INTERNATIONAL DESIGN CONFERENCE - DESIGN 2014
Dubrovnik - Croatia, May 19 - 22, 2014.

LIFECYCLE AND STAKEHOLDER-ORIENTED INTEGRATION OF COGNITIVE FUNCTIONS INTO PRODUCT CONCEPTS

T. Metzler, M. Witzmann, T. Deubel and U. Lindemann

Keywords: cognitive functions, procedural model, design methods

1. Introduction

This paper presents a formal approach that supports the systematic integration of cognitive functions into product concepts derived from new product ideas and existing products. Therefore, a holistic procedural model for a lifecycle and stakeholder-oriented integration of cognitive functions is presented that is linked to methods that assist the implementation of single procedural steps.
The integration of cognitive functions, e. g. to perceive, to learn, to plan, etc., is important to meet and exceed customer expectations by reducing the need for human input, for example when such input is difficult or repetitive. Cognitive functions are well suited for the integration into a variety of products and systems, including Smart Products, Ubiquitous Computing (ubicomp), Intelligent Mechatronic Systems, Cyber-physical Systems, the Internet of Things and Services (IoTS) and Cognitive Technical Systems (CTS). Nevertheless, the integration of cognitive functions into products and systems is a difficult and often intuitive-driven process. The results are often influenced by the designers and their environment, experience and expertise.
The next section provides an overview about cognitive functions and how they can be integrated into products. In section 3, the problems and challenges are addressed that currently arise while trying to integrate cognitive functions into products, either using a systematic approach or not. In section 4, the procedural model for top-down and bottom-up integration of cognitive functions is introduced and methods are presented to assist the implementation of certain procedural steps. In section 5, the approach is applied using an example from the capital goods industry turning an existing product into one that is ready for the IoTS. Nevertheless, the approach is not limited to products for the IoTS and is applicable in other contexts equally. The paper concludes with a discussion exploring the potential of the approach to support the development of products using cognitive functions, and an outlook towards future research.

2. Background

Cognition is a process through which a system acts effectively in its environment, and in doing so its cognitive capabilities (its repertoire of executable actions and its ability of anticipating events) are improved continuously [Vernon et al. 2010]. "Cognitive products are tangible and durable things with cognitive capabilities that consist of a physical carrier system with embodied mechanics, electronics, microprocessors and software. The surplus value is created through cognitive capabilities enabled by flexible control loops and cognitive algorithms" [Metzler and Shea 2010]. What makes products and systems cognitive are their high-level capabilities. In this paper the term cognitive function is defined as follows: A cognitive function describes the cognitive purpose of a cognitive technical system in a solution-neutral way by relating input and output flows. They are used consistently to describe the basic functions enabling cognition as a whole. A single cognitive function is represented, analogue to Pahl et al. [2007] and Stone and Wood [2000], by verb-object pairs in a formal way, e. g. perceive data, learn that information, reason about information, etc. The cognitive functions are used to create functional models of cognitive product concepts by decomposing the main product function.

In literature, there is no commonly agreed list of cognitive functions to model a cognitive system, neither human nor artificial. Metzler and Shea [2011a] presented a vocabulary of cognitive functions and flows based on a literature research and structure the functions in a taxonomy. The taxonomy of cognitive functions is required to create formal functional models. Complementary, the functions of the Reconciled Functional Basis [Stone and Wood 2000] are used to describe the non-cognitive aspects of a cognitive product in a formal way.

Research was done to identify cognitive functions carried out by a single user during the interaction with a product [Metzler et al. 2013a,b]. The developed method, consisting of five steps, focuses on a single use-case, namely usage, of non-networked products with a single user. In step 1 an activity diagram of the internal functions of the product is created. This activity diagram is used in step 2 to include related user actions into the model, derived either directly from the interaction with the product or preceding/succeeding the usage of the product. In step 3 the involved cognitive functions are identified by a comparison of the user actions and the Taxonomy of Cognitive Functions [Metzler et al. 2011a] before they are evaluated in step 4 using the approach presented in Metzler et al. [2013b]. Finally, in step 5 the product-system boundary is interpreted to include promising (user) actions.

