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COHERENT TEAM STRUCTURE IN A THREE-DIMENSIONAL CAD NEW PRODUCT DEVELOPMENT (New PD) ENVIRONMENT

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Abstract

This study examines the influence of a variable ratio between engineers and technical draughtspeople in New PD teams in a Three Dimensional CAD New Product Development environment on economic and socio-psychological efficiency. With the implementation of the 3D CAD software (Three Dimensional Computer Aided Design) the world of engineers seemed to become a completely new and fascinating one in which the engineer is a 100% creative part in the New PD process of an innovative company – with all supporting activities taken over by a marvelous software, automatically and completely [1, p. 11]. Technical draughtspeople who did supporting activities so far declined rapidly and engineers have more or less lost their "right-hands", the technical draughtspeople [2], especially in mechanical development departments of medium-sized companies. Recent analysis of the workload of engineers under 3D CAD-conditions revealed – unsurprisingly – that at least one third of the hours of work are related to supporting activities, to distributable work [3, p. 189]. According to that situation these companies more or less lost the advantages of coherent work distribution and as a consequence of that the opportunity to overlap creative and routine activities between engineers and technical draughters. Based on the discussion of two important properties of the information to be exchanged, sensitivity and evolution [4, p. 440], this paper will show how overlapping can be processed from the creative to the executive phase between engineers and technical draughtspeople. Coherent work distribution plus overlapping procedures should finally increase the economic and socio-psychological efficiency of the development department and the company as a whole, measured by lead time, costs – including opportunity costs, quality and various soft facts. The subject of this paper is, to elaborate the reasoning for a cause-effect analysis which is in preparation by the author (see Addendum).

Research Question

The person who is faster in presenting convincing concepts determines the customer's mindset and has therefore a better chance to succeed in the current, hard competition. In the background of that, the ability to transfer new ideas to commercial products in a timely

manner is an important competitive factor with high influence on the corporate success today [5, 6]. A survey on the topic of problems concerning research and development, held by Prof. Dr. Klaus Ehrenspiel, showed the following: the dominating problem of the development process where all members of staff, every company, all hierarchical positions and every line of business meet are project durations and deadlines [7]. In departments concerned with the development of products, reaction time, processing time, lead time and innovation performance are being influenced by the availability of qualified members of staff. On the other hand members of staff within the development departments are comparatively expensive. The high percentage of qualified employees – more than half of them (55%) are academic personnel, around 20% are technician [8, p. 178] – means high personnel costs for a company. Owing to a tremendous deficit of qualified employees, which is already now being lamented and which will probably even increase [9; 3; 8, p. 479], personnel costs for this group of employees are likely to incline in the following years. That is why the appropriate number of personnel will become even more and more expensive, but in the meantime it is one of the most crucial basic conditions of the ability to innovation [10]. In the face of the importance of high costs for the general competitiveness and innovativeness, new ways of thinking have to be taken into consideration here. One possible approach towards an economical and socio-psychological efficient development process in a New PD environment within a 3D CAD engineering environment could be the consistent assignment of technical draughtspeople in mechanical development departments in medium-sized companies who would relieve the development engineer from all part and assembly orientated documentation. According to the BMBF [11, p. 30] is the ability to innovation of small and medium-sized companies especially strong related to the sufficient availability of qualified and experienced members of staff. Not only is the number of qualified staff in medium-sized companies for the above mentioned reasons small, but it is also getting even shortened through a typical form of work organization. Not – as you can often register in large companies – specialization is the problem, but mainly the engineers' overloading through a lot of organizational and auxiliary tasks. The development engineer has to fulfill several tasks at the same time: he works in the sales; accompanies the manufacture and assembly or the work preparation for problems with new products, is responsible for the order of tools plus machines and generates nearly the whole product documentation [7, p. 277]. Interruptions and unforeseen tasks are characteristic for his or her daily routine. Time for the actual product developments is drastically restricted. Additionally there occurred due to the 3D CAD growth another auxiliary task to engineers in development departments of medium-sized companies. The 3D CAD revolution led to a personnel structural change in medium-sized mechanical development departments, which are responsible for the development of new products. Medium-sized companies were successfully conveyed that engineers can – on the side – easily take over product documentation with this 3D CAD software. Technical draughtspeople who did this kind of work so far declined rapidly. 1999 the product development industry had 143.483 technical draughtspeople under social insurance contribution – 2007 there were only 118.513 left. The population index declined from 100 in 1999 to 83 in 2007. In the same time frame the population of engineers increased from 637.935 to 682.384 people under social insurance contribution. The population index increased from 100 in 1999 to 107 in 2007 [12]. As a consequence the overall ratio between drafters and engineers in Germany went from 0.23 in 1999 to 0,17 in

