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ENGINEERING DESIGN IN INTEGRATED PRODUCT DEVELOPMENT
Design Methods that Work

RESEARCH INTO THE PRACTICE OF DESIGN ENGINEERING WORKING METHODS WITHIN AUTOMOTIVE COMPANIES

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Abstract: *Before implementing a PDM-system within a company, the internal processes of product and process development and the information handled herein should be organized well. To enable this organization, one should be able to see the bottlenecks and therefore the working methods and the documents involved should be made transparent. Thereto we have started a research project in which the development processes of three automotive suppliers are analyzed and documented in three representations, formatted according to a generic scheme. Based on these representations a so-called induced model of product and process development is created. The induced model can be used on the one side as an initial expectation when charting an as-is situation of a development trajectory for a company and on the other side as a resource of ideas when creating a to-be situation. In this paper, the format of the representations will be shortly explained, the working method laid down in the resulting induced model will be presented and the research problems that came up during the research will be described.*

INTRODUCTION

Objectives

In literature very little is found on details about the information handled within product and process development of industrial companies. To gain insight into that kind of information a research project was started in 1992.

Approach

First, a method and instruments were developed to consistently capture the representation of the product and process development together with the relevant information in a database and in clearly structured diagrams. Three instruments were developed:

- a generic representation scheme defining the format of company-specific representations,
- a software tool to facilitate the application of the representation scheme and
- a method for the application of the scheme.

Based on this method, the product and process development as well as the information belonging to it were charted systematically, resulting in a consistent representation.

Subsequently, the development processes of three automotive suppliers were analysed and laid down in three company-specific representations. These representations were formatted according to the generic representation scheme that was specifically developed for the case studies. In these representations, the organisation, the relationships between documents and the activities of product and process development were mapped to each other. The three descriptions were then compared mutually as well as with current theories.
The research was carried out with the help of an industrial sounding board in which the three companies were represented.

Results

The three instruments that were developed (generic representation scheme, software tool, and induced model and method altogether) act as a still camera producing a snapshot of the product and process development of a company. By doing this, it makes several aspects visible, including the information that was handled. The snapshot reveals possible bottlenecks and, at the same time, it checks the con-

sistency. Thus, it provides the companies with a means to make the information regarding their product and process development, as well as the development process belonging to it, transparent.
In the three cases, sufficient similarities in the product and process development were found to make the creation of a more generic so-called induced model possible. Thus, based on these findings an induced model of product and process development, describing both activities and information, is created. This way, the knowledge and experiences of the three companies are brought together into one induced model. The induced model can be used as an initial expectation when recording an as-is situation of a company. Furthermore, the induced model is useful as a resource of ideas when creating a to-be situation for a product and process development trajectory for a company.

MORE ABOUT THE RESEARCH METHOD

As said before, in order to determine and chart product and process development together with the information, case studies are carried out. In the beginning of the research project, it was unknown to what extent companies look alike in their development processes and information involved. That is why we have selected companies with comparable clients, comparable products and comparable magnitudes etc. That way we would have the greatest chance of finding similarities.

The current research project is an explorative research. Furthermore it can be qualified as being qualitative [Baarda and Goede, 1995]. The research data are collected by interviewing company people and by analysing existing documents of the companies. These documents include procedures of the working method, quality handbooks (including ISO9000 and QS9000 documents), copies of all the engineering information documents, such as the drawings, bill of materials and all kinds of forms.

The research strategy is derived from the inductive-hypothetical strategy [Sol, 1982], [Meel, 1994], [Vreede, 1995]. The inductive-hypothetical research strategy consists of five activities, which are:

1. Initiation, which leads to a descriptive empirical model
2. Abstraction, which leads to a descriptive conceptual model
3. Theory formulation, which leads to a prescriptive conceptual model
4. Implementation, which leads to a prescriptive empirical model
5. Evaluation, a comparison of the descriptive empirical model (1) with the prescriptive empirical model (4).

