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COLLABORATIVE ENGINEERING – ISSUES AND EVIDENCE FROM INDUSTRIAL PRACTICE

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1. Introduction

Collaborative Engineering is an important enabler in today's product developing industries. Whether coordination, cooperation or collaboration [Lu et al. 2007], there are still a lot of challenges to be managed in any occurrence of distributed product development. Many of them are special problems that only occur as a result of the application of distributed product development and collaborative engineering processes and methods. This paper describes investigations in the field of collaborative engineering as well as German's automotive, aviation and plant engineering industries, regarding those special problems. Due to the fact that collaboration includes shares of cooperation and coordination, the terminology shall be used as a superordinated concept. In an industrial context, this collaboration includes activities between colleagues within a single department, between departments within a company, between companies within a supply chain or between partners in product development endeavours (Figure 1).

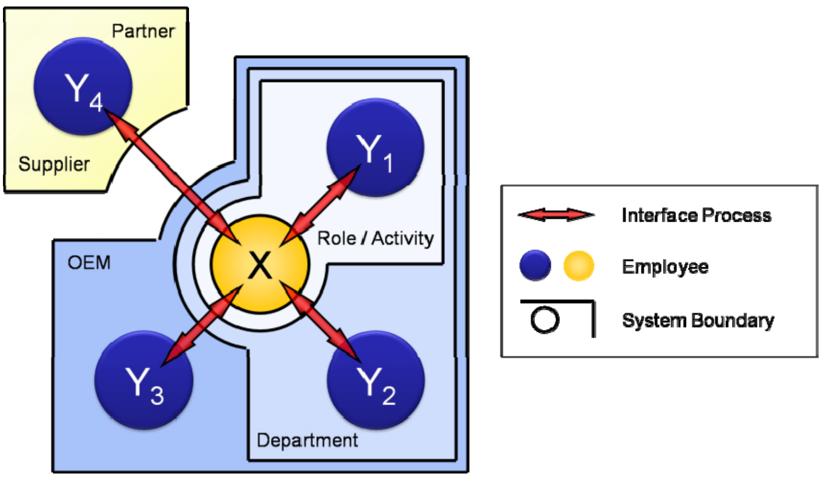

Figure 1. Collaboration Interfaces in Virtual Product Creation [Stark and Stoeckert 2009]

An enduringly growing number of system boundaries needs to be crossed in Virtual Product Creation which leads to a large number of obstacles in the collaboration process. This research work is based on the concept of interface errors in distributed product development which states that process interfaces between process steps and activities are the main problem area in collaborative actions [Stark and Stoeckert 2009]. Virtual Product Creation refers to "all activities across the product's lifecycle where product information is generated, processed or stored computer-aided" [Stoeckert et al. 2009].

After describing issues and obstacles to smooth collaboration with the according theoretical background, process and method requirements (PMR) will be introduced. Then, the conducted empirical survey “CE-Study 2009” as well as the key findings and possible interpretations are presented. Identified next steps to improve collaboration in product development in a sustainable manner will be shown in the conclusion.

2. Obstacles and issues to smooth collaboration in virtual product creation

Nowadays, developing innovative and economically feasible products ensures a company's long-term competitiveness. Growing demands on quality, time and cost efficiency can only be met with the help of supporting IT-systems. When it comes to IT-support, there is a huge variety of systems that can be deployed in the product development process. Figure 2 illustrates the necessity of collaboration in a horizontal as well as in a vertical manner.