2007 and the population index falls from 100 in 1999 to 77 in 2007. The decline in medium sized companies was even worse. As a matter of fact the 3D CAD software cannot take over the product documentation automatically and the engineer in medium-sized companies usually these days creates the documentation (mainly part and assembly drawings) which take intensive time consumption. One of the engineer's main tasks lies in the conceptualization of future systems. This means it is rather a complex process which requires both analytical skills and creativity to generate innovative solutions for the next generation of commercial products. Developing new concepts is a creative field of activity where engineers use their knowledge well-directed in order to give systems particular functions, forms and traits. Owing to the above described developing engineer's multi-functionality, in practice proven concepts which offer with given resources the best possible solution are often preferred [7]. These exploitation processes with their unsound fixation to existing solutions is one big hurdle for innovation [13]. The traditional main task of technical draughtspeople is the drawing up of norm-proven technical drawings as draft, itemization or assembly drawing in form of outlines, details, views and sections. Besides they write technical documentations and carry out project entries, evaluations plus calculations. This paper is understood to be one of various components to provide the evidence that a coherent team structure is a prerequisite for the application of modern management methods, such as concurrent, overlapping project processing. And these methods should enable mechanical development departments of medium-sized companies within a 3 D CAD engineering environment to carry out product development efficient, fast, innovative and competitive.

The paper will analyze the method of overlapping, identifying a kind of a missing link in the mechanical development departments concerned, compare sequential vs. overlapped mode, introduce the notions of fast and slow evolution and high and low sensitivity, present a framework of four types of overlapping, that may help project managers to decide for the applicable extension of overlapping in a special environment, present the conclusion of that analysis and indicate the structure of a causal model in preparation.

The concrete research question is: Does the employment of technical draughtspeople in mechanical development departments of medium sized companies within a 3 D CAD engineering environment increase the economic and socio-psychological efficiency? The subject of this paper is, to elaborate the reasoning for a cause-effect analysis which is in preparation by the author (see Addendum).

Overlapping; A General Management Method

Let us think of the activities to be undertaken by a top manager after having received an appointment with the German chancellor: The top manager will not at all wait for all detailed information necessary for this meeting, he will immediately pass all information available at this moment to his supporting staff (secretary etc.) in order to start with the arrangements – for an escorting team, for presentation documents, for a flight etc. And he will try to get further details which he continuously will make available to his staff in order to have a successful meeting. This example demonstrates overlapping activities in its simplest way: overlapping can be found everywhere, in commercial or private environment; overlapping give all project members more time to find good, best solutions; overlapping is applicable for project members

of different expertise; overlapping can be efficient in single working unit as well as in big organizations, in every cooperative and communicative process…

Scientific paper on overlapping processes often concentrate their research on new development activities as these are commonly understood as crucial for the success of a company in a rapid changing market and the cause-effect relations are obviously not as simple as in our overlapping story above – though the method is not at all restricted to that processes.

