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Capturing product development knowledge with task patterns: evaluation of economic effects*

by

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Abstract: Importance of managing organizational knowledge for manufacturing enterprises has been recognized since decades. This paper addresses two specific aspects of organizational knowledge modelling: (1) capturing organizational knowledge for supporting product development with so called task patterns and (2) evaluation of task pattern use with focus on economic effects achieved. Starting from an industrial case of product development, the paper introduces the concept of task patterns and the method used for development. The evaluation of task pattern use in product development is based on an adaptation of the balanced scorecard approach. The industrial application of task patterns did not only prove feasible and deployable, but resulted also in a number of positive evaluation results. There is reason to believe that lead times can be shortened, the quality of product documentation increases, and the quality of best practices in general seems to improve when using active knowledge models instead of conventional documentation.

Keywords: enterprise modelling, product development, economic effects, knowledge modeling, knowledge pattern.

1. Introduction

The importance of managing organizational knowledge for manufacturing enterprises has been recognized since decades. Examples for areas contributing to this field are enterprise integration, agile manufacturing and enterprise knowledge modelling. Starting in the early 1990s, enterprise integration aimed at facilitating coordination of functional entities in order to contribute to fulfilment of enterprise goals (Vernadat, 1996). Capitalization of enterprise knowledge and know-how was seen as one of the main motivations for capturing knowledge about work processes with enterprise modelling and for developing frameworks like GERAM or CIMOSA. One of the basic features of agile manufacturing is,

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according to Gunasekaran, McGaughey and Wolstencroft (2001), the knowledge-basing of solutions to customer's individual problems developed in virtual organizations. Knowledge is considered a key differentiator for successful agile manufacturing solutions. Enterprise knowledge modelling aims at capturing reusable knowledge of processes and products in knowledge architectures supporting work execution (Lillehagen and Karlsen, 1999). These architectures form the basis for model-based solutions, which often are represented as active knowledge models (Krogstie and Jørgensen, 2004). A common denominator for the above areas is the expectation that capturing and reusing organizational knowledge will contribute to the competitiveness of the enterprise under consideration.

This paper addresses two specific aspects of organizational knowledge modelling: (1) capturing organizational knowledge for supporting product development with so called task patterns and (2) the evaluation of task pattern use with focus on economic effects achieved from an enterprise perspective. The work brings together experiences in validating business value of IT-solutions and in enterprise modelling. Our approach consists of active knowledge models for capturing product development knowledge and balanced scorecards for evaluating the effects achieved. The results presented are based on work in the EU-FP6 project MAPPER (Model-adapted Process and Product Engineering).

The paper is structured as follows: Section 2 introduces the industrial product development case, being the context for development and evaluation of task patterns. Section 3 presents the task pattern concept and the method for capturing organizational knowledge in task patterns. Section 4 discusses the evaluation approach and the results achieved. Summary and outlook on future work are presented in Section 5.

2. Product development case study

The industrial case defining the context for work presented in this paper is taken from automotive industries and focuses on distributed product development and multi-project lifecycles in a networked organisation with different suppliers. The main partner is the business area "seat comfort components" of a first tier automotive supplier with the main product development sites in Scandinavia. The seat comfort products mainly include seat heater, seat ventilation, climate control, lumber support and head restraint.

During the MAPPER project, analysis of requirements for collaborative engineering support, development of a collaboration infrastructure and application of this infrastructure in everyday work was performed in this industrial case. The focus was on the advanced engineering unit, where product development tasks are concentrating on pre-development of new concepts and new materials. Development of products includes elicitation of system requirements based on customer requirements, development of functional architecture, design of logical and technical architecture, co-design of material, electrical and mechanical components, integration testing and production planning including production logistics, floor planning and product line planning.

The process is geographically distributed, involving engineers and specialists at several locations of the automotive supplier and sub-suppliers for specific tasks. A large percentage of seat comfort components can be considered as product families, i.e. various versions of the components exist and have to be maintained and further developed for different product models and different customers. In this context, flexible product development in networks with changing partners on customer and sub-supplier side is of crucial importance. Main challenges for collaborative engineering in this scenario are:

- To support fast integration of geographically distributed collaboration partners
- To enable flexible development processes, including the possibility to combine well-defined and ad-hoc process changes.
- To coordinate a large number of parallel product development tasks
- To allow for richness of variants and at the same time reuse and generalisation.

The overall target for the product development phases within automotive industries is to enhance quality and reduce time to market for new products and functions. Collaboration within the company and with external partners is a key success factor to meet these demands.

