure – or more demonstrative: between modules and between disciplines. Furthermore, this happens on different levels of detail. The functional integration is especially difficult, since in a complex mechatronic system even functions, which are far away, have to be integrated. Another big problem is, that the effects of one discipline on the others are hard to predict. E.g. the software should be independent from the electronic network, but changes in the electronic network may require changes in the software and failures in the software might disturb the whole electronic network (also due to security measures in the software); other problems might be electromagnetic compatibility (based on the geometry of the electronics), etc. Within strongly interconnected products, the integration can also only take place in the whole product in order to get final information on the behavior of the product.

Together, these aspects do not allow a step by step integration, i.e. regarding a V-model, integration takes place on all levels of the model work simultaneously. The complexity of the possible variants of a product aggravates the integration, too, since ideally every possible variant should be integrated, which realistically is not accomplishable. Combining the complexity of the mechatronic product and of the variants, integration needs many supporting methods and covers a big part of the design process.

5.9 Problems and chances concerning testing

The notion "testing" summarizes virtual and physical analyses of the product and process performance. In the example mechatronic product development processes the testing philosophies in the different disciplines were perceived as very different. In mechanical engineering stress test were dominant which investigate certain possible but improbable extreme situations. Due to the comparably high expenditures for mechanical product tests a small amount of tests represented a large product variety. A large amount of experience is the basis which allows the testing engineers to choose sensible testing scenarios in terms of testing loads, testing configurations, and tested product configurations. The main challenge in this testing philosophy seems to be the sensible modeling of reality in a small number of possible tests. In electronic engineering elaborate testing procedures were applied which included most of the probable situations. Methods like "hardware in the loop" allow intensive testing with small expenditure in terms of time and money. This situation is similar but even more apparent in software engineering. The main challenge in this testing philosophy seems to be the high functional complexity of electronic and software and the large number of possible use cases. In the exemplary product development processes a small amount of coordination and synchronization of testing between the different disciplines could be observed. The communication between the testing departments was less frequent than between the design departments. This phenomenon may be caused one the on hand by the difference in testing philosophy, on the other hand because communication between these departments was considered less valuable. However, if the large expenditure for testing in terms of time and money are considered a stronger integration of testing activities is mandatory for future mechatronic product development. This integration is aggravated by the different philosophies, but also by the different necessities and possibilities. Integrated testing strategies which take care of these aspects need to be developed by academia and need to be implemented in practice. This is also valid, when a lot of testing can only take place in the whole integrated product (compare engine control) and happens redundantly in the different departments; here, methods to structure the testing efforts have to be applied and further optimized.

5.10 Problems and chances concerning production

While the focus of this contribution is on product development, some aspects of production as well as marketing and after-sales shall be addressed in this and the next chapter, where product development is concerned. Most of these problems are due to inadequate communication between these units – but not only – and due to inadequate, missing, or different, not compatible documentation of the development and its outcome in the different disciplines – a main problem not yet mentioned in the chapters above.

Production often follows other processes with other timelines and deadlines than product development, with its deadlines being very strict since the actual production is based on it. These timelines are the basis for product development (when does a certain software has to be finished) and often enough do not meet product development timelines (e.g. dates for large test events in specific areas). This is not only for series production, but also for prototypes and experimental cars, which are produced in the plants, too. Another problem is that on one assembly line different types of cars are produced. When developing a new software package, this does not only have to fit to the new product, it also has to be compatible with products which are already in production (in order to reduce the amount of variants). Other problems concerning production are e.g. self-learning algorithms, which have to run in the production before the product is delivered, or problems which only occur in production such as the very first start of an engine, which are normally not the focus of product development, where final customers' situations are mainly regarded.

5.11 Problems and chances concerning marketing and after-sales

Problems concerning marketing and after-sales are again based on inadequate communication and documentation. In marketing, it is difficult to communicate all functions of the product to the customer. Both marketing and service need documentation of the functions quite early in order to produce their marketing documents or service tools. But at this early point, product development often does not know which functions will be finally implemented. This especially refers to diagnosis functions of the engine, which also in product development can only be finalized after the rest of the product is finished. Another problem is the worldwide distribution of software and software updates, combined with the compatibility with the products already in the market.