One crucial direction of New PD are attempts being strongly influenced by Japanese way of proceeding to shorten development times of products through overlapping development activities for the product and the overall New PD process. Additionally to the avoidance of downtime further potentials in proceeding time have been identified and harnessed. It is possible to link pairs of activities by starting first actions of a succeeding activity even with only incomplete information gotten from its prior activity and to avoid later delaying touch up through intensive co-operation in interdisciplinary teams – quite similar to the above overlapping story. Simultaneous Engineering, Concurrent Engineering and Integrated Product Development are the key methods of overlapping procedures. Overlapping, defined as the partial or full parallel execution of tasks (Figure 1B, 1C) and functional interaction, meaning the degree of information shared between business functions, became more and more popular for many companies which act in a fast moving environment. With the new overlapping mode of New PD activities, these companies think to have a substantial advantage in lead time.

The flow of information and the process execution in practice is largely sequential, with information being generated and finalized by the upstream activities before being absorbed by the downstream development activities [4]. That means in New PD – first (upstream) the preparation phase then – downstream – to the creative phase and at last – downstream – to the execution phase. But also in the three New PD phases the different tasks can be done sequential or overlapped, for example within a development project by allocating various components to one (sequential) or to various engineers (overlapped), or by transferring finalized (constructed) part-information to technical draughtspeople for documentation progressively (overlapped) – or not (sequential). At the first glance the overlapping mode seems to be faster. Actual researches are concentrating on various selected aspects of overlapping, such as on dynamic rework in overlapped schedules [14], on acceleration model for projects with known rework fraction caused by overlapping [15], on measurement of the coupled strength of tasks [16] or on a systematic approach to reduce costs and risks [17]. All these papers are more or less based on the seminal work on overlapping strategies by Krishnan et. al., "A model based Framework to overlap product development activities" [4]. They provide a framework to help designers or managers to decide when and how to overlap pairs of activities with the intention to reduce product development lead time and to ensure at the same time that adverse effects on product quality and development effort are minimized. Subject to this paper are creative and routine activities in New PD. The idea of this paper is to demonstrate that overlapping activities in the execution phase with coherent utilization of supporting staff is a method to decrease development lead time and hence development costs and it will finally increase the economic efficiency of the development department and the company as a whole. Based on an assessment of the pros and cons of concurrent / overlapped engineering this paper will show how overlapping can be processed efficiently from the creative to the execution phase, respectively from the task of engineering design to part and assembly documentation, of New PD between engineers and drafters.

Sequential vs. Overlapped Mode

It is commonly agreed in theory as well as in practice that speed is the key point for success in commercial competition [5, 6] and the "intense competition forces manufacturing firms in many industries to develop new, higher quality products at an increasing rapid pace" [4, p. 1]. And as it is also an established fact that projects are almost always behind schedule [7], "overlapping product development is an important component of concurrent product development that can help firms to develop products faster" [4]. Imai et. al. observed that faster product development processes are more overlapped [18], but they do not give any explanation how to overlap the New PD process. Furthermore they imply that all activities can be carried out concurrently. Clark et. al. recognized that frequent face to face and bilateral communication of preliminary information makes overlapping more easily [19] – instead of reserved handling with incomplete information. "However, since product development activities may be coupled in complex ways, overlapping interrelated activities can present many difficulties. Without a careful management of the overlapped product development process, the development effort and cost may increase and product quality may worsen" [4, p. 437]. These are undoubtedly serious concerns in respect to any overlapped project processing, as e. g. in the area of marketing, capital investment etc. Therefore Krishnan et. al. designed a model which goes beyond the common recommendation to simply overlap activities as much as possible. He describes four types of overlapping based on two determining properties of a design process, on "evolution" – a measure for the speed of upstream information generation – and on "sensitivity " – a measure for additional downstream efforts due to changes of upstream information – and illustrates the model with industrial applications. These terms "evolution" and "sensitivity" and the four types of overlapping, the Iterative Overlapping, the Divisive Overlapping or Non Overlapping, the Preemptive Overlapping and the Distributive Overlapping must be explained and analogies to the development tasks between engineers and drafters respectively creative and routine activities will be shown.

Acceleration can be reached by overlapping development activities in combination with a more frequent exchange of preliminary information (Figure 1).