The derived research strategy includes the following steps (see figure 1):

1. Selection of three companies and the development of a generic representation scheme.

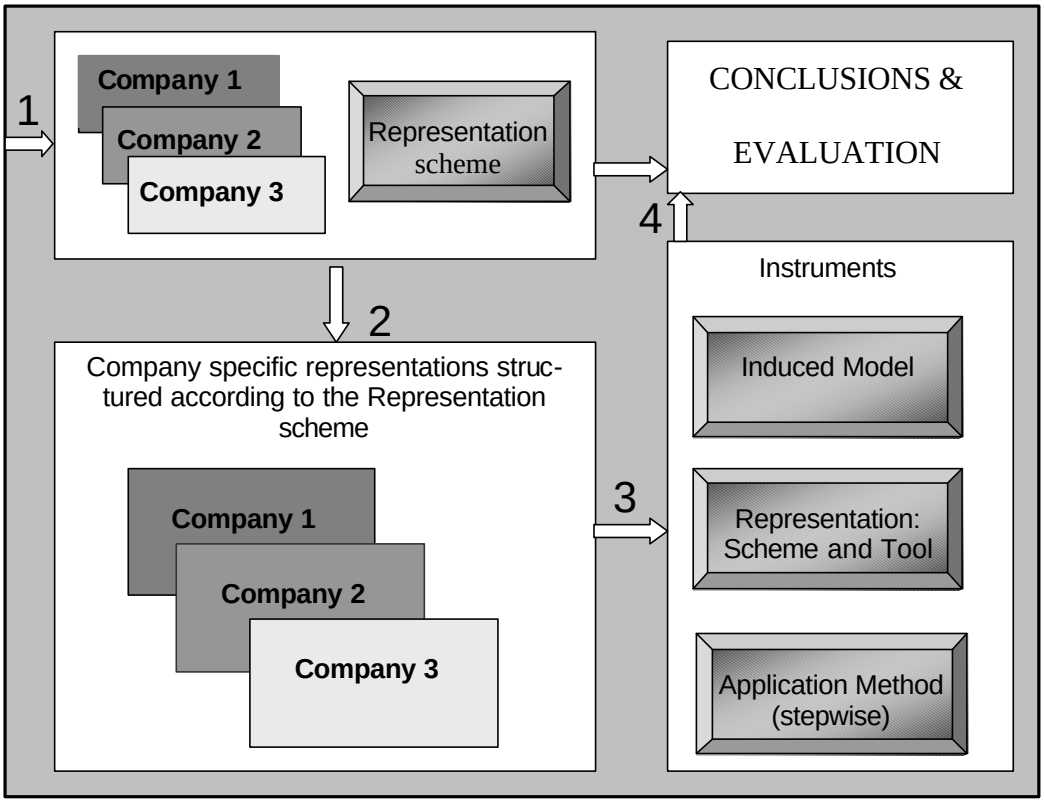

Fig.1. *Research strategy*

2. Description of the three companies according to the generic representation scheme, resulting in three company specific representations of product and process development. In parallel, a tool is developed to facilitate and accelerate the application of the generic representation scheme.
3. Comparison of the three company specific representations and the creation of the induced model. In this step also the method used in describing the companies is laid down [Vroom, 2001].
4. Supported by the three companies and by the industrial sounding board, the results are evaluated, conclusions are drawn and recommendations are formulated.

GENERIC REPRESENTATION SCHEME FOR PRODUCT AND PROCESS DEVELOPMENT

The genericrepresentation scheme defines the format for the company specific chartings. In the representation scheme, the development of a product and process is considered being a project having a clear starting and ending point. A project is represented by three aggregates of object classes (called main object classes):

- Subject (to register the organisation)
- Activity (for the processes)
- Information

These three main object classes represent who (subject) does (activity) what and with which information. In the next figure the main object classes and the relationships between and within these main object classes of the representation scheme are represented.

