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Coherent Division of Labor in a Three-Dimensional CAD New Product Development Environment

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This experimental field study examines the influence of a variable ratio between engineers and technical draftspeople in New Product Development (NewPD) Teams in a three-dimensional CAD construction 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 NewPD process of an innovative company – with all supporting activities taken over by marvellous software, automatically and completely. Technical draftspeople who did supporting activities so far declined rapidly. The literature review shows the improvements by 3D CAD, the areas where the SW is over-challenged and a discussion of division of labor in detail. The Causal Model for socio economic analysis shows possible cause-effect relations between different team constellations in NewPD teams under 3D CAD conditions.

Keywords: *New PD, economic/socio-psychological efficiency, new product development, division of labor*

JEL Classification: *M54 - Labor Management*

1. Introduction – Division of Labor / 3D CAD – Fascination and Demystification

With the implementation of 3D CAD the world of engineers seemed to become a completely new and fascinating one in which the engineer is a 100% creative part of an innovative company – with all supporting activities taken over by marvellous software, automatically and completely. The intention of this paper is to demonstrate how the day-to-day-life of engineers in medium-sized companies actually has changed and to claim for a rethinking of the really achievable improvements by 3D CAD and where the SW is over-challenged. Based on this reassessment of the strengths and weaknesses / the pros and cons of 3D CAD this paper will try to develop an approach of how to find an adequate team structure by analysing the various kinds of tasks to be fulfilled by an engineer within a development department of a medium-sized company with respect to the level of qualification required. And following this, the paper will try to define the prerequisites for a coherent division of work which should finally increase the economic and the socio-psychological efficiency of the development department and of the company as a whole, measured in terms of time, cost, quality, job satisfaction and the methodical responsibility of the engineer.

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2. Literature Research – Theoretical and Empirical Evidence

2.1. The Starting Point: Organisational Basics vs. "Modern" Engineering

It is commonly agreed in theory as well as in practice that speed is the key point for success in commercial competition (cf. Scheer, 2003; Hirzel et al., 1992) and that the development departments are one of the greatest bottlenecks in the turbulent, fast-moving business environment (Ehrlenspiel, 2007). There is actual a basket of methods available to overcome the pressure on engineers in development departments, e. g. project management, process oriented approaches, standardization or division of labor. According to these ideas companies have worldwide established their procedures since decades, some up to more than 100 years, until a "revolution" has dramatically changed at least the organization of mechanical development departments in medium-sized companies, the 3D Computer-Aided Design. With 3D CAD the engineers in these companies have more or less lost their "right-hands", the technical draftspeople and the massive drawing documentation work was creeping towards the engineer. This over-reaction was initiated by the fulsome praise of the software companies, was unconsciously fostered by the universities and was put in operation by the medium-sized companies - in expectation of substantial reductions of lead time and cost. But one tricky outcome of the 3D CAD revolution was that even with the new design system the possibility to "produce" more variants and the customer demand for more variations increased essentially, with a rather negative impact on the workload of the engineers. In that context Wildemann (2003, p.7) found that from 1980 till 1997 the number of variations in the receipt of orders inclined within growing markets by 410% whereas the number of orders increased only by 240% and this trend continued unbroken and even more extensive in stagnating markets. Recent analysis of the workload of engineers under 3D CAD-conditions revealed – unsurprisingly – that at least one third of the hours of work is related to supporting activities, to distributable work (Wittenstein, 2007, p. 189). The development engineer has to fulfil several tasks at the same time: he works for the sales, supports the manufacture, the assembly or the work preparation in the case of problems with new products, is responsible for the order of tools plus machines and generates nearly the whole product documentation (Ehrlenspiel, 2007, p. 277 sqq.). The organization of his daily work, correspondence and travel management has to be done on the side. Interruptions and unforeseen tasks are characteristic for his daily routine. Time for the actual product developments is drastically restricted, especially in medium-sized companies. 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 (Ehrlenspiel, 2007). These exploitation processes with their unsound fixation to existing solutions is one big hurdle for innovation (Kliesch-Eberl and Eberl, 2009) and according to BMBF (2007, 2011) the capability to innovation of small and medium-sized companies is especially strong related to the availability of sufficient qualified and experienced members of staff. There is obviously a strong need to apply proven organizational basics in order to utilize valuable resources adequately.