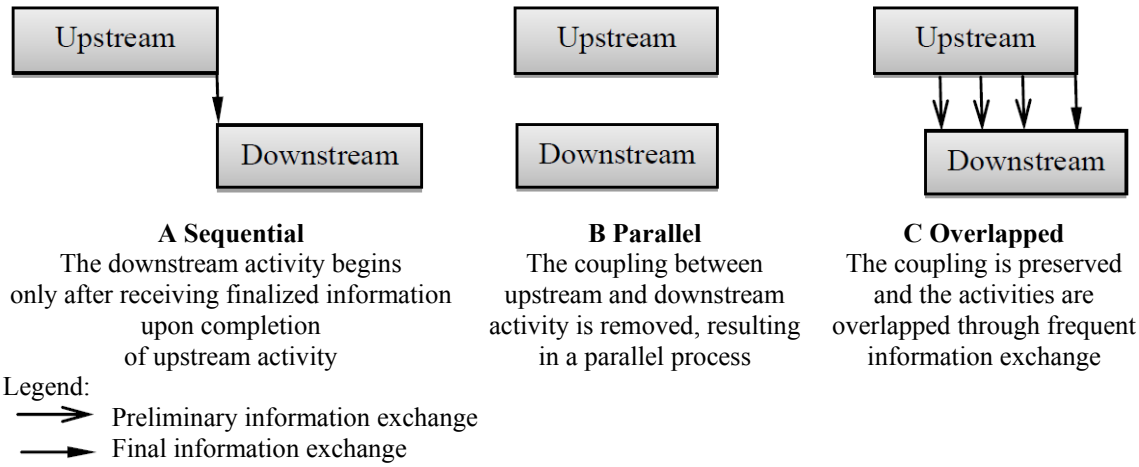

Figure 1. Sequential, Parallel and Overlapped Processes [4]

Contrary to that method "is a one-time transfer of finalized information – a sequential process" [4, p. 437]. In a sequential process the downstream activity does not begin until the upstream activity has finalized and completed the information. Whereas the overlapped process begins earlier by using preliminary information (Figure 1C). This overlapped mode needs a disaggregation of the exchanged information. But "when preliminary upstream information is utilized by downstream activity too early, further changes have to be incorporated in time consuming subsequent iterations, resulting in an increase in the downstream duration and effort. On the other hand, when parts of the upstream-generated information are finalized early, the upstream activity loses the flexibility to make future changes along these dimensions" [4, p. 438]. Convinced of a solvable imbalance in respect to the allocation of personal resources in mechanical development departments within a 3 D CAD environment, which is subject of this paper, the discussion of overlapping development activities must be examined in detail to see if there are any combinations in information sharing which are suitable and economically efficient between engineers and technical draughters in a 3 dimensional engineering environment.

Introduction of Fast and Slow Evolution and High and Low Sensitivity

From the information processing point of view "Individual development activities are themselves viewed as information processors, receiving input information from their preceding activities, and transforming this input information into a form suitable for subsequent activities. The sequential process assumes that the upstream-generated information is available for downstream use only at the completion of the upstream activity." [4, p. 440]. During the upstream activity the development process continuously narrows and refines the information from an initial rough assessment of a design parameter to a final value. For that refinement process from the preliminary to the final value, Krishnan et. al. use the term evolution [4, p. 437]. In the metaphorical sense he compares the information processing progress with a hopper/funnel from a large diameter (begin of the activity) to a final point, which represents the exact information for the downstream and subsequent New PD activity. The performance of this process can vary from fast to slow, depending of the character of the individual development project. The term fast evolution explains a redesign development project. The components and the technology are mostly known. That means information in the creative and the design phase of New PD can be generated fast. In other words – major changes happen early, the exchanged information gets close to its final form rapidly and can be frozen and passed downstream early in the upstream process without much quality penalty for the upstream activity. The term slow evolution on the other hand explains an innovation, a product using new components and technology. Here the information generation starts slowly at the beginning of the creative and the design phase and increases rapid to the end of that phase. The modification of the interchangeable information increases as the upstream activity progresses. In this case, finalizing upstream information early in the upstream process either would be impossible or would entail a huge quality penalty for the upstream activity [4].