The three coherent main object classes together make up a three-dimensional model in which the three main object classes are the three dimensions. This three-dimensional model represents the coherence, but does not give a good overview. That is why two-dimensional pictures of the model are required. Therefore eight diagrams are defined. Three of which represent the relationships within the main object classes. Three other diagrams represent the relationships between the main object classes. Furthermore there is one diagram representing the semantic relationships within the main object class Information and one diagram that represents the activities in the proper order and frequency alongside a time-axis.

The product and process development of three industrial companies are analysed and represented according to the representation scheme developed.

To improve the accessibility of the data within the three company specific representations for third parties, the knowledge and experience at the field of product and process development of the three companies is bundled in a so-called induced model of product and process development.

This induced model is based on the similarities found in the three company-specific descriptions.

This induced model is structured according to the same representation scheme, as were the case studies.

The instances of the object classes contain all information required to automatically generate six of the eight diagrams that represent the development process. That is why a software tool is developed facilitates and accelerates the application of the generic representation scheme. In fact the tool generates pictures from the contents of the database.

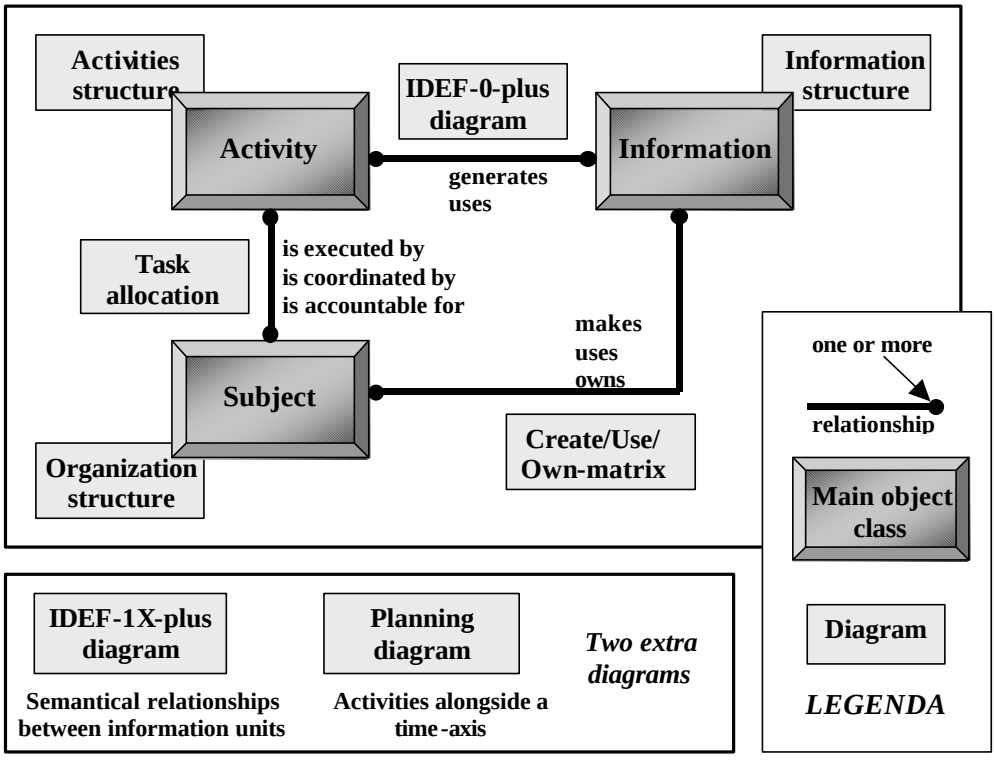

Figure 2. *Generic representation scheme*

THE CREATION OF THE INDUCED MODEL OF PRODUCT AND PROCESS DEVELOPMENT

Introduction

The induced model is created based on comparisons of the company specific models. At first some of the guidelines that are used for the creation of the induced model are explained. Then the activities part of the induced model is presented.

