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LONGITUDINAL ANALYSIS OF THE IMPACT OF REQUIREMENTS MANAGEMENT ON THE PRODUCT DEVELOPMENT PROCESS IN A MEDIUM SIZED ENTERPRISE

M Schmidt-Kretschmer and L Blessing

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1 Introduction

The management of interfaces between organisational units is becoming increasingly important within the context of globalisation. This can be organised using structured models for the execution of the product development process. Many of these prescriptive models (e.g. [1], [2], [3], [4]) have been developed and discussed by the scientific community [5] and are increasingly supported by empirical investigations [6]. Industry too has attempted to standardise product development activities in Product Development Process (PDP) models. These are developed in an iterative process. After an initial situation analysis, a process is defined and executed (i.e. a product developed), then the process is evaluated and where necessary improved. The improvements can also be made during the execution of the process. For the initial definition of the process both academic models and company-specific models are used and combined if useful. Such process concepts may be regarded as a support or as a burden [7]. In either case, deviations from the defined process indicate possible scope for improvement. The most important reasons for rejecting academic models are their complexity and the terminology used [8]. Both aspects complicate communication and confirm the importance of the control of communication and of the interfaces within the product development process.

A key factor for clear communication is requirements engineering, i.e. requirements development and management. The relevance of the "voice of the customer" is frequently described in the literature (e.g. [9]), Furthermore, there has been extensive research into requirements development (e.g. [10], [11], [12]) and there are commercial tools (e.g. Doors [13] and Cradle [14]) to manage requirements (i.e. configuration management, change control and traceability [15]). However, instructions are not sufficiently clear [16]. Small and medium companies often use company-specific process descriptions and methods, also avoiding the cost involved in the use and maintenance of existing commercial programs. This situation causes substantial problems in product development.

The aim of this paper is to examine the interactions between the actual course of a project and the defined and standardised PDP regarding in particular requirements management on the basis of a longitudinal analysis of several product development projects within one company. The focus is on requirements management during the project because of its crucial role in product development. The paper describes typical problems as well as best practice solutions. The following questions are addressed:

- For which activities in the PDP are requirements relevant?

- When in the PDP is the fulfilment of requirements evaluated?
- How do the requirements affect the definition of interfaces between organizational units?
- What are typical problems when managing requirements (and how can these be avoided)?
- How can requirements be managed effectively with a holistic view of the PDP?

2 Case description and methodology

The context of the qualitative case study is described here using categories already proposed by Blessing [17] for the classification of descriptive studies. A longitudinal investigation (1994-2003) forms the core of the research approach. In a globally active, medium-sized industrial enterprise, the first author investigated (in part in his role as process manager) six development projects and the development of the company PDP itself. All investigated projects were original highly complex mechatronical design projects, i.e. number of objects to be designed more than 100 parts. All projects had comparable project goals. The average lead-time of the regarded project phases inclusive definition of the requirements was 30 months, with an average of 40 team members, including 27 designers. The defined standardised PDP specified the overall company objectives, the arrangement of process phases/stages and the operational sequence of the projects, roles and responsibilities of all stakeholders, as well as the structure of requirements lists and the tasks of the project management. The projects were executed within a matrix organisational structure. There were only small changes of the organization of the company with an impact on the proceeding of the projects, i.e. the fluctuation of internal core team members was ignored, since no influence on the project processes was observable.

The investigations covered the main phases of the PDP between requirements capture and production release with events analysed on a month by month basis. The investigations of the first third of the time period were retrospective.

The investigation included:

- The extensive analysis of the project documentation (manuals, minutes, reports, product and process documents).
- An extensive analysis of interdisciplinary team meetings and presentations; intensive interviews and discussions with all project members.