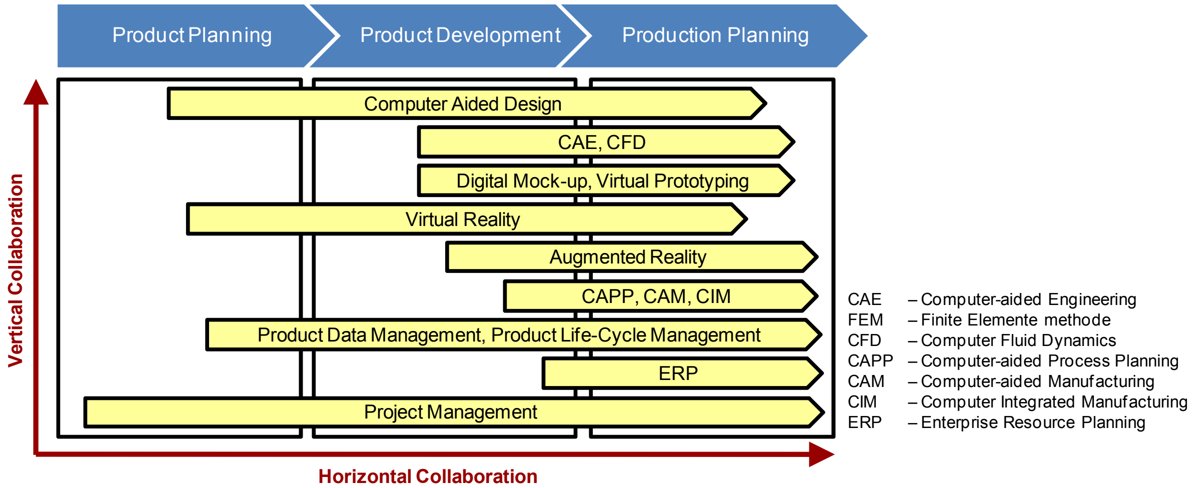

Figure 2. IT-support across the product development process [Stark et al. 2009]

Regarding the horizontal aspect, product- and process-related data has to be exchanged, e.g. the product model between CAD and CAE systems. In this case, integration challenges are arising because either a company relies on systems of one OEM, but that may lead to undesirably process changes, or the company decides to not change the processes but to implement different IT-solutions. In that case, heterogeneous data between different systems has to be exchanged. However, on the one hand the IT-support has to be adapted to customer needs and on the other hand it has to suffice to the following criteria:

- Provision and the representation of different data formats for the same information
- Formal quality (quality of CAD data, conversion problems) and content-related quality of the data (information content and information quality)
- Processing time increases according to the volume of transferred data
- Extraction and integration of complex information structures (e.g. product structure)
- Risk of error due to different conventions and regulations in information and data exchange

Nevertheless, the complexity of the described heterogeneous IT-systems holds a high failure potential in collaboration. Additionally, the potential of failures increases significantly the more complex the supplier network is.

Modern product development not only deals with mechanical products but rather with mechatronic systems [VDI 2006] or even (industrial) product-service systems [Müller et al. 2009]. Mechatronic systems are the synergistic interaction between the disciplines of mechanical engineering, electrical engineering and information technology (software). These disciplines have to be considered during the development of industrial products and the product’s properties and characteristics have to be defined in the design process [VDI 2006]. Due to the increased cooperation between these disciplines, the performance limits of purely mechanical or electronic products can be overcome and the functionality

and design flexibility of the systems can be increased. According to [MIT 2003] the mechatronic and electronic inventions represent 80 to 90 percent of the innovations around the machinery and automotive branch. This makes the reliability of mechatronic systems is essential. Eventually, the functionality of mechatronic systems is based on the interaction of heterogeneous subsystems. However, this represents a considerable increase in the complexity and interdisciplinary in the development of mechatronic products. Thus the complexity places high demands on the development of mechatronic systems. The design and verification effort grows exponentially with the number of components. Especially product developers and designers are confronted with new challenges caused on (vertical) collaboration disaccords and a lack of experience regarding the usage of appropriate methods and tools (horizontal collaboration).
Furthermore, the market records a strong trend towards an integration of services and products. These are commonly called Product-Service Systems (PSS) [Müller et al. 2009]. PSS are understood as equal components of products and services in order to satisfy customer needs. An explicit consideration of the interdependencies between physical and service performances and their need of collaboration during the development stage - in particular, and in the interaction - is not yet state of the art and offers significant potential for the development of appropriate approaches and metrics. However, vertical and horizontal collaboration is necessary to develop successful PSS. But when it comes to coordination and cooperation between the different disciplines a high potential of failures arises. Guidelines that allow a systematic demand generation and quality assurance are currently state of research. Moreover, existing approaches focus either on products, services or IT. The first integrated approaches are currently developed (see [Müller et al. 2009]). A further development of approaches to a comprehensive collaboration management is, however, still necessary.
Additionally, the sustainability aspect has to be taken into account when it comes to product development. The focus is no longer on quality, time and costs but also on sustainability issues. Products and processes related to development, production, use and end-of-life directly influence the living conditions of today's and future generations. As a result, the product properties which are defined during the process of product creation should support and ensure sustainable development throughout both the product and the factory life cycle [Lindow et al. 2009]. Regarding the engineering collaboration, this means that economical, ecological, social and technical issues have to be aligned.