The detail level used in the induced model

Each main object class of the representation scheme is levelled into object classes. For example the main object class Activity is levelled into the object classes:

- Analysis area
- Subdivision of analysis area
- Procedure
- Task
- Activities & Decisions

That is why the most adequate level of each main object class to be used for the induced model had to be determined. These choices are made pragmatically balancing between too abstract, which would make the induced model not very informative, and too detailed, which would not give enough overview.

With regard to the main object class Activity it is decided that the level of Tasks is the lowest level to be represented. The levels higher than Tasks are hierarchical related to the level of Tasks and therefore they will be represented as well.

Naming entities in the induced model

The names of the entities determine partly the clearness of the induced model. For instance A-1 is called Project start and therefore all activities involved with the project start should be included in A-1. From that view (internal consistency) sometimes is chosen for a regrouping of activities, or to change the names of the activities compared to the names used in the case representations.

Scope of the development process in the induced model

The representation of the process in the activity structure is broader than the original focus of the research. This means that the preparation of a development order (earlier in the process than the original scope) and the production process (at the end of the process) are represented too. This way the boundaries of the area of interest are shown too. Also the project-independent activities are not part of the original focus of the research area, but they are represented in the induced model for as far as they have come up during the interviews with people from the companies.

Result: the activity structure of the induced model

In figure 3 an overview is given of the Subdivisions of the analysis area in the induced model.

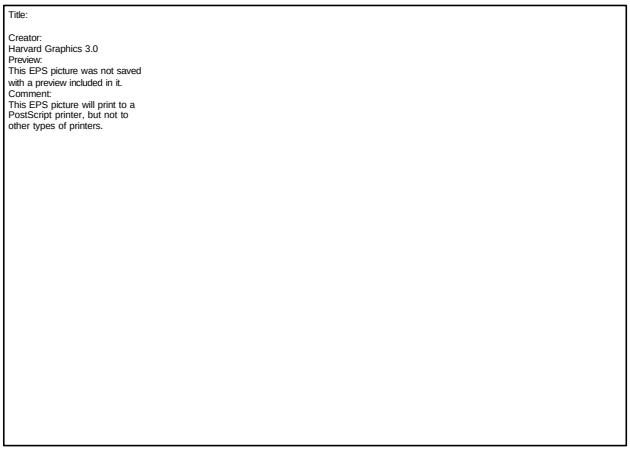

Fig. 3. *The subdivisions of the analysis area*

In figure 4 the same Subdivisions are illustrated but this time as processes, which take, time and are subsequent or (partly) parallel to other Subdivisions.

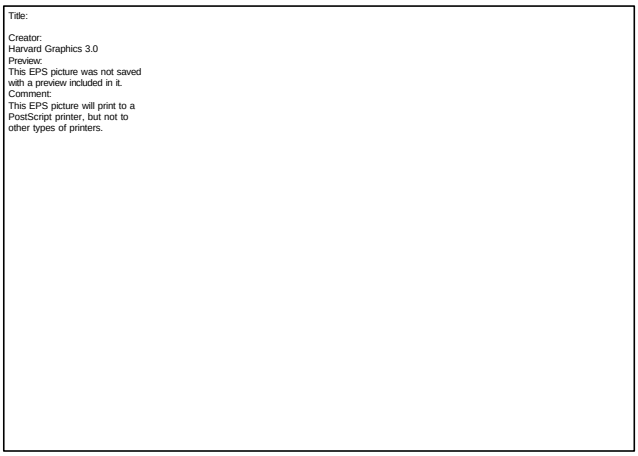

Fig. 4. *The subdivisions of the analysis area*

For the correct understanding of this figure it is important to know that the product design is frozen at the end of the product development (A-4). Then also the drawings are released. That is why the changes (A-10) from that moment on will be established according to a formal change procedure. In A-9 (Releases) the parts, the tools, the process and the final product are released.

In this paragraph the activity structure of the induced model is presented. For this activity structure the Subdivisions of Analysis (A-1 to A-13) are further elaborated down to the level of Tasks. The results of this elaboration are presented below, tree structured in a border per Subdivision.