Further, Dumitrescu [2010] presents a procedural model for the systematic development of cognitive products which contains a set of methods and tools that are designed especially for cognitive product development. This procedural model is based on the VDI guideline 2206, tailored to the development of mechatronic products, and focuses on the early development phases like the concept phase during the product development process. The aim of the model is to integrate cognitive functions into mechatronic systems.

3. Problem Description

The method presented in Metzler et al. [2013] focuses on integrating cognitive functions derived from an analysis of a single end-user's actions to relieve this single end-user from repetitive or difficult cognitive input. Thus, the method initially aimed at the consumer goods industry with products the end-user interacts with. Other use-cases of the product along the product-lifecycle as well as multiple stakeholder interactions with a product were not considered to derive integratable cognitive functions.

Discussions with experts from two mechanical engineering companies and from academia, all familiar with the method, showed that designers are not solely considered with single lifecycle-phases and single stakeholders, especially in a company environment. All experts stated that cognitive functions seem applicable and valuable in multiple, product specific use-cases along different lifecycle-phases including multiple stakeholders and networked products. To make the method presented by Metzler et al. [2013a] applicable beyond the customer goods industry, e. g. for industry producing capital goods, following challenges were identified and have to be addressed:

1. The method must support top-down and bottom-up development of cognitive products
2. The method must be applicable and consider different use-cases along the product lifecycle
3. The method must be able to consider multiple stakeholders, e. g. service technicians, users, mechanics, etc. and the product
4. Interaction between stakeholders and the product as well as between different stakeholders within certain use-cases must be considered
5. The method supports the modelling of sub-activities of the stakeholders and can represent several alternatives depending on a stakeholder decision, sub-activities can be optional and sub-activities can be carried out simultaneously
6. Problems or failures the stakeholders encounter when interacting with the product or other stakeholders must be identified by the method and considered as useful input for product improvement

7. Additional and new functionalities are difficult to sell and thus have to create additional value to the stakeholders. This can be enabled by cognitive functions making the usage of the product more economic, easier, safer or more comfortable
8. Object flows, e.g. material, energy, etc., are not necessarily required to model stakeholder actions. Instead a control flow can be applied to model sequential and parallel actions

In section 4 the presented challenges are addressed and solutions presented.

4. Method to Support the Lifecycle and Stakeholder-oriented Integration of Cognitive Functions in Product Concepts

The method described in this section consists of a procedural model for the top-down and bottom-up integration of cognitive functions and further methods supporting the implementation of certain procedural steps. In section 4.1 a holistic procedural model (Figure 1) is introduced. In Section 4.2 methods to support the integration of cognitive functions into products and in this paper in particular into products for the IoTS are presented. The procedural model and the methods in combination address the challenges discovered through discussions with experts from industry and academia described in Section 3 and thus enable a broader support for the development of cognitive products.

4.1 Procedural Model for the Top-down and Bottom-up Integration of Cognitive Functions

Initially, solely the holistic procedural model is described, shown in Figure 1. It includes two strategies to develop cognitive product concepts, top-down and bottom-up, contrasting two development approaches. Methods detailing the individual procedural steps are presented in the following section.
The first development strategy is a top-down approach that starts with the creation of a new cognitive product idea and concludes with an integral and formal functional model of the new product. The second development strategy is a bottom-up approach that relies on an existing product and again results in an integral and formal functional model. Efforts to develop new cognitive products using a top-down approach, partially described in Metzler and Shea [2011b], showed that new ideas are often based on existing products. Thus, the procedural model must allow a transition from one approach to the other during the development process, e. g. to ground a new product idea into an existing product. In conclusion, the procedural model addresses challenge 1 which demands support for top-down and bottom-up approaches and allows a transition between both strategies during the development process.