3. Process and methods requirements (PMR) – promising but challenging

The conducted survey addressed a lot of topics in the field of collaborative engineering. Only hypotheses, findings and interpretation with regard to internal process and methods requirements (PMR) shall be discussed here as an excerpt.
PMR are requirements from the product development process itself, directed to single process steps. They are explicitly no customer requirements and originate from subsequent processes in the product development process or are derived from strategic product development plans. Easy examples are naming and numbering rules, specified ways of using layers in CAD systems, descriptions of product development methods and guidelines for consistent work result documentation. In industry, they are often called Standard Operating Procedures (SOP), Methods and Processes (MAP) or just Product Development Process (PDP). These documentations can be very extensive and are meant to standardize development processes for better interoperability and to guide engineers through various product development methods. Therefore, PMR consist of mainly procedural and partially declarative information. A selection of topics that can be covered by PMR documents are:

- Configurations management
- Product structure
- Variant management
- Versioning
- Naming & numbering
- Release processes
- Development phase characteristics
- Effectivities of Product Data
- Maturity states
- Modelling restrictions for DMU
- Modelling restrictions for FEM
- Management of mirror-inversions
- Derivation of construction drawings
- Restrictions of software functionalities

The extensiveness of PMR in global product development requires a systematic management.

Occurring issues are for instance missing PMR, unknown PMR and violation of known PMR due to misunderstandings, wrong prioritisations, appliance in the wrong context, lacking impact recognisability or purposeful violation based on several possible intentions of the user.

4. Empirical Study on the relevance of collaboration issues in industry

Practical experience and several one-to-one interviews in the German product development industry, especially in the aviation and plant engineering area, are the basis for this research activity. The findings of the subsequent literature studies, which had partly been published already [Stark and Stoeckert 2009], have now been evaluated in industrial practice. Additionally, the practical relevance of the identified issues and obstacles to smooth collaboration in virtual product creation had to be proved for the addressed industry branches.
To simplify the investigated scenario, the participants have been subjected to a striking distinction. They could choose their role as an engineer or manager. An engineer could for example be a construction, designing or CAD engineer. Managers act as division or department leaders, project managers or they are responsible for administrative tasks in product development such as product data management or supplier integration. Furthermore, the participants have been divided in two groups: Employees working for Original Equipment Manufacturers (OEM) and employees working for Supplier Companies (Supplier).
Generally, there is a large variety of cooperation activities between OEM, suppliers and partner companies. In Figure 3, a showcase supply chain network is visualized.