3. Capturing best practices with task patterns

This section introduces the method applied in the industrial use case for capturing organisational knowledge (3.1) and the concept of "task pattern" as a means to structure and represent this knowledge (3.2). Furthermore, related work in the area of organisational patterns is discussed (3.3).

3.1. Enterprise knowledge modelling methodology

Modelling product development knowledge in the industrial case was performed according to the C3S3P methodology. C3S3P is based on work in EU projects from the area of networked and extended enterprises. An extended enterprise is a dynamic networked organization, which is created ad-hoc to reach a defined objective using the resources of the participating enterprises. In order to support solutions development for such extended enterprises, the EXTERNAL project developed a methodology for extended enterprise modelling (Krogstie et al., 2000), which initially was named SGAMSIDOER. This methodology was further developed towards a complete customer delivery process, named C3S3P, which was used in the ATHENA and MAPPER projects. C3S3P distinguishes between seven stages called Concept-study, Scaffolding, Scoping, Solutions-modelling, Platform integration, Piloting in real projects and Performance monitoring and management. The work performed in MAPPER included two cycles of using

C3S3P. The first cycle focused on capturing organisational knowledge and best practices for networked manufacturing enterprises with task patterns. The second cycle focused on integration of product knowledge into the task patterns.

During task pattern development, the C3S3P stages roughly included the following work:

- the concept study and scaffolding phase aim at understanding of visual knowledge modelling and at creating shared knowledge, views and meanings for the use case subject and for the challenges,
- the scoping phase focuses on creation of executable models pilots supporting the use case,
- the solution modelling, which enriched the models developed in the scoping phase and also included requirement modelling, i.e. the identification of requirements from many sources and project partners with regard to platform, methodology, approach and solution,
- during platform integration, adjustments for executing the solution models in the execution environment were made (see Johnsen et al., 2007)
- piloting in real projects was done only for one project; during this piloting, the need for including the product perspective much more extensively was detected, i.e. the second C3S3P cycle was initiated,
- performance monitoring and management was not performed.

The concept study and scaffolding phase of the second C3S3P cycle were considerably shorter than in the first cycle, as a lot of shared understanding of the problem domain already had been created. However, there was still a need to explore the principal design solutions, configurable components and parameters of the product area under consideration. The scoping phase to a large extent consisted of identifying the required configurable workplaces, which were created during the solution modelling phase. Platform integration and piloting in real-world projects were not clearly separated due to the tight project schedule. Creation of configurable visual workplaces for engineers at the use case partner in running projects was the main aim. The performance monitoring phase was not yet performed (see Stirna, Persson and Sandkuhl, 2007, for a more detailed discussion).

3.2. Task patterns

Within the MAPPER project, collaborative engineering was supported by adaptable models, capturing best practices for reoccurring tasks in networked enterprises. These best practices were represented as active knowledge models using the POPS* perspectives. Active knowledge models are visual models of selected aspects of an enterprise, which cannot only be viewed and analyzed, but also executed and adapted during execution. The POPS* perspectives include the enterprise processes (P), the organization structure (O), the product developed (P), the IT system used (S) and other aspects deemed relevant when modelling (*) (Lillehagen, 2003).

The term "task patterns" was introduced for these adaptable visual models, as they are not only applicable in a specific company, but are also considered relevant for other enterprises in automotive supplier industry. Task pattern in this context is defined as a "self-contained model template with well-defined connectors to application environments capturing knowledge about best practices for a clearly defined task" (Sandkuhl, Smirnov and Shilov, 2007). In this context, self-contained means that a task pattern includes all POPS* perspectives, model elements and relationships between the model elements required for capturing the knowledge reflecting a best practice. Model template indicates the use of a well-defined modelling language and that no instances are contained in the task patterns. Connectors are model elements representing the adaptation of the task pattern to target application environments.

Reusing organizational knowledge will in practical contexts require a way to store the knowledge and retrieve it for a given problem. This requires a representation suitable for use in knowledge repositories or portals. The representation of a task pattern consists of three main elements:

- description of the problem addressed by the task pattern; currently, scenario descriptions represent this part;
- knowledge model proposing a solution for the problem addressed
- rationale behind the solution, i.e. an explanation of the most important preconditions, principal results and most important work steps; these elements all are included in the model; the rationale is meant as a support for finding and selecting the best suitable task pattern for a problem.