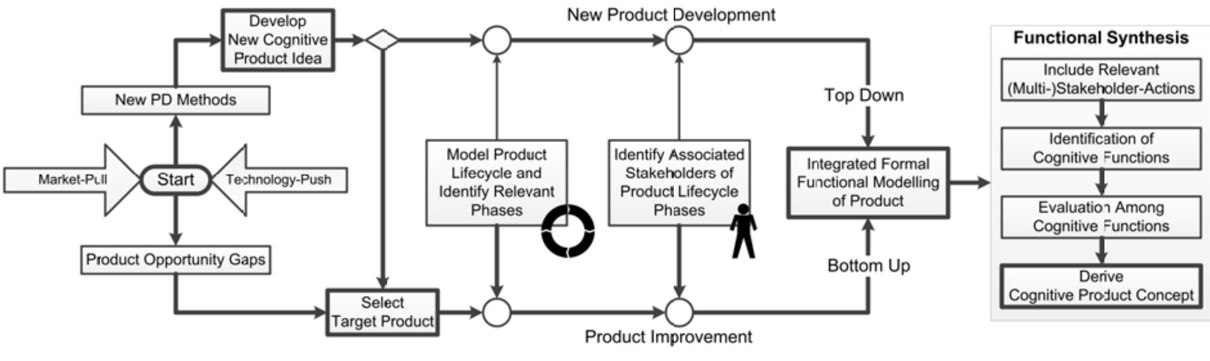

Figure 1. Procedural Model for the Integration of Cognitive Functions into Product Concepts

The authors use and recommend for the top-down approach as well as for the bottom-up approach to use the Reconciled Functional Basis [Stone and Wood 2000] and the Taxonomy of Cognitive Functions and Flows [Metzler and Shea 2011a] to create formal functional models.
In addition to the work presented in Metzler et al. [2013a], the existing or planned lifecycle of a product or product idea is modelled optionally to get an overview of all lifecycle phases and identify the potentially relevant ones for the integration of cognitive functions. For the relevant lifecycle phases stakeholders can be identified and their interaction with the product as well as interactions among different stakeholders can be modeled. In particular for the development of networked products, e.g. for the IoTS, all networked products can be considered and act like any other stakeholder. The result is a holistic model that can provide insights into where interactions with the

product happen, where problems in the interactions occur frequently and where cognitive functions are used by one of the stakeholders.

Taking the functional model as a starting point, in both cases, a functional synthesis is carried out according to Metzler et al. [2013a,b]. All relevant stakeholder actions are included into the functional model and cognitive functions are identified. Finally, an evaluation among the cognitive functions is carried out and a cognitive product concept is derived.

The methods to implement the procedural steps are described in section 4.2.

4.2 Methods Supporting the Procedure of Integrating Cognitive Functions

This section introduces specific methods that assist the implementation of important procedural steps of the holistic procedural model (Figure 1) presented in section 4.1. The goal is to support the designers to integrate cognitive functions into product concepts. Procedural steps aiming at the development of new cognitive product ideas, identifying product opportunity gaps or selecting a target product are not described in this paper because common product development methods addressing these issues exist and can be used for cognitive product development likewise (compare [Metzler and Shea 2011b]).

4.2.1 Model Product Lifecycle and Identify Relevant Lifecycle Phases

According to challenge 2 the method must consider and be applicable for different use cases in different lifecycle-phases. The method to integrate cognitive functions [Metzler et al. 2013] into products is generally applicable to different use-cases. Nevertheless, most important is that the designer becomes aware that several use-cases exist and that the method can be applied to all relevant use-cases. This can be supported with a procedure, process or method. For this reason, the authors suggest to identify or record the existing lifecycle of the product to be improved or anticipate a lifecycle for the new product idea. The starting point for the designer can be a product lifecycle found in literature (e. g. an overview is given in [Hepperle et al. 2010]) suitable for the own product concept. In a company the existing lifecycle of the product can simply be identified and modelled if a model of the lifecycle is not already known and available. Figure 2 shows how a model of a product lifecycle can look like and highlights two phases, framed with a dotted line, which are the exemplarily identified relevant phases into which cognitive functions can be integrated.