The data analysis followed six steps:

1. Classification of the projects into two groups regarding project success. The target parameters (cost, time) between project-kick-off and production release were compared with consideration of the effects of requirements changes. Additionally, minutes of meetings, reports and interviews with the clients were examined to understand the external assessment of the projects.
2. Selection of events which affected the course of the projects and which were discussed in the cross-departmental meetings of the core team.
3. Identification of events with direct connection to the selected focus of the investigation, which was represented by the categories: *requirements management (RM), and evaluation (RE), interface (IF)* and *product development process (PDP).* Regarding *PDP,* the reasons for all deviations were inquired in interviews. The representation of the events took place

with allocation to the project phases. Furthermore changes of the context were examined regarding factors affecting the project. The events were identified predominantly on the basis of project documents. The reasons were determined in retrospective interviews and if necessary also by discussions with the project team members.

4. Classification of events regarding the central topics of interest. The category *RM* includes all events which deal with conflicting, missing or incorrect requirements, apart from events of the initial requirements capturing phase, which were not taken into account. The category *RE* includes requirements evaluation problems like lack of definitions for test parameters (without responsibility). Category *IF* includes all problems which deal with unclear responsibilities. Category *PDP* includes all unclear or missing descriptions of the process.
5. Determination and evaluation of effects and reactions of the projects.
6. Reflection about the longitudinal effects regarding the interactions between the projects and the defined and standardised PDP. Therefore not only project-specific or project-internal aspects were considered, but also the estimation of the projects within the company by discussions with the company management, e.g. executive committee, or quality department.

3 Findings and Discussion

3.1 Classification of the success of projects

The success of the projects was evaluated in terms of the main project parameters: costs and time. This was the basis for the evaluation of the results, the comparability of the projects and the derivative of recommendations. The goal quality, i.e. the realization of all requirements of the stakeholders was rated for all projects as fulfilled, since in everyone of the regarded cases the production release was obtained. Additionally the evaluation of the clients at the time of the production release was considered.

Table 1. Operating statement of costs of the projects and course of the project after production release

Project name	Deviation of costs % of target	Deviation of time % of target	Estimation of client	Estimation in study
U1	+ 60	+ 44	unsuccessful	unsuccessful
S2	0	+ 18	ambiguous	successful
S3	0	0	successful	successful
U4	+ 100	+ 55	unsuccessful	unsuccessful
U5	+ 25	+ 30	ambiguous	unsuccessful
S6	0	+ 13	successful	successful

Table 1 shows the deviations of the actual values as proportions of the target values for costs and lead-time of the projects, the estimations of the clients after production release and the selected estimations in the context of the study. Due to the large overshoots and the negative or ambiguous evaluation of the clients, the projects U1 and U4, U5 were assigned to the group of *unsuccessful* projects.

3.2 Identification and classification of events

The relevant events are identified directly, by the analysis of substantial temporal goal deviations regarding the respective causal events, (table 2), and indirectly by all events which were the subject of cross-departmental meetings, (table 3). Particularly the latter often increases the work load significantly, if lots of small delays add up and operational counteractive measures cannot be adopted.

Table 2. Categories of events which cause project delays

Category	Project					
	U1	**S2**	**S3**	**U4**	**U5**	**S6**
Requirements management (RM)						
Requirements evaluation (RE)		x				
Interfaces (IF)	x				x	x
Project development process (PDP)		x				x
Others	*x*			*x*	*x*	*x*

Table 2 shows the categories of events which caused substantial time delays. Although all projects classified the categorized events as problems, the categories *RM* and *RE* were not rated by team members in the connection (exception S2) with the project delays. The teams of the projects U1, S2, U4 described in the interviews that they did not accomplish a constant pursuit of the requirements by means of clearly defined requirement lists, although these were present in accordance with the company PDP. However, they were using additional redundant sources for requirements. In the projects which were not successful the team members perceived the causes of delay very differently. When not clear, the event was assigned to the category *others*. In the projects U1 and U5 additionally the category *IF* was included as a result of unclear department responsibilities and poor support by other departments.