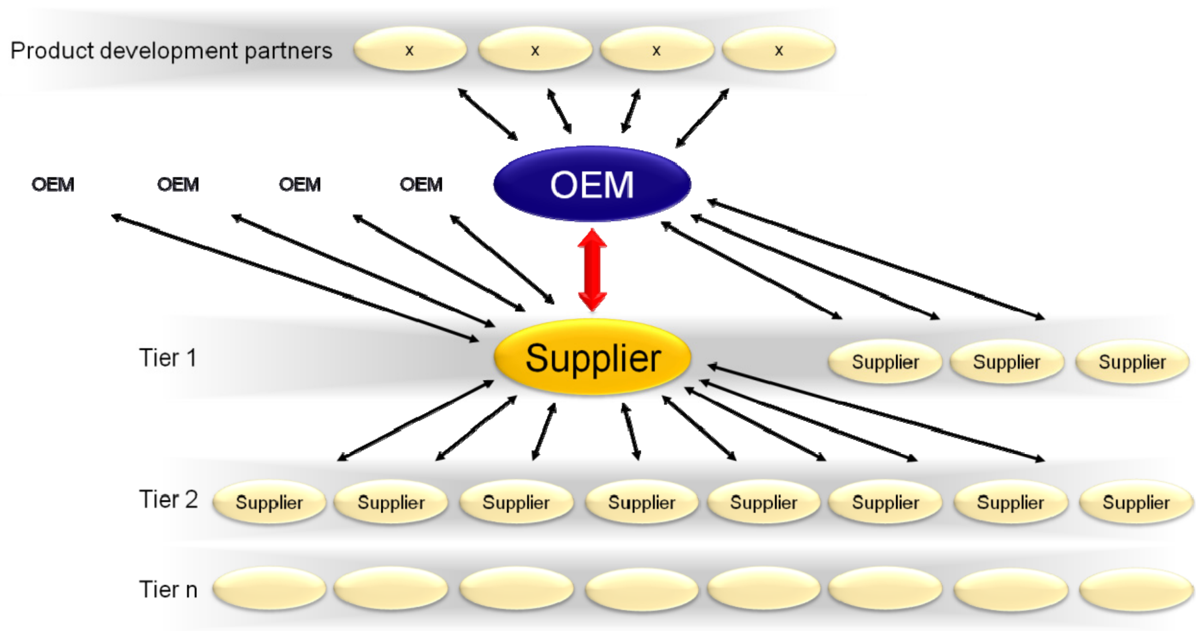

Figure 3. OEM and supplier in a collaborative supply chain network

The central interface between the focussed OEM and supplier (red) seems to be a 1-to-1 relation at first glance. But with more scrutiny, it comes to have n-to-n possible occurrences within the product development industry. To reduce this complexity, the scenarios have been reduced to the following relations:

- OEM to 1st tier supplier
- Supplier to OEM or upstream supplier

Thus, the two remaining cases are the OEM as supplied party and the supplier as supplying party (yellow). Considerations with the Supplier as supplied party, OEM as party which supplies to other OEM (grey) or further special cases are not taken into account. Figure 4 underlines this point of view.

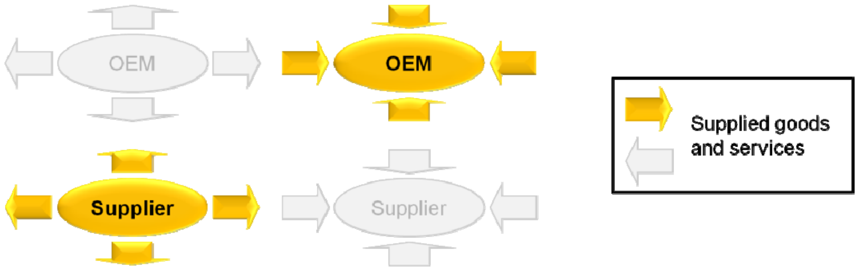

Figure 4. Considered and neglected supply relations in the OEM supplier network

4.1 Concepts and methods of the empirical study

The empirical study has been conducted as an online-survey which has been distributed to 3160 engineers and managers in product development companies in Germany. The survey has been conducted from 11. September 13. October 2009. The response rate of 4.2 percent is comparatively low, which may be due to the extensiveness of the study or due to the fact that the receivers have been contacted without prior contact, which is also labelled as "Cold Calling". 119 responses have been usable for analysis.

The survey has been designed as a confirmative study with explorative elements. Several survey elements such as multiple choice questions, multiple answers permitted in some cases, open questions, interval scaled choices and metric scaled choices have been used. All data has been collected anonymously. The sample has been composed of participants from many different branches, which are shown in Figure 5 (left; multiple answers permitted) together with the composition of OEM, suppliers, engineers and managers in the sample (right).