In the overlapped process, the upstream activity shares preliminary upstream information at defined breakpoints with the downstream activity (Figure 1). The downstream activity begins to perform its normal development iteration using the exchanged information.

This iteration process is to be repeated after the next releases of the meanwhile improved information of the upstream activity until the final value is available. Under this aspect the downstream activity has – as Krishnan et al. are calling it – a particular sensitivity, ranging from high to low. If substantial changes can be accommodated quickly by the downstream activity the downstream sensitivity is understood to be low and if the incorporation of changes in contrast is joined with time consuming rework the downstream sensitivity is understood to be high.

Whether overlapping can be installed as a measure for improving lead time etc. depends on a careful assessment of the particular project, development or any else, which is argued in more details in the next section. Since every product development project creates a different number of new components there is a good chance in a redesign construction to transfer every single component information parallel/overlapped from the engineer to the technical draughter to produce part and assembly drawings/documentation which serve worldwide as documents of order – provided a supporting staff has been set to engineer's side. On the one hand, as already stated above, normally the evolution in redesign construction is fast and major changes are not expected at the end of the engineer's – upstream – activity, on the other hand the downstream sensitivity is low as the main structure remains, little – and also bigger – changes can be easily accommodated / reworked by the technical draughter's – downstream – activity, because the drawing is already created. When a part is constructed and ready to take in orders, it is basically complete and changes keep within small limits. As a result, the duration of the individual activity may actually increase through overlapping (more communication and iteration), while the total project lead-time can decrease due to the concurrent work on different activities [14]. To compress schedules by overlapping is very likely.

The Four Types of Overlapping

Krishnan et. al. illustrated and substantiated their model with application to the design process of an automobile door panel and door handle (with the overlapping pair of activity: engineering design and prototype development) and with application to the development of an electronic pager (with the overlapping pair of activity: industrial design and engineering design). The automobile example for instance resulted in a lead time reduction from 18 plus 4 weeks (sequential) to 18 plus 1 day (overlapped), which is a substantial contribution to overall cost of the development of an entire automobile, estimated to at least 1 million $ per day [4, p. 446]. Figure 2 shows the four extreme situations of overlapping which can occur – fast or slow upstream evolution and high or low downstream sensitivity [4, p. 448]; the original figure is expanded by text boxes and additional arrows to highlight the engineer – drafter – overlapping option.

Iterative Overlapping: When upstream evolution is slow and downstream sensitivity is low, "it is possible to commit downstream resources based on preliminary upstream information" [4, p. 448]. Even large changes in the – slow – upstream exchanged information have no or marginal influence on the downstream activity. In that slow upstream evolution major changes happen late in the upstream process and the information cannot be finalized until the completion of the upstream activity. Early information finalization of the upstream activity may result in a large quality penalty for the upstream activity. That means, when information is

finalized early and committed with the downstream activity, there is no possibility to take in better concepts in the downstream activity. However as downstream sensitivity is low iterations for changed parameters are easily performed. That development situation appears, when a completely new product comes into being, but for example manufactured with known technologies [4].