2.2. 3D CAD: A very powerful SW - but no Jack-of-all-trades

The features and benefits of 3D CAD as described e.g. by the (PTC - Parametric Technology Corporation, 2013) are:

- Superior product differentiation and manufacturability by powerful parametric design capabilities
- Fully integrated applications allow to use a single application for the entire development cycle - from concept to production
- Automatic onward transfer of design changes to all downstream delivery components for increased confidence in the construction work
- Comprehensive functions allow for virtual simulation improved product performance and an even higher product quality
- Automated generation of associative tooling design and manufacturing deliverables.

This is according to (Solid Edge/Siemens, 2000) to be understood in combination with a remarkable cost saving potential, e.g. productivity jump in the ratio of 4:1 (= personnel cost minus 75%), minimized alteration service due to reduced error rate by 90%, reduced tooling costs by more accurate and more complete information, less waste, less inspection effort, fewer test runs in development. This is not the place to analyze all these benefits of a really mighty SW; they are actually realized also in medium-sized companies to a certain extent. However, what is most critical for the daily practice in these companies was the "promise" of full integration from concept to production and the remarkable personnel cost saving potential which was obviously taken as the signal to change the team structure of mechanical development departments dramatically by reducing the commitment of technical draftspeople. Furthermore the components which are to be constructed have become much more complex (DFA-extensive functional integration, deterministic finite automation), and free-form surfaces, which had not been possible so simply before 3D CAD were invented, led to a higher level of complexity – amongst others - within the drawing up of technical drawings. As a matter of fact the 3D CAD software is not such efficient to work them out automatically and it is the engineer in medium-sized companies who creates the drawings usually in these days. In an empirical study (Kessler and Chakrabarti, 1999), found that clear time-goals, longer tenure among team members, and parallel development all could increase speed, whereas design for manufacturability, frequent product testing, and computer-aided design (CAD) systems decreased speed. Moreover, they also found that some factors speed up radical innovation (e.g., concept clarity) and slow down incremental innovation. Actually for this study it is important to mention that there is already empirical evidence that CAD decreases speed in new product development. This is completely contrary to the promises of the 3D software companies. As already explained, it is not at all the intention of this paper to query the investment decision for the implementation of 3D CAD in development departments of medium-sized companies, for that 3D CAD is really a strong tool, but the paper intends to demonstrate that these companies have good chances to increase their efficiency considerably by using it adequately and - by going back to the application of the basic ideas for efficient organization, to a coherent division of labor.