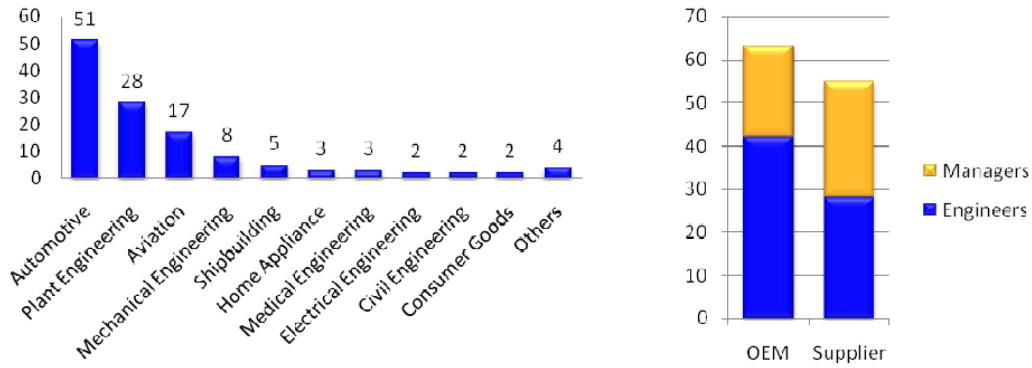

Figure 5. Composition of the sample

4.2 Hypotheses, findings and interpretations

A number of hypotheses have been defined to prove the findings of the industrial interviews and literature studies right and check the relevance for multiple branches in product development. A sample of twelve hypotheses shall be discussed in the following section. The hypotheses have been wisely selected to form a unit that is understandable even without knowing the research background in detail. As a common ground, they all refer to the process of distributed development in general or to the process and methods requirements (PMR) describing requirements from product development companies to their own and their suppliers' engineers. In the following, every hypothesis will be contemplated before the findings and interpretations will be described.

4.2.1 Distributed Product Development leads to a large additional expenditure of time for the responsible engineers.

- Result:
    - Hypothesis approved.
- Findings:

- Applying the methods of distributed product development, every hour of actual development work is accompanied by two hours and forty minutes of miscellaneous tasks. This overhead of 265 percent is equally spread over product development industries. Engineers themselves have a slightly more optimistic estimation with 246 percent overhead, whereas managers tend to expect a 300 percent overhead.

- Interpretation:
  - On one hand, this overhead is a huge loss of efficiency for product development activities. On the other hand, it shows that the application of distributed product development provides huge potential and advantages to the product development industries, as they still seem to draw profit out of an activity which consists to 73 percent of overhead tasks. Hence, there is still vast potential for improvement by reducing the overhead tasks to the necessary minimum, which will always be part of the story.

4.2.2 Despite the long proclaimed "Digital Master" [Krause et al. 1998; Nobelius 1999], the engineer has to deal with a large amount of different types of digital models.

- Result:
  - Hypothesis approved.
- Findings:
  - Product developers estimate an average amount of 46 different types of digital models in their companies. The numbers vary between three and 500 whereas small numbers tend to come from companies with small product development divisions. OEM estimations outnumber supplier estimations by 20 percent. Managers estimate about twice as much model types as Engineers. All answers that were 5.000 or higher have been regarded as outliers possibly due to misinterpretation of the question. Otherwise, the average number of model types would have been 90.
- Interpretation:
  - In general, different model types need different applications, different processes and methods as well as different domain specific expertises to be handled appropriately. Therefore, this large number of different data types is one reason for the highly complex work environment in product development. Due to a better survey of different company activities and a presumably longer presence in the company with presumably more experience in the field of product development, the higher management estimation might be closer to the truth than the estimation of the rather department focussed engineers. Several approaches are possible to reduce the amount of complexity. For instance, reducing the overall number of different model types or supporting product developers in complexity handling by means of assisting organisational structures and technical systems. All approaches are being taken by industry and science, but the technical system approach is currently highly overrepresented.

4.2.3 Documents describing process and method requirements (PMR) are usually at hand in product development companies.

- Result:
  - Hypothesis approved.
- Findings:
  - 92 percent of the respondents state that PMR from their own company are available. 43 percent have PMR at hand that originate from clients outside the company. Only in two percent of the cases there are no documented PMR available. Suppliers tend to have external PMR in about 58 percent of the cases whereas OEM have external PMR in 30 percent of the cases. Apart from that, there are no significant differences between the reviewed participant groups.

- Interpretation:
  - The necessity to govern requirements between process steps, i.e. on process interfaces, has been recognized. The integration of external partners in the product development process has only fairly been achieved. A lot of potential for optimization is present here to reduce friction in collaboration processes.