Figure 2. Sample Product Lifecycle and Identified Relevant Phases

After the model of the lifecycle is compiled it is necessary to identify the relevant lifecycle-phases where cognitive functions can be integrated. The relevant lifecycle-phases depend strongly on the product or product idea. The lifecycle-phase "use" is often highly relevant regarding the integration of cognitive user actions for products and product ideas that are used by an end-user, e. g. a washing machine or a vacuum cleaner. In contrast, capital goods, e. g. pumps or valves, do not offer a lot of potential to identify cognitive user actions during the lifecycle-phase "use" because the user does not interact with them while they are in use. Instead, the lifecycle-phase "service" or "assembly" might offer a great potential for the integration of cognitive functions. Again, it is more important that the designers become aware of the fact that several lifecycle-phases exist and that different cognitive functions can be integrated to support different lifecycle-phases than selecting the most relevant lifecycle-phase. The decision about which lifecycle-phase is predestined to integrate cognitive functions is influenced by: the management, the marketing department, customer needs, competitors, the service department, etc. If no decision is obvious a pairwise comparison of all lifecycle-phases helps to deduce an order. It is possible to integrate cognitive functions in multiple lifecycle-phases.

Possibly, synergies can be used in terms of information collected during the analysis of use-cases and stakeholders as well as in terms of hardware and software required to implement cognitive functions.

4.2.2 Identify and Document Associated Stakeholders for Relevant Lifecycle Phases

According to challenge 3 the method must be able to consider multiple stakeholders for every use-case. Thus, after the relevant lifecycle-phases have been identified, it is necessary to identify the associated stakeholders for the relevant lifecycle phases. In literature standard stakeholders for different lifecycle-phases can be found as well as methods that help to identify relevant stakeholders (e. g. [Sharp et al. 1999]). Best practice derived from conducted industry projects is to talk to the known stakeholders and ask them what other stakeholders are relevant in that certain lifecycle-phase because they collaborate or interact with them. With this approach the majority of stakeholders can be identified. Figure 3 illustrates the previously identified two lifecycle-phases and exemplarily assigned stakeholders.

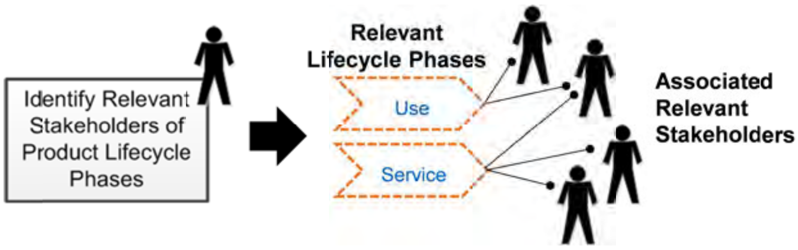

Figure 3. Identified Stakeholders for the Relevant Lifecycle Phases

The identified stakeholders for every relevant lifecycle-phase are documented systematically, e.g. in a multiple domain matrix (MDM) that links stakeholders and lifecycle-phases (similar to [Panshef et al. 2009]). The advantage of using an MDM is that it becomes obvious how many and which stakeholders are associated to a lifecycle-phase and a comparison with other lifecycle-phases is enabled. In addition, if a certain stakeholder is of particular importance for the future development it becomes obvious in which lifecycle-phases this stakeholder can or must be supported. Figure 4 shows a partial MDM linking the lifecycle-phases and stakeholders. The in section 4.2.1 identified relevant lifecycle phases are highlighted in Figure 4 and make assigned stakeholders visible.