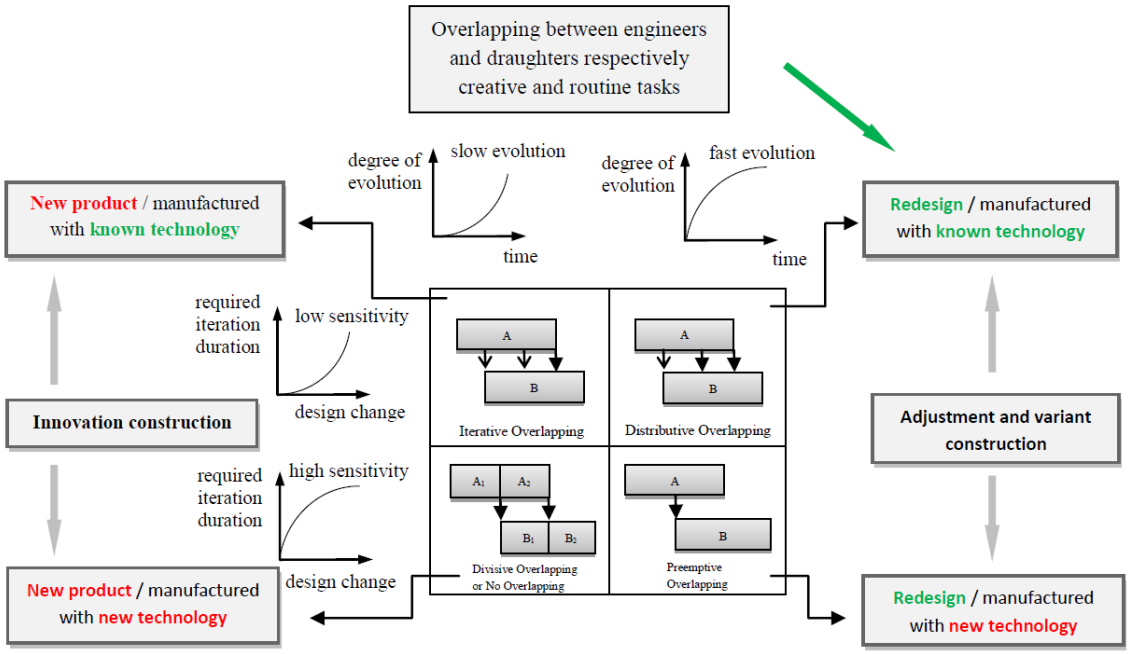

Figure 2. Iterative Overlapping, Distributive Overlapping, Divisive Overlapping or No Overlapping and Preemptive Overlapping [4]

Divisive Overlapping / No Overlapping: When upstream evolution is slow and downstream sensitivity is high, it is not desirable to start downstream activity with preliminary information, because major changes happen late in the upstream process and the duration of iteration loops in the downstream activity is too high. That development situation appears, when a completely new product comes into being with new manufacturing technologies. An exception might be the possibility of dividing the complete upstream activity and identifying within the slow process parts of fast evolution [4].

Preemptive Overlapping: When upstream evolution is fast and downstream sensitivity is high the upstream information can be finalized early – parts of the problem solving are accelerated – without much quality loss. This situation would help to reduce development time by starting the downstream activity earlier in time with preemptively frozen information of the upstream activity. That development situation appears, when a product redesign with new manufacturing technologies accrues [4].

Distributive Overlapping: When upstream evolution is fast and downstream sensitivity is low, it is possible to start downstream activity with preliminary information (no need for

freezing early) and continue with the onward progress of the New PD process with preemptively finalized upstream information, because large changes in the upstream process happens early and finalized information – before the end of the upstream activity – do not lead to huge quality losses in the upstream process. The low sensitivity means, that large changes in the magnitude of the upstream information exchange do not entail large iteration loops. Both activities, the upstream and the downstream, are contributing to an efficient overlapping process, the involvement is distributed [4]. That situation is most favorable for overlapping. – Transferred that idea to the activities from the creative to the execution phase of New PD, respectively engineering design to part and assembly documentation – the work sharing between engineers and technical draughters means, that when part and assembly construction/design is widely progressed through the engineer the drawing documentation, executed through the drafter, can start. That development situation appears, when a product redesign with known manufacturing technologies accrues and that complies with a variant construction, the most frequent construction worldwide and – it complies explicitly with the subject to that dissertation.