4.2.4 In general, PMR are presented in a way that is rather uncomfortable for the user.

- Result:
  - Hypothesis approved.
- Findings:
  - Most of the PMR are presented in text form without semantic value. Figure 6 shows the shares of different PMR representations in the survey sample.

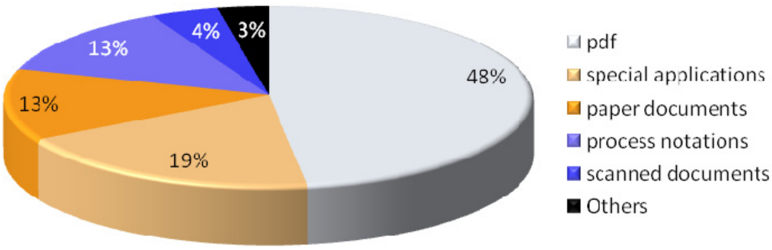

Figure 6. Shares of PMR representations in the survey sample

- Interpretation:
  - Generally speaking, PMR are not presented in an elaborate, adequate way such as professional requirements managements systems, extensive process documentation in the form of process visualizations or other semantically enriched representations. Although paper documents and scanned documents became rare for PMR, they are still in use, especially at supplier companies. This indicates that suppliers do not have the necessary resources to keep up with advancements at OEM companies. Possible reasons are the lack of availability regarding finances, spare time and maybe regarding competences, too.

4.2.5 The compliance to PMR leads to a considerable amount of additional work.

- Result:
  - Hypothesis approved.
- Findings:
  - Product developers estimate 26 percent additional expenditure of time for complying with process and method requirements. Managers answered 23 percent in average whereas engineers assume 31 percent additional expenditure of time. Apart from that, only minor differences are noticeable in between the groups of respondents.
- Interpretation:
  - PMR are specified to improve the integration of process steps towards a continuous flow. Nevertheless, they implicate a considerable amount of extra work load. This workload does not only affect time but also the amount of mental workload the engineer has to bear (cf. 4.2.6). Assistance systems and context sensitivity are approaches that might help to reduce mental workload and therefore mental stress and time exposure as well.

4.2.6 The compliant realization of PMR is a problem for the responsible engineer.

- Result:
  - Hypothesis approved.
- Findings:

- Only 19 percent of the respondents do not see the compliance to PMR as a problem with regards to content. 41 percent have drastic or big troubles with fulfilling PMR.

- Interpretation:
  - Although one of the purposes of PMR is to assist the engineer in case of manifold and complex work tasks by pointing him or her in the right direction, inadequate representation, variability, inconsistence, incomprehensibility and the mere number of different requirements have become a problem themselves. Assistance systems and context sensitivity again promise to be a great help (cf. 4.2.5).

4.2.7 Not all relevant PMR are known to the engineer before start of work.

- Result:
  - Hypothesis approved.
- Findings:
  - 80 percent of the respondents state that not all relevant PMR are known to the engineer before start of work. Nine percent (aviation industry: 20 percent) even think that even after the whole work is done, not all relevant PMR are known.
- Interpretation:
  - This strongly indicates the inappropriateness of PMR regarding transparent classification and adequate representation. Amount and structure of the requirements simply turn them to be unmanageable. Consistent revisions and knowledge transfer from professionally experienced engineers to novices in the supply chain network is urgently necessary.

4.2.8 Full-text search is the main method to screen for PMR that are applicable to the current step of procedure.

- Result:
  - Hypothesis refused.
- Findings:
  - Full-text search is referred to on fourth place in the list of methods used for screening for applicable PMR. Consulting colleagues is on first place. Figure 7 shows the used methods in comparison to each other (multiple answers permitted).