6 SUMMARY

This paper aims to identify fields of action for academic research concerning mechatronic product development. In contrast to other publications the main focus was on the differences between the disciplines. During a retrospection of successful industrial mechatronic development processes the authors were surprised by the large amount of chaos that could be observed. Disciplines are using different notions and models, no individual has an overview of the complete functionality, and activities with the same target are done several times with different procedures and tools, but still a successful product is developed. Some phenomena in the companies such as trust, identification with the main targets, unconscious knowledge of the process, etc. seem to allow mastering the chaotic process up to a certain degree. However, the expenditures caused by the chaotic process require optimizations, i. e. more efficient interdisciplinary processes. The problems and chances listed in this paper are meant as hints for promising fields for further research. Due to the small sample size these insights have to be considered preliminary.

REFERENCES

[1] Delphi Corporation, Technical Information: "Delphi Passive Occupant Detection - System B". Troy, Michigang: 2005.

[2] VDI 2206: "Design methodology for mechatronical systems", Beuth, Berlin, 2004.

[3] Gausemeier, J.; Möhringer, S.: „New Guideline VDI 2206 – A flexible procedure model for the design of mechatronic systems“, Norell, M. (Ed.): Proceedings of the 14th International Conference on Engineering Design (ICED)", Stockholm, 2003.

[4] Bathelt J.; Jönsson A.; Bacs C.; Dierssen, A; Meier, M.: "Applying the New VDI Design Guideline 2206 on Mechatronic Systems Controlled by a PLC". In: Proceedings of ICED05 International Conference on Engineering Design, Melbourne, Australia, 2005.

[5] Jansen, S.; Welp, E.: "Model-Based Design of Actuation Concepts: a Support for Domain Allocation In Mechatronics". In: Proceedings of ICED05 International Conference on Engineering Design, Melbourne, Australia, 2005.

[6] Rahman R.; Pulm, U.; Stetter, R.: "Systematic Mechatronic Design of a Piezo-Electric Brake". In: Bocquet, Jean-Claude (Editor): "Knowledge, Innovation and Sustainability. Proceedings of the 16th International Conference on Engineering Design". Paris: Design Society, 2007.

[7] Behbahani, S.; de Silva, C.W.: „ System-Based and Concurrent Design of a Smart Mechatronic System Using the Concept of Mechatronic Design Quotient (MDQ)". In: IEEE/ASME Transactions on Mechatronics 13 (2008) 1, pp. 14-21.

[8] Ehrlenspiel, K.: "Integrierte Produktentwicklung". 2nd Edition. München: Hanser, 2006.

[9] Lindemann, U.: "Methodische Entwicklung technischer Produkte. Methoden flexibel und situationsgerecht anwenden", Berlin: Springer, 2007.

[10] Pahl, G.; Beitz, W.: "Engineering Design: A Systematic Approach", Springer-Verlag, Berlin, 2006.

[11] Stania, M.; Stetter, R.: "Mechatronics Engineering on the Example of a Multipurpose Mobil Robot". In: Solid State Phenomena Vols. 147-149 (2009) pp 61-66.

[12] Daenzer, W.F.; Huber, F.: „Systems Engineering – Methodik und Praxis“, 1997.

[13] Crnkovic I., Asklund, U. & Persson-Dahlqvist, A.: "Implementing and Integrating Product Data Management and Software Configuration Management". London: Artech House, 2003.

[14] Cloonan, J.; Matheus, T.; Sellini, F.: "The Impact of Trust and Power on Knowledge Sharing In Design Projects: Some Empirical Evidence from the Aerospace Industry". In: Proceedings of the International Design Conference DESIGN, Dubrovnik, 2008.

[15] Pulm, U., 2005, "Product Development as a Complex Social System". In: Proceedings of the International Conference on Engineering Design ICED 05, The DesignSociety, Melbourne, August 15–18, 2005.

[16] Stetter, R.; Lindemann, U.: "Transferring Methods to Industry". In: Clarkson, P. J.; Eckert, C. M. (EDS.): Design process improvement. Springer 2005.

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