A-1: Project Start

A-1.1: Prepare development assignment
Analyze market
Familiarize with the assignment
A-1.2: Draw up a Project proposal
Formulate Problem def. & Action plan
Draw up an initial rough Planning
Draw up an initial List of Requirements
Propose people for the Project roles
Agree on communication & responsib.
Lay down initial ideas for solutions
Unite above results into Project proposal
A-1.3: Determine feas. of Project proposal
Assess req. processes, knowl.&.conditions
Analyze knowledge in team and environm.
Determine lacunae in knowl. & solutions
Determine techn. feasibility of the project
Fix a price & det. financial feas. of project
Determine marketing feasibility of project
A-1.4: Decide about proj. & make Planning
Assess Project proposal mgnt + Proj.man.
Assess Project proposal by Principal
Determine Project plan
Make a Project planning

A-2: Project Management

A-2.1: Report about the Project
Keep the status of hours and costs spent
Report hours & costs to Steering g.& Cust.
A-2.2: Direct the project
Direct the project (by the Steering group)
Adjust the project (by Project manager)

A-3: Concept Development

A-3.1: Develop product concept
Elaborate List of requirements
Dev. partial solutions for techn.functions
Develop global total solutions
Select and lay down product concept
Lay down preliminary Bill of materials
A-3.2: Assess product concept
Simulate solutions
Descr. product conc. in exp. results (specs)
Assess product concept (using requirem's)
A-3.3: Review product concept
Det. conditions & req's for further dev.
Go/no go decision about cont. of project

A-4: Product Development

A-4.1: Prepare product development
Scan patents
Draw up Planning for creation of drawings
Elaborate Test manual
Make Planning for creat. prototype (parts)
Draw up Planning for testing
A-4.2: Elab. product conc. into prod. design
Develop product and make drawings
Calculate product design (strength etc.)
A-4.3: Make functional models (A-samples)
Make parts for funct. models (A-samples)
Assemble parts to functional models
Test & meas. func.models acc.to test man.
A-4.4: Analyze and assess product design
Elaborate list of specifications
Execute DFMEA analysis
Analyze product safety
Assess prod. design for cust. req.s & specs
Compare prod.design with comp. products
Execute analyses DFM and DFA
A-4.5: Patents search and apply for patents
Send in patent disclosures
Execute patent search (to avoid violation)
A-4.6: Predevelopment of the process
Predev. of process for production of parts
Predevelopment of the assembly process
Make soft tool samples (B-samples)
Test and measure soft tool samples
Draw up initial Control Plan
A-4.7: Review product design phase
Eval. techn.feas. of prod.des.& proc.conc.
Eval. financial feas. (verify costs targets)
Evaluate marketing
Determine req.s for remaining project part
Design review prod.des.& proc.concept

A-5: Process Development

A-5.1: Develop machines and tools
Elaborate process for production of parts
Develop a/o define means of production
Dev. a/o def. means of meas.& check.parts
A-5.2: Develop assembly process
Elaborate assembly process
Develop and/or define the assembly tools
Dev.a/o def. means of meas.& check.assy's
Create further required prod.ion documents

A-6: Outsourcing

A-6.1: Initiate and guide outsourcing
Set up order
Direct the outsourcing
A-6.2: Realization of the outsourcing
Parts prod. or processing by suppliers
Receive, test and store outsourcing

A-7: Realize the process

A-7.1: Realize the machines and tools
Realize means of production
Realize means of measuring and checking
A-7.2: Verify (qualify) means of production
Make hard tool sample parts (C-sample)
Measure and test hard tool sample parts
Evaluate and release means of production
A-7.3: Realize the assembly process
Realize assembly tools
Real. means of meas.& check. assemblies
Build assembly line
A-7.4: Verify the assembly process
Execute processing test of assembly tools
Assemble hard tool sample (C) (pilot run)
Test & meas. hard tl sample acc.Test man.