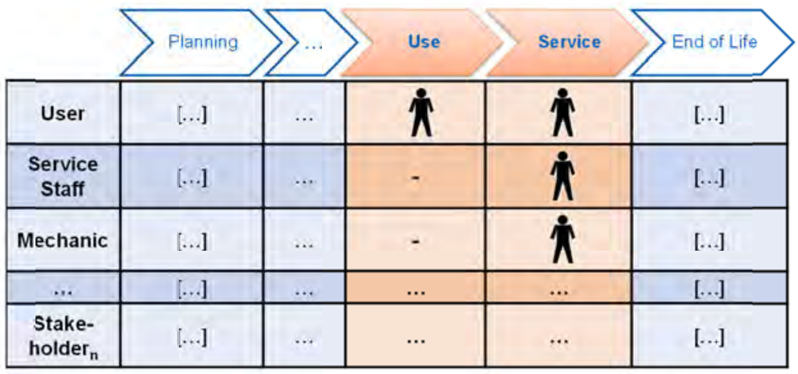

Figure 4. Exemplary Multiple Domain Matrix Linking Stakeholders and Lifecycle-Phases

4.2.3 Integrated Formal Functional Modelling

Core method for integrating cognitive functions into product concepts is the formal functional modelling of an existing product or a product idea. This is done using the RFB [Stone and Wood 2000] and the Taxonomy of Cognitive Functions [Metzler and Shea 2011a], both providing a vocabulary of functions and flows. Functions are defined as operations on flows and consist of verbs and objects. A detailed introduction to the functional modelling approach of cognitive products with cognitive functions is given in Metzler and Shea [2011a]. The functional modelling is an important procedural step but not focus of this paper and sufficiently described in previous publications.

4.2.4 (Multi-)Stakeholder-Oriented Functional Modelling

Challenge 4 demands that the method must be able to consider interactions of several stakeholders with the product as well as interactions among several stakeholders. This corresponds with the first step of the functional synthesis, shown in Figure 1 and presented in Metzler et al. [2013a] but instead of looking at single stakeholders this procedural step is adapted to be suitable for multiple stakeholders interacting with the product and among themselves. The method to support this is a multi-stakeholder-oriented functional modelling which is graphical and intuitive. In order to allow a stakeholder-oriented functional modelling of the interactions between different stakeholders and the target product as well as among multiple stakeholders, a systematic analysis of the individual actions performed by all identified and relevant stakeholders has to be carried out. The authors suggest interviews, (group-) discussions, questionnaires and workshops to determine *how*, *when* and *why* every single relevant stakeholder interacts with the product and with other stakeholders. The initial output of this analysis is unfiltered and unstructured information about current interactions and possibly also problems when using the product. This information is recorded, e. g. in mind maps. The process is illustrated in Figure 5.

Figure 5. Identifying Stakeholder Actions and Documenting the Results in a Mind Map

After collecting the necessary information from the stakeholders this information needs to be structured in order to identify potentials for the integration of cognitive functions. This is possible with a stakeholder-oriented cross-functional flowchart that can be derived from the unstructured documentation of stakeholder-actions. By structuring the information the interactions between stakeholders and the product and interactions among stakeholders become transparent. An example of a cross-functional flowchart with actions carried out by the previously identified three stakeholders (user, service and mechanic) in the lifecycle-phase "service" is shown in Figure 6.