Fig. 1 shows an example task pattern. This example visualizes in the upper part the process perspective of the task pattern. The process flow with the steps "1. Prepare draft", "2. Material Testing", "3. Process Trial" and "4. Release Material Specification" is shown. For "2. Material Testing" the refinement is included in the middle area of the figure. Above the process flow, objectives and documents which are input to the task pattern are included. The arrows indicate relationships between processes, roles, systems and documents or objectives. In the lower part, the roles involved in the process are included (grouped at the left hand side) and the IT systems and tools are shown.

In total, nine task patterns were developed, some of them specific for product development in automotive industries, other applicable also in other contexts:

- testing of new materials and technologies,
- establishment of material specifications,
- development of new test methods,
- support for meetings,
- brainstorming in order to identify new conceptual design solutions or innovation paths,
- external testing, i.e. direction and control of a test process performed by an external partner,
- prototype building,

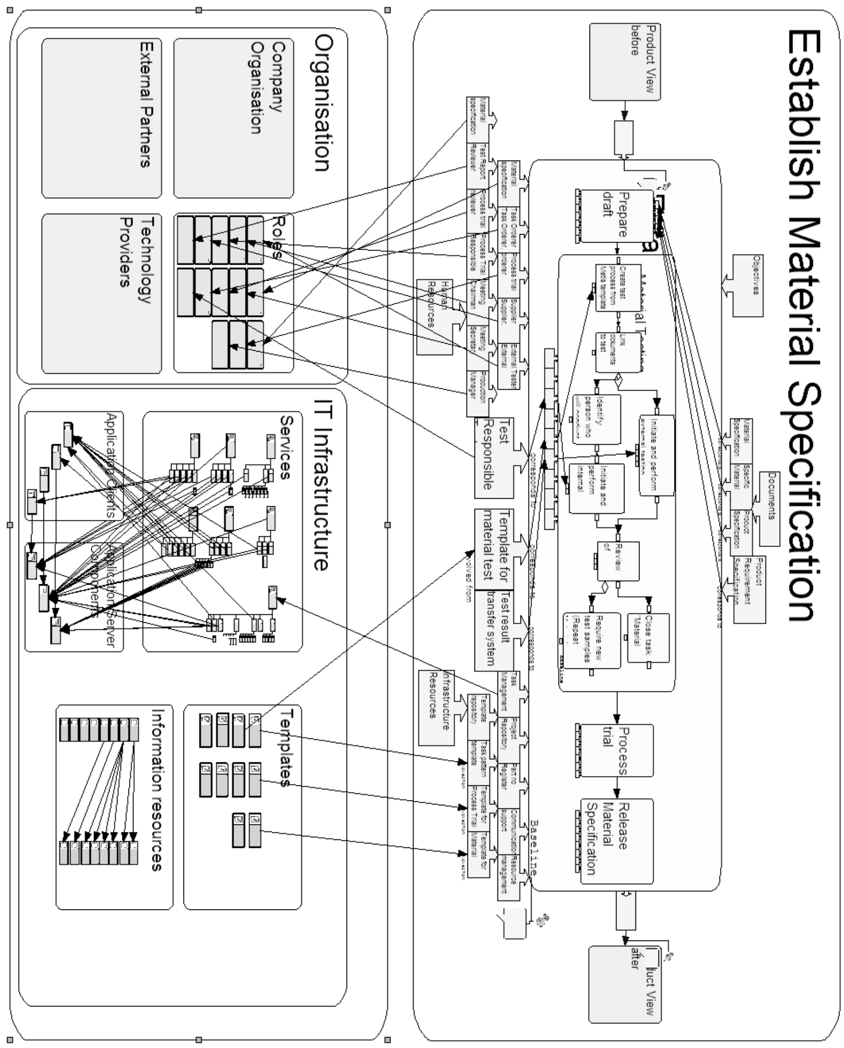

Figure 1. Task pattern "Establish Material Specification"

- establishing product specification,
- benchmarking.

The visual modelling language applied was MEAF (METIS Enterprise Architecture Framework), which is an extension of the Generic Enterprise Modelling language (GEM). The MAPPER collaboration infrastructure (see Johnsen et al., 2007) provides a web-based execution environment for these task patterns, i.e. the knowledge captured can be used for supporting distributed groups of engineers.