A-8: Documentation

A-8.1: Make, manage & dissem. Doc.tion
Document product and product parts
Verify customer documentation
Manage customer documentation
Disseminate documentation
A-8.2: Keep the dossiers
Keep Product Design Dossier
Keep Process Design Dossier

A-9: Releases

A-9.1: Release parts & the tools (Cm-value)
Release parts
Release assembly tools and assembly line
Release outsourcings
A-9.2: Release product as a whole
Release product for production (transfer)
A-9.3: Release the process internally (Cpk)
Execute trial production (Initial sample)
Release process for production
A-9.4: Release by the customer
Test product (by customer) (Initial samp.)
Release product (by customer) (ISIR-rel.)
A-9.5: Close the project
Formal transfer to production responsibilit
Close budget of project
Close project and team

A-10: Changes

A-10.1: Change product/process
Send in a change proposal
Assess change proposal
Process change

A-11: Production Preparation

A-11.1: Production preparation
Set up logbooks
Make stocks
Order parts at suppliers
Set up info about stock processing
Form production teams

A-12: Production of products and maintenance of the means for production

A-12.1: Produce products
A-12.2: Final check and test
A-12.3: Send goods to customer
A-12.4: Mainten. prod. a/o mns of prod.ion

This phase is outside the scope of research and is therefore not elaborated further.

A-13: Project independent activities

A-13.1: Make the procedure manual
Set up generic action plan
Set up procedures
Set up formats (e.g. for an assembly plan)
A-13.2: Make the company info manual
Set up options & constr. about assembly
Set up opt. & constraints about transports
Set up product style of the company
Set up company specific standards
Set up calculation models
Set up material properties
S.u. info resource cont.stand.techn. conc.
A-13.3: General (not proj.specific) research
Benchmark products
Make forecasts
Dev. Proj. independ. production processes

These activities are in principle outside the scope of the research

RESEARCH FINDINGS OF THIS PRACTICE-BASED RESEARCH

During the research the following problems came up:

- It appears to be problematic to create a snapshot with a short exposure time. However, during a longer exposure time, the situation within a company changes.
- Companies appear to have ambiguous working methods.
- The researcher's influence on changes in the development process is unclear.

The paper will go further into these problems and it will discuss the way the issues were handled in the research.

Long exposure time

The time needed to create a description of the situation in a company (i.e. to create the as-is representation according to the general representation scheme) varied between 6 and 12 months. This time frame was in fact the exposure time of my imaginary photo camera. This exposure time turned out to be too long to create a stable snapshot of the situation in a company. The working methods and processes that had to be described were changing continuously. It often happened that a described situation had already been changed when returning to a company to discuss the description of that situation. Simply making a new description was not a solution to this problem, because changes are so abundant that this approach would lead to an endless loop of describing and checking and describing again. Besides, even if one tries to go into that loop, another problem occurs. Some changes are namely hard to detect, which hinders the checking and describing again.
Nevertheless it often occurred that part of the description had to be adjusted because of major changes. In dialogue with the company people involved, we decided whether or not a change had to

be included in the description or not. When the description was almost complete it was frozen in the sense that no changes would be inserted anymore, and only those corrections and additions would be taken into account, that were needed for a complete and consistent description.

Ambiguous working method

A second problem was that companies usually do not have an unambiguous working method. Not nearly everything has been recorded in documents and for that reason, the researcher has to depend partly on stories told from the memory of people. Then it appears to be that the processes are described differently by different people of the same company. Furthermore the processes described by people are not completely compliant with the working methods recorded in the documents. Finally, the spokesmen of the companies usually already had some ideas to improve the working method and they had also introduced those changes to some extent. For a researcher, a problematic situation appears. He has to choose between describing a situation that is almost obsolete or describing a situation that has not yet completely been introduced.