Table 3. Phase-individual comparison of project groups proportions of the classified events

Cat.	**Project**	**Functional sample**	**Lab sample**	**Prototype**	**Preseries**	**mean**
		% of evts./phase	% of evts./phase	% of evts./phase	% of evts./phase	%
RM	**U1, U4, U5**	30.56	33.99	24.04	20.02	27.15
RE	**U1, U4, U5**	11.13	17.08	20.43	17.68	16.58
IF	**U1, U4, U5**	24.92	19.06	24.96	25.88	23.71
PDP	**U1, U4, U5**	6.77	3.96	4.54	3.62	4.72
others	U1, U4, U5	26.61	25.90	26.04	32.80	27.84
RM	**S2, S3, S6**	21.90	19.25	19.53	16.01	19.17
RE	**S2, S3, S6**	9.96	14.46	15.55	14.73	13.67
IF	**S2, S3, S6**	10.31	14.50	10.46	15.72	12.75
PDP	**S2, S3, S6**	17.74	14.21	14.50	11.10	14.39
others	S2, S3, S6	40.10	37.58	39.96	42.44	40.02

Table 3 shows the proportion of the categorized events in a comparison of the successful and not successful projects. It is clear that *RM* and *RE* events are often the subject of intensive communication during the execution of the project with a high relevance in all phases. The *RE* takes place not only department-internally for each stage-gate, but also in cross-departmental tests (user acceptance tests, usability test, lab sample tests, reliability tests, alpha/beta test, approval tests, etc.). A phase-specific distribution of the categorized events could not be determined from the data of the study.

In the comparison of the project groups, however, all not successful projects communicate more about *RM* and *IF* aspects. While for successful projects clearly more portions in the category *PDP* were observed. The interviews showed in the successful projects the teams consciously tried to use the large degree of freedom of the valid PDP by generating their own process definitions. Particularly to manage repetitive problems they tried to solve the problems strategically by a clear description which could be accepted by all stakeholders. The not successful projects mostly tried to solve their problems situationally, i.e. without changing the basic conditions or the PDP. However, no projects ignored the existing PDP, a "Need for neglecting the model" [7] could not be observed.

In interviews with the project team members it was confirmed that the events were almost exclusively serious problems with a cross-departmental character. In all projects, insufficiently defined evaluation conditions (the duration of a test, the required test personnel skills, etc.) caused problem at the stage-gates, and all internal projects were delayed by redundancies in the requirements lists, which led to additional coordination effort.

Table 4 shows detailed problems of the categories *PD*, *PE*, *IF* and *PDP*, which arose repeatedly (inclusive the cases considered in table 2), arranged according to their proportion of the total number of all 1172 events. Fourteen detected problems which are predominantly typical for complex projects [7], [15], concern approx. 43% of all events, which were communicated during the team meetings.

Table 4. Most important problems

No.	**Problem**	**% of all**	Cat.
1	Missing tests definitions (usability test, field test, reliability test, approval tests)	7.59	*RE*
2	Unclear change requests process	5.97	*PDP*
3	Redundancy within requirements list	4.78	*RM*
4	Change of responsibilities at stage-gates	4.78	*IF*
5	Missing responsibility of test execution	3.58	*IF*
6	Work packages without link to relevant requirements	2.47	*RM*
7	No commitment of requirements list by the stakeholder	2.47	*RM*
8	No definition of communication at system boundary internal/external	2.39	*IF*
9	Different representation of requirements in internal and external documents	2.05	*RM*
10	Unclear responsibility of fulfilment of requirements	1.96	*IF*
11	Unclear interfaces communication at stage-gates (e.g. mkt./R&D + R&D/prod.)	1.62	*IF*
12	Unclear definition of finalising stage-goals	1.45	*PDP*
13	Unclear definition of roles of staff units	1.37	*PDP*
14	Different validity of PDP for all purchase activities (same process for supplier)	0.68	*PDP*
		56.83	others

3.3 Description of the reaction of the projects

A detailed description of the reaction of the not successful projects cannot be carried out due to the specific situational character of the procedure in many individual situations and does not appear meaningful before the background of the final project-results, also. However, the analysis of the data shows clearly the weaknesses of a situational procedure within the available courses of the project, because the effort for communication, e.g. the length of the meetings, was clearly larger.