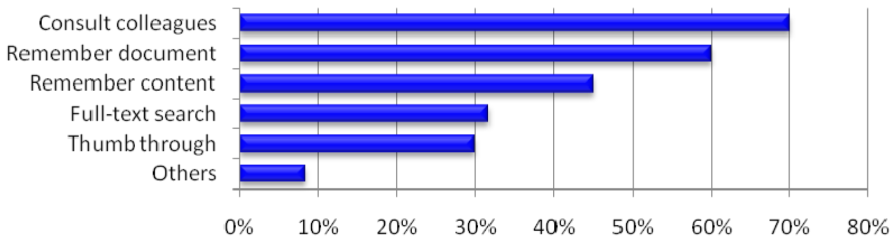

Figure 7. Methods to screen for relevant PMR

- Interpretation:
  - Compliance to PMR seems to be strongly affected by communication among colleagues. Therefore, systematic activities to support knowledge transfer promises to assist the compliance to PMR. Nevertheless, informal communication is an important and often underestimated critical success factor that must not be spoilt accidentally.

4.2.9 "Work instructions to engineers do not require any justification, explanation or background information" is the prevailing opinion among product development teams.

- Result:
  - Hypothesis approved.
- Findings:

  - A majority of 58 percent of the respondents says, that the mentioned statement reflects their experiences in workaday life completely or for the most part. By contrast, only 13 percent think of the statement as not or little in agreement with their experiences. There are no major differences between the reviewed groups of respondents.
- Interpretation:
  - Everyday work does not seem to happen on a level playing field for managers, engineers and collaborating partners. This kind of collaboration on a mere processing level is not very sustainable and seriously endangers innovative capacities in these community driven days with strong tendencies to informality, voluntary contributions and decentralisation. Possible savings in communication time due to short instructions without justification and background information seem to be heavily overcompensated by inefficiencies due to reduced motivation, error occurrences and limited innovation capacity.

4.2.10 OEM and supplier companies have strongly differing views on the collaboration process.

- Result:
  - Hypothesis not approved.
- Findings:
  - Survey participants from OEM and supplier companies seem to belong to the same population, statistically spoken. Besides isolated differences, the findings in both groups are very similar.
- Interpretation:
  - Both OEM and suppliers face the same or very similar problems and obstacles in collaborative engineering. The distinction between companies who act as OEM and companies who act as suppliers is therefore not vital for the analysis of product development collaboration and interface errors. Thus, developed solutions to improve collaboration processes should be equally applicable to all parties in the development supply chain.

4.2.11 Engineers and managers have strongly differing views on the collaboration process.

- Result:
  - Hypothesis not approved.
- Findings:
  - Only minor differences between engineers and managers have been detected. Distinctions are particular cases in consideration of special questions.
- Interpretation:
  - Those differences may as well originate from different seniorities of the participants, a characteristic which has not been prompted in the survey. A vital need to distinguish between managers and engineers in regard to collaborative engineering activities has not been proven right.

5. Conclusion

One rather general but very important hypothesis has not been mentioned in the previous section:
The major branches in product development are comparable regarding the investigated collaboration processes and issues.
At least the automotive, plant engineering and aviation industries have very similar characteristics in terms of collaboration processes and issues. There are some specifics regarding conservativeness, amount of different types of digital models used and the perception of justification for instructions. The plant engineering industry is rather conservative which becomes evident for instance in the amount of PMR that are stored in terms of analogue data such as paper documents or quasi-analogue data such as scanned paper documents. In the aviation industry, engineers have to handle about twice the number of model types than in other industries and the perception that employees have to do what

they are told to do, no matter why, is much more common than in comparable industries. Regarding justification, the opposite is the case for the plant engineering industry. Aside from these selective differences, the major industries in the study are comparable. Therefore, it is assumed, that tools and methods to support collaborative engineering can be used cross-industry for automotive, aviation and plant engineering.

The shipbuilding industry seems to make an exception in the interbranch comparison since there are differences to the overall sample in many cases. Unfortunately, the number of respondents from this industry is too small for statistically significant findings. The same is true for all other branches that have participated, but in these cases, the findings do not indicate differences from the overall sample anyway.

The question whether or not the size of the product development division in the company is relevant for the characteristics of collaborative engineering activities has not been answered, yet. All necessary data to answer this question, at least for the survey sample, is available and will be analyzed shortly.

In the end, most of the investigated hypotheses have been proven right. The selected approach for supporting collaboration management in virtual product creation based on the identified issues [Stark and Stoeckert 2009] will therefore be pursued.

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