Illustrative for these problems is also that within a company usually more projects are running in parallel, based on different working methods. The ambiguity manifests itself in this way because of the high frequency of changes in working methods and the long duration of projects (of which the order of magnitude is from several months to several years).

For the research project described, we chose to describe the "almost introduced" working method rather than the "almost obsolete" working method. Clearly, a researcher encounters more enthusiasm with company people when describing the best working method for the company one could imagine at that time, than by describing a working method that has already been rejected and that is considered not function optimally. Besides, the major assignment for the current research was to describe a good working method, in which the knowledge and experience of an industrial company are captured.

The researcher's influence

A third problem is the uncertain influence of the researcher on the changes and the ideas about changes in the working method. Just by asking the companies for cooperation of, one in fact already initiates a process of change. Company people involved in the research are inclined to deliberate the goals and problems of the research. This phenomenon can be triggered by various causes: just by talking with the researcher, by reading intermediate research reports, and also when the researcher calls attention to a possible problem area in their working method by. After the researcher has initiated a thinking process, company people could conclude for themselves that a working method is not optimal and they tend to change it as soon as they can.

This problem is especially important when the changes caused by the instruments developed, have to be described precisely. In that case the research method used is not accurate. In the current research, however, we chose to disregard the twilight zone of changes. Instead, statements by the company representatives about the merits of the applications are used to indicate to which level of improvement the instruments developed could lead.

Some general reflections

In the first years of investigation of this topic, there was a tendency towards research based on a more experimental setup, with the aim to attain more quantitative and reproducible results. However, in this research, many people from practice were involved, that is, not only the representatives from the companies but also the people of the sounding board. The members of this board were brought together from industry, consultancy and research centers. Their and our objective was to gain insight into existing situations and to use knowledge and experience of multiple companies. It is for this reason that in this research project a substantial practical component was retained. The statement of [Cantamessa, 2001], that industrial involvement appears to be beneficial, and should probably be actively backed in order to ensure a closer connection to reality, supports our decision.

As one of the options for the research approach "action research" was also considered [Vreede, 1995], [Whyte, 1991], [Meel, 1994]. However, action research focuses on the analysis of change processes inside companies, while in our case the change was an unwanted side effect that had to be coped with, rather than the main subject of interest.

Conclusions

A research project has its own specific goals. During the research it is important to reflect on the research method used and to identify it's possible imperfections. Dependent on the goals of the research, the method should be adjusted or not. This conclusion could be refined by the statement of [Samuel and Lewis, 2001] that *we need to establish the basic difference between research in the natural sciences and research in design. In natural science we are concerned with existing phenomena and our curiosity about the laws that govern these phenomena and how to predict such phenomena drive our research effort. In the practice of design we are most commonly faced with the need to achieve a goal. Our concern is to find the best or perhaps the least worst way to reach our goal. We are not driven by curiosity, but by our goal.*

It is hard to describe an as-is situation or a to-be situation based on a changing situation. When the goal is

to constantly improve the situation, then one can describe a hypothetical 'best-case' situation at a certain point in time to be used that for analysis. However when changes are being introduced, one has to be aware of the actual as-is situation to make sure that every change from that situation is registered.
In this kind of research, where company people are important information sources, it seems impossible to eliminate the researcher's influence on existing and future situations in the companies. We could say that the shorter the exposure time, the less influence the researcher can have. But, in this kind of research, where many sacrifices are required from company people over a long time, those people want something in return. They cannot be kept waiting for many years if so much is demanded from them. It is for that reason, that they received the intermediate reports as well. Therefore, despite short exposure times, the influence of the researcher will have its effects in case of a long research project duration.
Working methods in companies are not unambiguous. Not even people of one company describe the same working method the same way. They do not describe working methods in compliance with the procedures on paper either. And, when trying to reconstruct the working methods used within specific projects running in one company, it turned out that different projects have different working methods as well. These differences are caused by the many changes introduced in working methods, as well as the long duration of the development projects. In this research project, we described the method of working that was the best according to the company people.

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