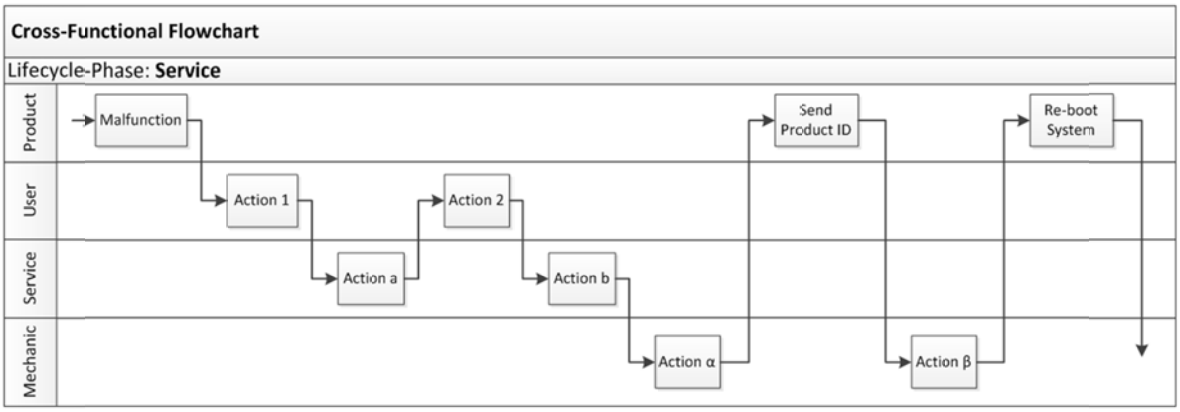

Figure 6. Cross-Functional Flowchart Linking Actions of Stakeholders for one Lifecycle Phase

Every cross-functional flowchart has several rows, one for every stakeholder, one for the product plus one highlighting the lifecycle phase. In the rows the actions of the associated stakeholders are modelled and sequentially connected using flow arrows (challenge 8). In Figure 6 the product shows a malfunction and the user carries out "*Action 1*". Next, the service technician carries out "*Action a*" before the user carries out "*Action 2*". In this way, all interactions between all stakeholders and the product are modelled. To do this in a formal way the vocabularies of the RFB [Stone and Wood 2000]

and the taxonomy of cognitive functions and flows [Metzler and Shea 2011a] are used. The formal modelling approach offers the potential to identify cognitive functions according to Metzler and Shea [2011a] easily with a simple comparison. This is important to satisfy challenge 7. The integration of cognitive functions offers a great potential for improvement when integrated into the product concept.
Beyond a pure sequential modelling of actions, cross-functional flowcharts offer the possibility to model stakeholder actions that are executed simultaneously or alternatively. The need to model simultaneous and alternative actions became evident while discussing the stakeholder-oriented functional modelling with experts, especially from industry. Figure 6 shows an example. After a malfunction of the product two stakeholders, namely the user and the service staff, execute actions simultaneously (*Action 1*, *Action 2* and *Action a*). Then, after the service staff carried out "*Action b"* two actions can be executed alternatively. Either the user executes "*Action 3*" or the mechanic executes "*Action α*" before the service staff can continue with "*Action c*". The possibility to model simultaneous and alternative actions carried out by different stakeholders satisfies challenge 5.

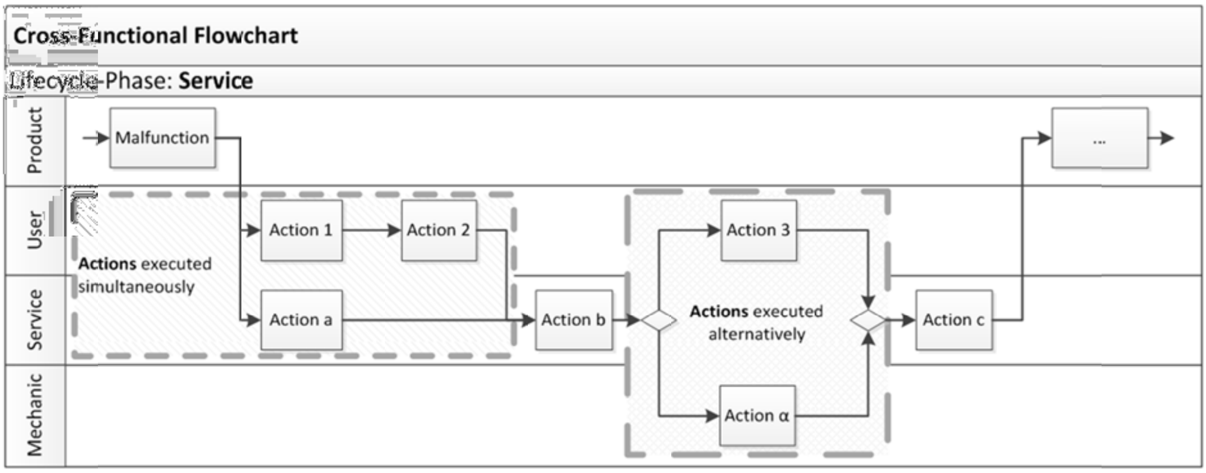

Figure 7. Cross-Functional Flowchart with Actions Executed Simultaneously and Alternatively