Conclusion – a Missing Link

There is no generalization possible, but if overlapping is approached in a careful and systematic manner, respecting possible quality, cost and risk impacts, a reduction in lead time seems to accrue largest [17]. A few figures may demonstrate the potential: Our standard project takes about 12 man/months with a supporting labor portion of about 4 month (8 month creative: 4 month supporting), it is one with about 20 new parts and 200 new drawings and the drawing part of the supporting portion is about 75% say 3 month or 60 working days, which means one part consumes about 3 working days. These figures imply under optimal overlapping conditions the option for a reduced lead time of (8+1) months + 3 working days = 9 months +3 days – vs. 12 months (with 1 month for various non-documentation, supporting tasks – and 3 days after the completion of creative activity for last part).

The overlapped procedure in general seems more adequate for an inherent iterative development process than a one shoot finalized information exchange like it is assumed in project management. In the New PD process preliminary information exchange is useful and profitable and especially the overlapped activities between engineers and drafter should lead to economic efficiency, measured with hard facts – lead time and costs. But as far as mechanical development departments in medium-sized companies within a 3 D CAD environment are concerned, there is, what I would call, referring to the term evolution in the original sense, a missing link:

One tricky outcome of the 3D CAD revolution was, as already outlined, the dramatic change of the personal structure. With 3D CAD the engineers in these companies have more or less lost their “right-hands”, the technical draughtspeople. The massive drawing documentation work was creeping towards the engineer as the 3D software isn’t efficient and able enough for an automated part and assembly drawing generation. According to that situation and apart from the advantages and disadvantages of concurrent/overlapped engineering these companies more or less unconsciously lost the option to overlap creative and routine activities between engineers and drafters. And exactly one of the major results of that analysis is that overlapping is very

preferable for the examined situation. Under that circumstance the drafters are actually the missing link which stops the evolution towards an efficient use of professional methods and expertise for New PD in mechanical development departments of medium sized companies within a 3D CAD engineering environment. In addition, what makes the prospects even worse, there is no chance to overcome that gap by employing more engineers, what might be seen as an option to get more flexibility in rapid changing markets. On the one hand the growing shortage of engineers is hardly under dispute. On the other hand, and not only based on that perspectives, it is not the intention of an engaged engineer to loose – on a permanent basis – too much time with supporting activities, valuable time which is required to apply and to improve his personal profession in the preparation and the creative phases of New PD. There are good reasons for the assumption that this understanding of professionality we express for the highly educated engineers is also applicable for all other highly educated experts. A respective investigation is recommended. (Please recall our overlapping story.)

It looks as if efficient New PD is actually not possible without the coherent employment of supporting staff. Following that argumentation the basic hypothesis can be formulated: The higher the assignment of technical draughtspeople for the generation of technical drawings in mechanical development departments of medium-sized companies within a 3D CAD environment, the higher the increase of economic and the socio-psychological efficiency.

The subject of this paper was, to elaborate the reasoning for a cause-effect analysis which is in preparation by the author (see Addendum).

Addendum

The Causal Model for socio economic analysis, which is in preparation, shows possible cause-effect relations between different team constellations in New PD teams under 3D CAD conditions and the economic and the socio-psychological efficiency. The structural dependent variable Y, the economic efficiency, will be measured by the endogenous latent variables as the lead time, the personal cost, the amount of concepts and the number of drawing errors. The structural dependent variable Z, the socio-psychological efficiency, is indicated by the engineer's methodical responsibility during creative phase of product development and the engineers/drafters contentment with the employment. Subject to the iterations, respectively manifestations for the independent structural variable X (variable ratio between engineers and draughtspeople in a defined project – variable team structure), are the distribution of drawings which must be generated in a defined standard project, the team structure and the education level of the team members matching with the development task. By arranging stress tests the model must prove its reliability. If the real environment and the model match for selected parameters, we can draw the conclusion that the model reflects the aspects of reality sufficiently. Two methods will be used to prove the derived hypotheses. On the one side a broad-based study is in preparation in medium sized companies using questionnaires. Participants of recent new product development projects (variant constructions) – engineers and technical draughters – will be asked accordingly to falsify respectively verify the model. On the other side defined standard projects are being executed at various levels of selected independent variables in an experimental field study.

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