3.3. Related work on organisational patterns

Concepts, methods and technologies for identifying, capturing and reusing organizational knowledge have been subject of research in organizational sciences and industrial engineering since more than two decades. Patterns of organisational knowledge are contributing to this area. Selected recent developments of importance for this paper are:

- Work of van der Aalst and associates (van der Aalst et al., 2003) in the field of workflow patterns. Van der Aalst et al. proposed patterns of workflow including different perspectives like control, data flow, resources or operational aspects. These patterns focus on the flow of work, but do not represent the interrelations to product, system and organisation perspective.
- The Patterns4Groupware project maintains a comprehensive online catalogue of patterns for groupware. Each pattern provides proven solutions for a specific groupware problem, and it is expressed independently from the underlying technology (Schümmer and Lukosch, 2007). The Patterns Of Interaction (Pointer) project identifies “regularities in the organisation of work, activity, and interaction amongst participants, and with, through, and around artefacts” (Martin, 2003). The project presents descriptive patterns of work and technology. As product development is increasingly performed in a collaborative way, a number of these groupware patterns and interaction patterns are of relevance for product design. However, these patterns cover general tasks of cooperation and communication in the collaboration process, but not the specific parts of product design.
- The Liberating Voices! Project (Schuler et al., 2008) uses patterns and a pattern language to provide a “knowledge structure” that represents the collective knowledge and wisdom of the community. The goal is to develop pattern languages supporting the community members to design, develop, manage and use information and communication systems. The project selected approximately 240 patterns, published on the project website and organized in themes and categories. Collaboration is one of these categories, but product development is not included.

4. Evaluating task pattern use

After having developed and introduced the task patterns of Section 3.2, benefits and shortcomings of task patterns in collaborative engineering were evaluated from different perspectives, including economic benefits, usability aspects or socio-technical effects (see Sandkuhl, Tellioglu and Johnsen, 2008). This paper concentrates on the economic perspective, i.e. on business value and business drivers, like reduced lifecycle time or increased flexibility. After introducing the general approach for evaluation and the adaptation for the MAPPER project (4.1), the process of capturing the indicators is introduced (4.2). The evaluation results related to task pattern use will be presented in Section 4.3.

4.1. Balanced scorecard

The balanced scorecard approach was selected as a suitable way to structure the economic objectives for the evaluation process and to implement a measurement system. In the early 1990s, Kaplan and Norton developed a new approach to strategic management and named this system "balanced scorecard" (Kaplan and Norton, 1996). The balanced scorecard approach provides a clear prescription as to what enterprises should measure in order to base management decisions not only on financial aspects, but to balance them with other perspectives. This system was widely adapted in industry because it solved some of the problems of previous management approaches.

The balanced scorecard is a management system including a measurement system, which provides feedback around both the internal business processes and external outcomes in order to continuously improve strategic performance and results. This management system supports enterprises to clarify their vision and strategy and translate them into action. The development process of a balanced scorecard usually includes the following main steps:

- Based on the strategic objectives of the project, the scorecard perspectives have to be defined. The traditional perspectives proposed by Kaplan & Norton are financial, process, customer and learning & growth perspective. The perspectives selected have to represent the different elements of the strategy.
- For each perspective, strategic goals have to be defined and preferably quantified, as quantifying them helps to reduce the vagueness in strategic goals. If possible, just one strategic goal for each perspective should be defined.
- The defined strategic goals have in a next step to be broken down in sub-goals. Guiding question when defining the sub-goals should be "What do we have to do in order to achieve our strategic goals?"
- For each sub-goal defined in the different perspectives, a way has to be defined to measure the current situation with respect to this goal. For this

purpose, indicators have to be defined contributing to capture the status with respect to the sub-goal.

- For each indicator identified, the measurement or recording procedure has to be defined. In this context, the feasibility of implementing a measurement approach should be considered carefully.

The above described development process of a balanced scorecard was performed for the MAPPER project resulting in a MAPPER scorecard. This scorecard included three perspectives with explicitly defined focus and goal:

- *The process perspective* focused on the work processes in a product development project. Main attention is put on effects of the adaptability and reconfigurability, which is offered by the model-basing of task patterns. The goal when using the task patterns was high quality and adaptability of the best practice captured in task patterns.
- *The finance perspective* aimed at observing potential effects on the costs related to product design projects. The focus here was on collaboration cost. Main goal was to reduce time and cost for collaboratively performed tasks including the set-up time for solutions.
- *The knowledge perspective* reflected the objective of supporting distributed groups of engineers in creating innovations. Main focus was on capturing effects of sharing knowledge and stakeholder involvement. The goal was intensive knowledge sharing for creating innovations and avoiding errors

Fig. 2 illustrates the three perspectives of the MAPPER scorecard including the focus of attention.