Critical actions that can cause problems during the interaction with the product can be highlighted, either using a special shape or colour. It is also possible to use different categories for different types of problems during the interaction and use a different shape or colour for every category. This makes the clustering of problems of the same category very simple in the final functional model. The possibility to highlight critical actions satisfies challenge 6.
After the modelling of the cross-functional flowchart is completed the functional synthesis according to Figure 1 continues with the identification of the cognitive stakeholder-actions, their evaluation and integration into the product concept. This procedure is described in more detail in Metzler et al. [2013a].

5. Initial Application in Industry

The presented bottom-up approach in the procedural model and the supporting methods have, so far, been applied in a project with the innovation department of one big company. This company is acting globally and known for producing high quality capital goods for more than 500.000 customers. The goal of the project was to identify lifecycle and customer-oriented potentials that offer technological and economical surplus value for future products. The focus was on developing products for the IoTS and the integration of cognitive functions likewise. The aspired results were new and innovative product concepts and a prototype realizing one concept and demonstrating the key capabilities.
The project coordinator from the company holds the position of an innovation manager. The application, extension and validation of the bottom-up development approach as well as the design of several product concepts and the development of a functional prototype was done by a student doing his final year project in this company. The company had few reference models for the development of products for the IoTS and was looking for additional support, new input and innovative ideas.

For the project certain constraints were set by the company. The project built on existing products and not on completely new product ideas. This is obvious because the company wants to improve products from their field of business. The management of the company regarded the trend towards products for the IoTS and cognitive functions as highly relevant and encouraged the employees, especially from the innovation department, to make efforts towards developing products making use of these trends or follow the trends and create new product ideas.
Because the whole array of products has more or less the same lifecycle, it was not necessary to choose one specific product for the integration of cognitive functions in the beginning of the project. Due to this similarities and the well known and available lifecycle, the first steps in the procedural model shown in Figure 1 were not necessary or very simple. The identification of relevant lifecycle-phases took place after several interviews with company-internal stakeholders, e.g. product development, sales, service, application engineering, in discussions with the innovation and development department, the coordinating innovation manager and the academic supervisor. It was identified that the lifecycle-phase "service" offers a lot of potential for the IoTS and the integration of cognitive functions across several products in the array of products.
Next, the relevant stakeholders for the lifecycle-phase "service" were identified and interviewed. The actions performed by every stakeholder were recorded in a mind-map and subsequently transformed into cross-functional flowcharts. In total, five use-cases were identified in the whole service process. The first two use-cases of the service process, "problem encounter" and "service call", are shown in Figure 8. The relevant stakeholders in these use-cases were the client and the service staff. Further use-cases, e. g. remote diagnosis, on-site diagnosis, are not shown.