2.3. Coherent Division of Labor

Convinced of a solvable imbalance in respect of the allocation of personal resources, the next step must be, to examine the discussion on division of labor in detail. Since the beginning of the industrial revolution at the end of the 19th century up to the 60s of the 20th century the concept of Taylorism, the scientific management was the dominant system for the organization of operating procedures in order to achieve maximum productivity (cf. Taylor, 1911; Heinen, 1974, p. 449). The headstone was already laid down more than 100 years before by Adam Smith with his proposal to increase productivity by specialization via a process of deepening division of labor extensively (Smith, 1776). According to these ideas productivity will increase by reduced work training, learning effects, higher speed of completing one's task, better assignment of responsibilities and possible faults, reduced burden and less labor cost (Kieser and Walgenbach, 2003, p. 81). While A. Smith concentrated his researches on macro-economic aspects of the division of labor, F. W. Taylor studied the micro-economic ones. F. W. Taylor's merits can be seen in the relieve of work operations from their deficits laying in the workers, the tools and the materials by a systematic and methodical analysis and by assembling the results, deactivating all random events (Gutenberg, 1966, p. 144-146). For this paper especially the arguments of achieving more speed and lower cost etc. by a systematic and methodical analysis will be followed up later. But this completely mechanical point of Taylor's view - had to make way for the social welfare and human relation movement (Heinen, 1974, p. 451f) for various reasons e.g. the workman is condemned to monotonous routine and thinking, initiative, work satisfaction and joy are denied and individuality and innovative spirit are being destroyed. Insights about the disadvantages of a too extensive division of labor are described many times (cf. Kieser and Walgenbach, 2003, p. 81 sq.; Ehrlenspiel, 2007, p. 184 sqq.). According to these insights and accompanied by an overall change in values and even individualization, science of work has turned to the aim of arranging for human working surroundings since the 70s of the 20th century. Re-integration is one of the basic attempts of previous eliminated labor contents to design integrative tasks with the aim of disposal of negative effects of the division of labor and to increase the motivation of members of staff by job enrichment, use of different abilities, social interaction, areas of independent decisions and personal development (cf. Kieser and Walgenbach, 2003, p. 82 sqq; Ulich, 2001). But even task integration as well as specialization is limited: „Important is to have a task and job based specialization" (Weltz and Bollinger, 1987, p. 52 sqq.). Kühn et al. (2006, p. 154) noted a rising integration of tasks by specialized experts, of tasks, which could easily been done by people with a lower level of expertise. Therefore Mayer (1988) demands a cooperative division of labor with a specialized expert in the center. There are no definite determinations concerning way and level of division of labor in the development of products. Different kinds of division of labor can simultaneously be seen within only one company or even only one project. The concrete distinctness is dependent on the level of the complexity of a project as well as of the size of the company. Within product development a task can in principle be divided sequentially - in different single steps, worked on one after the other - or parallel - divided according to quantities or objects - (Ehrlenspiel, 2007, p. 163 sqq.). In addition a horizontal division – in tasks equal in ranking – and a vertical division - in optional and performing tasks or in, what is subject to this paper, creative and routine activities – must be under consideration (Scholz, 1995). Hubka (1976, p. 14) distinguishes among five different kinds of development / construction tasks:

- Skilled labor in terms of technical and scientific considerations to think ahead of a mechanical system.

- Activities associated with the description of the mechanical systems.
- Skilled labor, but no direct contribution to the design of mechanical systems.
- Supporting work, e.g. copy, cut and archive of drawings.
- Management activities.

Based on this structure (Mayer, 1988, p. 80 sqq.) raises the question how the coordination between experts and supporting members of staff must be designed. Vertical task integration proves itself so long as coherent as it does not lead to uneconomic use of (high) qualification. Wittenstein (2007, p. 98) substantiate this demand with what she is calling "Sinnvoll verteilbare Arbeitseinheit – SVAE - practically distributable work unit". One of the essential influencing variables for a practicable distribution, one of the k.o.-criteria, is the ratio of effort of time for distribution vs. temporal scope of effort; the smaller the ratio is, the better is the suitability for distribution (Wittenstein, 2007, p. 136). It is subject to this paper to outline a verifiable procedure to determine a coherent package of tasks to discharge the development engineer in development departments of medium-sized companies, to establish a motivating, autonomous work package for a draftsperson in modern design under 3D CAD-conditions and to increase the efficiency of the development departments – without losing flexibility in highly competitive markets.