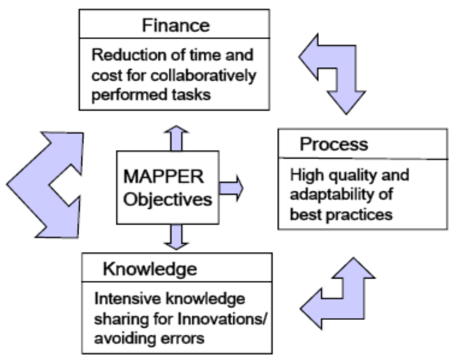

Figure 2. Perspective of the MAPPER scorecard

All three perspectives were refined with sub-goals and implemented in a measurement system at the four industrial use case partners in the MAPPER project.

4.2. Indicator capturing

An essential part in the evaluation process was to capture the baseline before the use of task patterns started. In practice, this included to determine the values of all indicators linked to the sub-goals, which was performed by the four use case partners based on the measurement instruments implemented. The baseline measurement also formed a way of validating the measurement procedures defined for most of the indicators. Some indicators dedicated to specific characteristics of the task patterns, like the “number of refinement levels”, could of course not be measured in the baseline, as they required the existence of task patterns.

After the determination of the baseline, the four industrial partners captured the indicators continuously during a period of one year. The indicators were evaluated at three points in time: at the beginning of the one year period (baseline evaluation), in the middle of the period (intermediary evaluation) and at the end of the period (final evaluation). The intermediary evaluation primarily was performed in order to generate feedback to the method development and technology development tasks in the project.

Fig. 3 shows an excerpt of the data collected during the evaluation process within the use cases. The table contains seven main columns:

- Perspective: MAPPER scorecard perspective, i.e. finance, process or knowledge
- Criteria: sub-goal or criterion addressed
- Indicator name: name of the indicator collected
- Indicator description: what does the indicator capture?
- Values: the data captured. This column includes a sub-column showing the use case partner collecting the value and three sub-columns for baseline, intermediary and final value
- Tendency: shows which tendency the value development has for each use case partner. We distinguish between improvement (+), worsening (↓) and no change (→)
- MAPPER conclusion: shows the overall conclusion for MAPPER. We distinguish between positive development (+), negative development (-) and unclear (empty circle).

4.3. Evaluation results

In total, the values of 48 indicators were collected at three points in time (baseline, intermediary, final), most of them by all four use case partners. From this data, the indicators most relevant for judging the effects of task pattern use in product development were selected and will be discussed in the following. We decided to include indicators from all four use case partners, i.e. not only from the case in Section 2, in order to improve significance. The four use case partners will be referred to as P1, P2, P3 and P4. The development projects performed

Perspective	Criteria	Indicator Name	Indicator Description		Values			Tendency	Conclusion
					Baseline	*Intermediary*	*Final*		
Process	Best practices and quality of their documentation	Number of best practice descriptions	How many descriptions of best practices exist?	**P1**	n/a	3	4	+	+
				P3	13	16	18	+	
				P2	20	20	25	+	
				P4	0	9	9	+	
		Average level of detail of best practice descriptions	How many refinement levels do the best practice descriptions on average include?	**P1**	4	n/a	4	→	O
				P3	n/a	3	3	→	
				P2	4 levels	4 levels	4 levels	→	
		Average number of use of best descriptions per month	How often are the best practice descriptions on average used per month?	**P3**	5	5	8 p. pers.	+	+
				P2	no data	no data	no data	→	
				P4	0	2	2	+	

Figure 3. Excerpt from collected data

at these use case partners during measurement of the indicators included a new product version for a seat heating product, a new system-on-chip product and part of the target setting for a new automotive product.

Use and quality of task patterns

The number of best practice descriptions increased significantly. P1 reports 7 additional best practice descriptions provided by MAPPER. For P3 the number of additional best practice descriptions is 5, for P2 6 and for P4 9. These best practice descriptions are actually the task patterns developed in MAPPER. The overall tendency is clearly positive, as the growing number of task patterns, which are reusable organisational knowledge models, is considered very valuable from the use case partners' perspective. Several indicators were used to contribute to the criteria "quality of best practices", which addressed existing descriptions before the start of MAPPER and the task patterns developed during MAPPER. The average level of detail of the best practice descriptions at P3, P1 and P2 did not change during the runtime of the project. At P4 the level of detail for the best practices which are part of the use case increased significantly, which is a very positive development.