The successful projects reacted to the problems with requirements to shape the daily work as possible as simple and regarding the entire course of the project to relieve themselves. A clear allocation of causes and effects were not realisable, since the effects of the numerous measures could not be measured individually or analysed from the documents.

Table 5: Solutions of the regarded successful projects

	Problem (see table 4)													
Measure / Process	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Full description of all tests within the requirements list (incl. equipment, personnel, processes)	S2, S6				S2									
Establishing a redundant requirements controlling system	S3, S6			S6						S3, S6				
Establishing a formalized stepwise change request process		S2, S3, S6												
Use of stage-gate checklists			S6	S6							S6	S6		
Coding and structuring of all requirements and the use of templates			S6											
Clear classification of requirements to work packages			S2, S6			S2, S6								
Unification of all internal and external processes and documents								S3, S6	S3					S3
Use of a defined responsibility matrix										S3, S6	S3, S6			
Definition of a strategy of escalation							S3, S6			S3, S6	S3, S6		S3, S6	
Independent audits of staff units or departments													S2	

Nevertheless it appears valuable to present the measures used in the successful projects, particularly since at least these processes became generally accepted within the company. Table 5 shows the generated and realised processes or measures, which ensure a consistent and a transparent requirement management, as well as the connections between the problems P1 - P14 and the initiated processes:

- For the application of requirements, which is needed through the whole process-chain, the requirements were clearly coded using main headings after [1] or structured matrix forms (similar to [10]) and assigned in work-packages. All evaluation tests, i.e. for each requirement, were defined additionally and comprehensively in the requirement list. The ensuring of the completeness and continuous improvement took place with the help of a template-like data representation.

- Redundantly for the regular pursuit of the requirements, a system was introduced, in which each stakeholder has access to generate requirements at each time or to observe irregularities of the requirement realisation and to track the reaction of the project team. The evaluation of system contents took place by an interdisciplinary commission that also controlled the management of system contents. At the same time the conversion of the measures was prioritised regarding the stage goals.
- Establishing a formalized stepwise change request process. Each change of requirements was examined regarding the feasibility and the reaching of the goals of all stakeholders. For this the change request went through the following stages: rough formulation of the

change with the project manager - first examination of the feasibility by the core team into more detailed requirements - specifying of the feasibility and the consequences by all departments involved - unification of the department estimates by the project manager - discussion and if necessary modification of the change request in the team - feedback and discussion of the effects on the project goals with clients – approval of the change request with all effects on the project by clients. The described process does not prevent changes, but does make these calculable. Furthermore, the definition of a requirement change process simplified communication at the interfaces between marketing and development and thus between development and production departments.

- At the stage-gates or milestones the fundamental requirement of concurrent engineering has been maintained by the fact that phase-specific checklists were passed, even if necessary, with timely defined burden. The checklists oriented on the structure of the requirements lists (see above), whereby requirements were classified additionally regarding the phases. Early intervention was thus ensured to avoid problems.
- The unification of all internal and external processes and documents was aimed by the successful projects, but only single cases were converted, since existing long-term contracts limited the possibilities of modification. Primarily external documents (e.g. descriptions of test) were implemented in the internal document structure.
- Use of a defined responsibility matrix and definition of a strategy of escalation. Both process descriptions ensured the smooth interaction of the project members in the context of the matrix organisational structure. Responsibility was differentiated by the categories: Decision / execution / tuning. In the strategy of escalation, stages were defined that have to be run through in the case of conflict with dependency of maturity and prominence.
- Department audits were initiated because in a matrix organisational structure the ability of the projects to influence the decisions and proceedings in line is limited.