3. Research - Premises, Methodology and Analysis

3.1. Establishing a coherent, dynamic Team Structure

The research design of this paper is constructed with the intention to work out whether the employment of technical draftspeople in mechanical development departments of medium-sized companies for the setting up of drawings (product documentation) will increase the economic and the socio-psychological efficiency i.e. whether an optimal team structure can be established under 3D CAD construction conditions. The methodology is to perform projects in the real industrial environment with different team configurations in an experimental field study. Basic requirement is to define a comparable 3D CAD standardized project. A comparison of time, costs, quality of the drawing set, human resource development and job satisfaction will be made between division of tasks (with draftspeople) and multi-function (engineers alone) - with different personal commitments and in quantities qualified for statistical analysis. To do this the standardized project has to be specified to standardized engineering drawings without further capacity burden. As development activities can be distinguished through the level of novelty of the task into: innovations, adjustment constructions and variant constructions (cf. Ehrlenspiel, 2007, p. 256 sqq.) a representative kind of development activity in mechanical development departments of medium-sized companies is to be selected. A construction is called innovation if all phases of the construction process are gone through and if a new product with on principle new solution comes into being. In an adjustment construction the concept exists and the draft is adapted according to changed demands. Variant construction means that the draft is at least given roughly-qualified and essentially, measurements have been changed due to the customer's performance or rather interface demands. Researches have shown that the highest percentage of time is being filled with variant constructions and partly also with adjustment constructions. Innovation constructions make up only 10% of the development tasks (Ehrlenspiel, 2007). This paper intends to define and to analyze one of the three typical performance variants in technical departments. To have a high external validity that type of project is selected, because of its worldwide major dissemination. The paper will demonstrate that the statement "there is no detailed argumentation required to prove the effect of increasing productivity/efficiency by division of labor" made about 45 years ago by (Gutenberg, 1966, p. 144) is still valid under 3D CAD conditions in mechanical development departments of medium-sized companies and therefore it is even today possible and necessary to define an optimal team structure – also in that specific environment. Cohen et al. (2000) analyzed several new product performance metrics. The analysis showed the dilemma between ambitious time to market, product performance and development costs. An overly ambitious time-to-market target leads to an upward bias in resource intensity usage and a downward bias in product performance (i.e., evolutionary product innovation). Given a target product performance, the analysis show that the coordination between marketing and R&D is easier because the resulting development resource intensity and time-to-market decisions becomes separable. However, an overly ambitious product performance target leads to an upward bias in the development resource intensity and a delayed product launch that misses the window of opportunity. Finally, the analysis show that the target development cost approach can lead to a downward bias in product performance and a premature product launch. In the case of this paper there are good chances to increase all of the three commonly used new product performance metrics: (1) time-to-market, (2) product performance and (3) total development costs by finding a coherent ration between engineers and drafters in a 3D CAD construction environment. The selective manipulation of that ratio should lead to differences in the three metrics plus differences in employee's competences and job satisfaction.

3.2. Causal Model

Basic Hypothesis: The employment of technical draftspeople for the setting up of technical drawings (product documentation), increases the economic and the socio-psychological efficiency of mechanical development departments in medium-sized companies.

According to figure 1 defined standard projects are to be executed at various levels of selected independent variables. The standard projects belong to variant construction, the most frequent development project identified in general (cf. Ehrlenspiel, 2007, p.256 sqq.). Previous research suggests that project complexity can have significant influence on a team performance (Ancona and Caldwell, 1992) and speed to market / lead time (Kessler and Chakrabarti, 1999). Therefore a standard project as already mentioned is defined to have evidence that the manipulation of the independent variables leads to changes in the dependent one´s. Every development project is divided into three phases, the preparation phase, creative phase and executing phase. In the first two phases engineers have to be always present. In the third one there is also extensive repetition work to do and in this phase division of labor is possible between engineers and technical draftspeople depending on the task. This third phase is the starting point for measuring the lead time of the defined standard project and the center piece of the presented model. The time required for phase 1 and 2 depend from a lot of factors outside the engineer's range of influence and so the spread of lead time should be drastically reduced. The selective manipulation of the independent variables should lead to visible changes of lead time. The intention of this scientific project is to generate substantial cause-effect relationships for the above mentioned conjecture, the basic-hypothesis, with due regard to the scientific quality criteria as validity, reliability and representativity – knowing from Buckler (2001, p. 17), that a final proof of causality is not really possible. The method used is a causal analysis, the established method for the analysis of various social and economic issues. The causal analysis is - in general - a confirmative procedure to validate a complex set of hypothesis in respect of the dependence structure between research variables by empirical collected data. Causal analytic models are mathematical constructs which shape proposed cause-effect relations and try to prove them by statistical procedures, as co-variation- correlation- and regression analyses (Neuert, 2009, p. 134 sqq.). According to Buckler (2001, p.31) a causal model is basically composed of an independent structural variable (X) which has effect on the dependent structural- to be explained variables (Y, Z), i.e. - in the simplest case - Y/Z = f(X). The independent structural variable (X) itself is explained by a set of exogenous latent variables whose values are determined by factors outside the model (measured by x_1- x_n) and in this connection X is a dependent variable. The dependent - structural variables Y and Z are determined by factors within the model i.e. by X and measured by latent endogenous variables y_1- y_n and z_1- z_n. Transferring this understanding to the object of that study we receive the following explanatory model:

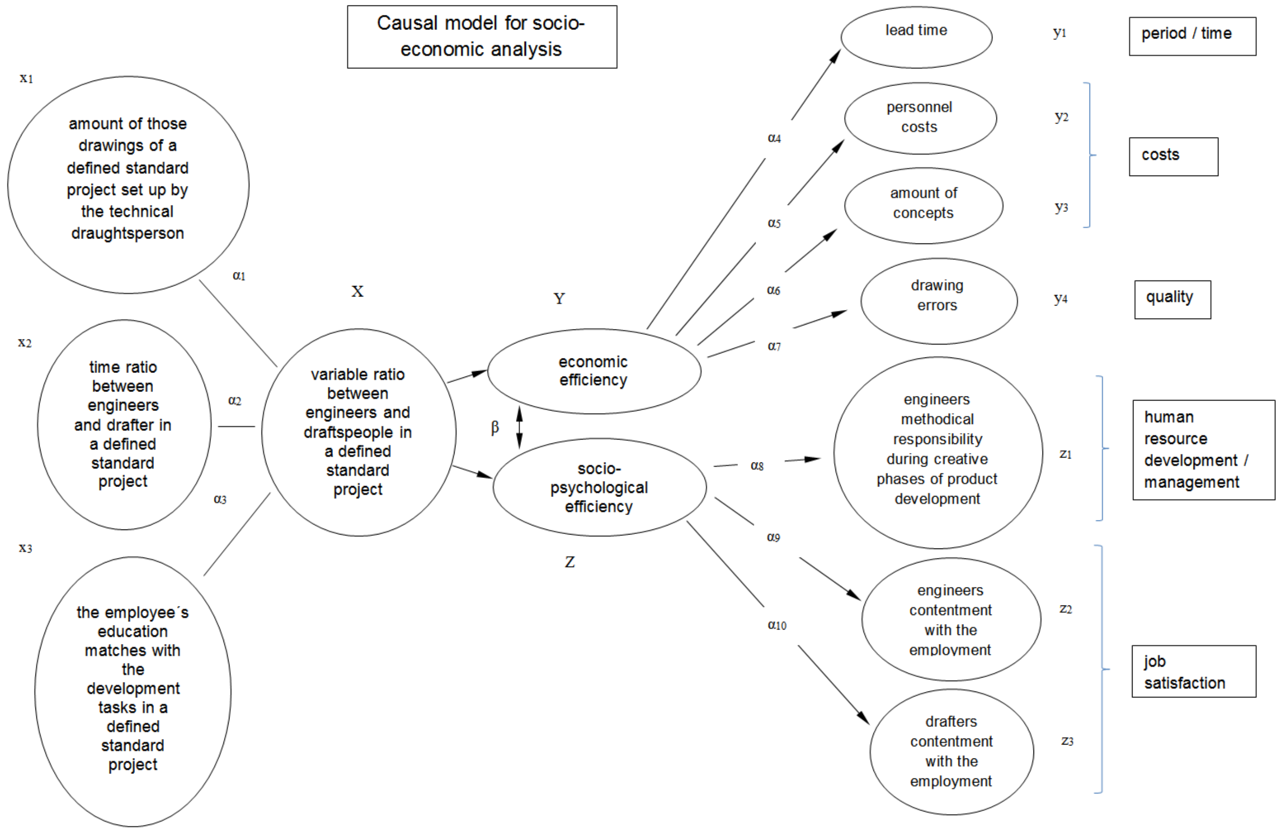

***Figure 1**. Explanatory model*
Source: Author

Legend for the causal model:

X	= independent structural variable
$x_1 ... x_3$	= latent exogenous variables (measurement variables)
Y, Z	= dependent structural variables
$y_1 ... y_4$	= latent endogenous variables (measurement variables)
$z_1 ... z_3$	= latent endogenous variables (measurement variables)
$\alpha_1 ... \alpha_{10}$	= correl. degrees of dependence between structural & measurement variables
β	= correlative degree of dependence between dependent structural variables

The model demonstrates the system of exogenous latent variables $x_1 – x_3$, the structural independent variable X, the structural dependent variables Y and Z and the set of observed endogenous latent variables y_1-y_4 and z_1- z_3 (for the measurement of achieved impacts on Y and Z by various degrees of X). The preparation of the characteristics of the cause-effect relations between the variables (α_1 - α_{10} and β) is an essential part of this verification procedure. The action parameters (exogenous latent variables) to establish a set of manifestations of the independent structural variable X, the variable ratio between the employment of draftspeople and engineers, are: x_1: the amount of drawings set up by drafter, x_2: the time ratio engineer – drafter and x_3: the education level of the team members matching with the task – in a defined standard project. These parameters/variables must be transferred into operational, measurable values in order to work out a statistical-quantitative analysis and at least a compound indicator for the independent variable as a whole. They will be modified following coherent limitations. The structural dependent variable Y, the economic efficiency, is measured by the endogenous latent variables y_1: the lead time, y_2: the personal cost, y_3: the amount of concepts and y_4: the number of drawing errors. Following the classical subject of microeconomics the variable Y must give information on cost, revenue, expenditures, benefit etc. This study will use a cost-benefit-calculation for an economic efficiency analysis to provide the option of combining hard and soft (socio-psychological) facts. y_1, the lead time is a very strong measure. Time is the incorruptible, genuine dimension for a comparison of different procedures. All subjective, company-"political" impact is omitted. With variable y_2 the different hourly rates for engineers and draftpeople are taken into account. y_3 and y_4 give further indications for an adequate assessment of economic values. The structural dependent variable Z, the socio-psychological efficiency, is indicated by z_1: the engineers' methodical responsibility during creative phase of product development z_2: the engineers' contentment with the employment and z_3: the drafters' contentment with the employment. As far as contentment with the job is concerned indicators received from satisfaction survey, absence and fluctuation must be considered. Based on the definition of main features of a standard project and the minimum requirements for work sharing between engineers and drafters the tests will be performed with a frequency required to get statistical relevant data. Subject of the iterations are the team structure (from for example 70% engineer: 30% drafter over 85:15 up to 100% engineers) and the number of drawings (about 200 drawings distributed from 100% engineer up to 100% drafter). The education level of the team members will be recorded for each of the individual iteration.

For validation of the model, i.e. verification respectively falsification, the statements in the form of hypotheses will be compared with results of the investigation, the real facts (Neuert, 2009, p. 136). 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 conclusions that the model reflects the aspects of reality sufficiently.

4. Discussion and Conclusion

With this paper one of the central elements of the causal model in discussion is addressed. Further components such as functional respectively competence diversity, modern PD methods and task satisfaction respectively cognitive dissonance must be considered accordingly in order to elaborate a solid theoretical and empirical basis necessary to supported the assumption of causality (Weiber & Mühlhaus, 2010, p. 13 sq.). After these additional comprehensive studies the scientific evaluation of the proposed causal relation between a coherent team structure and socio-economic efficiency in selected areas of NewPD within a 3D CAD environment can be performed and conclusions and suggestions inferred. A coherent solution for the imbalanced allocation of personal resources in NewPD is likely.

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