The partners were also asked to rate the accuracy of the best practice descriptions, i.e. how well does the description fit to practices performed in the company? On a scale from 0 to 10 (10 is the best accuracy) P1, P2 and P4 awarded a 7. Only at P4, there was an improvement of the value (from 6 to 7). P3 rates the best practices only with 3, i.e. the best practices should be urgently revised. The average number of mistakes in best practice descriptions was only provided by P3. Considering the low accuracy reported by P3, it is quite consistent to see a quite high number of mistakes in the best practice descriptions reported by P3. Furthermore, P4 investigated whether the best practice descriptions could be used for training new employees or employees who shifted to another role within P4. The indicator shows that in total four employees were trained based on the task pattern, which P4 considers very successful. From a MAPPER perspective this indicates a clear benefit of MAPPER results. The time needed to update best practice descriptions when changes are made within the organisation was quite stable at P3 and P1; at P2 and P4 the time reduced considerably. P4 considered substantial changes in the development process and reported a reduction from 6 to 4 months. P2 considered major changes and reported a reduction from 22 days to 14 days. Summarizing the overall impression regarding the quality of best practices, the result is clearly positive, but not outstanding. Level of detail, time to update the best practices, grade regarding accuracy and the use for training new employees illustrate the positive evaluation of the best practices.

Quality of product documentation

The criterion "quality of product documentation" included indicators regarding the product structure and regarding design rules. With respect to design rules, P2 shows a clear increase of the number of rules from 95 to 160; P3 reports a slight increase from 25 to 27; P4 reports no changes. In all three companies, all existing design rules are in use. The product structure related indicators were only captured by P4 and show a very positive development. The number of configurable components, which are included in the product structure, increased with the use of MAPPER technology from 0 to 16; the refinement level improved from 3 refinements to 4; the number of elements in the product structure remained stable. P4 defined a number of indicators contributing to the criterion “new product functions”. The intention was to measure, whether knowledge sharing facilitated by MAPPER technology would lead to an improvement regarding the productivity. The indicators used were number of new product functions created, number of patents registered and number of alternative solutions for technical problems. The values collected by P4 were based on four product development projects, some of them still ongoing. The values do not show any changes between baseline, intermediary and final capturing. One explanation for this unchanged situation is the relatively short period of time considered: within the time frame of 10 months between baseline and final capturing, no product innovation project could be completed in all phases. The selected indicators might show a tendency after one-two years of measurement.

Cycle time, time to market

P4 provided indicators, which were contributing to the objective of reducing cycle times and time to market. The criteria connected to this objective were the average length of the development process and of certain phases in this process. The values provided by P4 are estimations based on the experiences when using the MAPPER infrastructure and based on the expected effect on the overall development process and its phases. A clear reduction of the time needed is reported for the material specification task: from four months before MAPPER to three months when using MAPPER technologies and methodologies. This reduction by 25% is considered as a major success story of MAPPER. For the overall process length, no changes are reported. The main reason for this unchanged situation is that the most intense use of MAPPER happened in the material specification task. A complete development project based on MAPPER technology was so far not performed.

P1 used several indicators to assess the effects of MAPPER on target setting and problem solving process. The average length of the target setting process and the average time for assessing solutions for a customer problem show very encouraging trends: the length of target setting decreases from 14 to 12 months and time for assessing solutions is reduced by 50%. However, the time needed for developing new solutions proposals does not change with MAPPER technology.

5. Future work

Based on an industrial case taken from product development in automotive supplier industries, the paper presents an approach used for capturing organisational knowledge and the concept of task patterns for support of fast and flexible product design in networked manufacturing enterprises. Task patterns are reusable models of enterprise knowledge capturing best practices for typical collaboratively performed development tasks.

The evaluation of benefits and shortcomings of task pattern use in product development is based on a balanced scorecard approach. The industrial application of task patterns did not only prove feasible and deployable, but resulted also in a number of positive evaluation results. There is reason to believe that lead times can be shortened, the quality of product documentation improves, and the quality of best practices in general seems to improve when using active knowledge models as compared to conventional documentation.

The main limit of the research presented here is the limitation of evaluation period and scope: just one year of runtime in only four industrial companies from two different domains. Future work should include a comparison between different industrial domains. It would be worthwhile and interesting to also include experiences from more task pattern developments, in particular aiming at collaboration support which is not domain specific. However, this would also require a different research design with preferably an additional focus on organizational learning.

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