Table 5 also clarifies the advantage of the strategic procedure of the successful projects, because the measures and/or process definitions affect different problems. However no weighting of the measures can be derived. From the interviews it followed that particularly the formalised requirements change management process produced large clarity and reliability regarding the realisation of the goals of the project.

The following statements were made about the conversion of the measures and process definitions:

- The department-comprehensive development of processes with holistic adjustment produced a very good project climate and the feeling of increased ability to affect the project success.
- Clear definitions led to simplified communication and to higher transparency and produced a very high identification of all stakeholders.
- The complex dependencies and interaction effects of the project were facilitated by consistent handling of requirements.

3.4 Findings regarding the longitudinal aspects of the investigation

During the investigation period, many of the processes, compiled by the successful projects, have been established on a project management level. Despite the fact that the execution of the generated processes had also been accepted by the executive committee, the defined and standardised PDP has not been changed during the long investigation period. But one and a

half years after the investigation, most of the generated processes were introduced within a new edition of the standardized PDP. Particularly the last successful project S6 could profit by the effects of the defined processes, and purposefully worked after these processes, table 5.

However, most of the regarded projects did not use the measures compiled in other projects immediately and purposefully, due to the missing default of a PDP. The interviews showed some reasons:

- In particular some of the projects were running nearly parallel or with an overlap of up to 50% of lead-time, so it was not easy to estimate the effects of the specific processes.
- Although there was mostly the same staff working on the projects during the nine years (in different combinations), the other projects were often regarded rather critically, particularly since the projects were in a competitive situation with each other.
- Due to the analysed documents and the numerous interviews the problem perception (and also the problem solving) could be classified as project-specific, however the reasons could not be represented clearly.

The limits of the investigation were clear, and the transparency of the proceedings of some departments could not be identified. The use of process definitions was positive, but in some cases the defined processes were used for demarcation. All interviewed persons attributed this to the high workload; some departments stood in direct competition with external suppliers for the project subtasks. The direct comparison of the internal with the external project U5, shows clear disadvantages for the external project. By normalizing project lead times, it was shown that this outsourced project had a much longer definition phase. In this case, the requirements lists became longer and more complex. This caused misunderstandings at the interfaces and led to follow-up orders for the external partner. In comparison with project S6, the efficiency of the "requirements template approach" for setting up requirements was clearly detected, because project U5 accepted engineering design specifications with a very large extent and an extremely complex representation, without the internal definitions described in paragraph 3.3.

4 Conclusion

Due to the complexity and interdisciplinarity of the PDP, consistent and transparent requirements change management is crucial for project success. Consistent management is reached by clear redundancy-free definitions of requirements and by appropriately "cross-linking" organisational requirements. Transparency is reached by a requirement management approach which includes all project partners not only during the initial definition of the requirements, but also when changing requirements. The more consistent the handling of requirements, the more easily the organisational and process interfaces can be arranged and controlled during the product development process.

The study also has implications for further investigations. The analysis of the use of prescriptive process models of the industrial application shows similarities for the use of prescriptive design methodologies. A tendency towards strategic self-organisation could be observed for successful projects. Against the background of the acceptance of prescriptive design methodologies, and the obvious similarities with prescriptive process definitions of industrial enterprises, further studies could identify meaningful synergies. Further questions are the number of degrees of freedom that have to be implemented while defining process

models or descriptions, so that the implementation of a project can be arranged as effectively and efficiently as possible, and in which context situational or strategic procedure has proven to be a gain.

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Corresponding author:
Dr. Michael Schmidt-Kretschmer
Technical University Berlin
Engineering Design and Methodology Group
Strasse des 17. Juni 135, D-10623 Berlin, Germany
Tel: +49-(0)30-314 28434
Fax: +49-(0)30-314 26841
E-mail: michael.schmidt-kretschmer@fgktem.tu-berlin.de