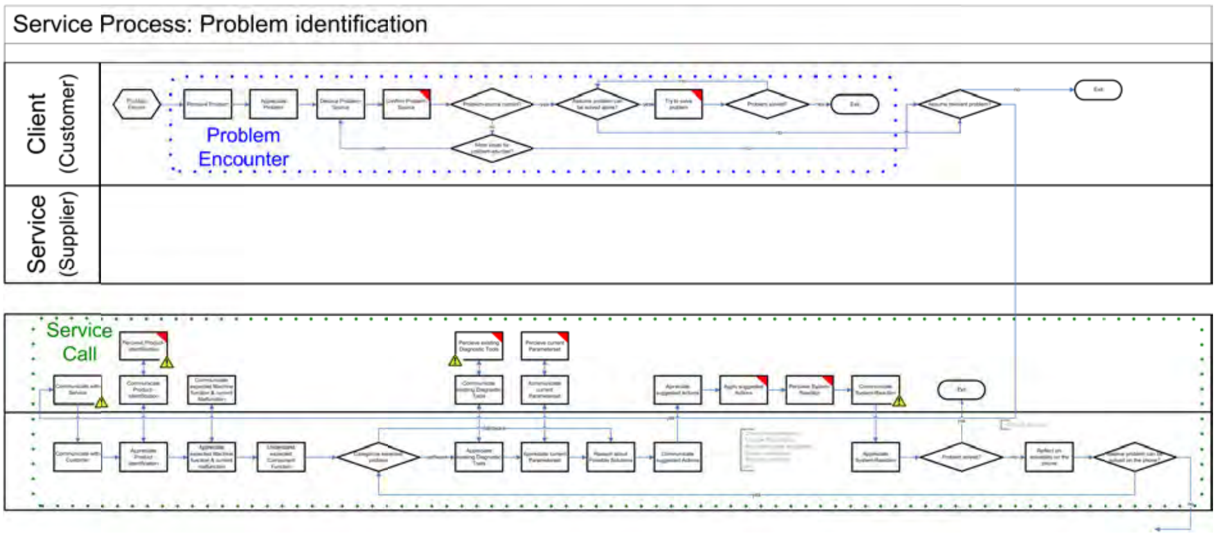

Figure 8. Partial Cross-Functional Flowchart of the Service Process from the Case Study

In addition to documenting the stakeholder-actions, it was documented which actions often caused trouble and are highlighted in the model. The final multi-stakeholder-oriented cross-functional flowchart was used to identify the following potentials: cognitive functions (represented by cognitive stakeholder-actions), direct interactions with the product (highlighted with a red corner in the box of an action) and pain points during the interaction between stakeholder and product and among stakeholders (with a yellow exclamation mark). In total, 25 cognitive functions, 18 direct service interactions with the product and 6 service pain points have been identified.
All identified potentials have been transferred into a table and were evaluated regarding the defined goals and requirements of the project. Instead of addressing each potential individually, it was analysed if several potentials can be implemented using the same or similar embodiment and what combination offers the most powerful product improvement. This resulted in three viable product functions: remote diagnosis, error warning and self-identification. These functions were systematically integrated into a future product concept and realized in a prototype. Several functions were implemented using the same hardware and partially build on the same software. Thus, synergies are

used and the costs for every individual function became less. The implementation of the prototype was very successful and a combination of several potentials was realized and worked adequately. The result was new and innovative and fulfilled the requirements. The company was convinced by the product idea and the prototype. A patent application was written and submitted to the patent office. In addition, the prototype won the company internal innovation award which led to an increased effort in the further development of the product.

6. Discussion

The procedure to include cognitive user-actions, presented in Metzler et al. [2013a], is extended significantly. The identified challenges described in section 3, discovered in expert interviews and during the application in an academic context, are addressed by the presented procedural model and the supporting methods. The systematic integration of cognitive functions is applicable for new product development and product improvement in relevant lifecycle-phases considering all associated stakeholders. The approach points the attention of the designer to the importance of considering multiple lifecycle-phases and stakeholders. This is important because cognitive functions can be integrated into products not only to assist during the use-phase but also during other phases, e. g. assembly, service, etc.. Another issue that is very important is the fact that stakeholders sometimes have to interact with other stakeholders in certain lifecycle phases. The cross-functional flow chart is a modelling technique that makes interactions of stakeholders with the product and with other stakeholders explicit and thus provides a very good overview about who is interacting with whom/what. The advantages of cross-functional flowcharts are:

- they offer a graphical representation that is easy to understand for stakeholders and designers,
- it is flexible and can easily be extended according to the number of relevant stakeholders,
- simultaneous and alternative actions can be modelled,
- allows to highlight actions where often problems occur,
- swimming lanes in the model make the allocation of actions to stakeholders very easy.

The formal functional modelling approach, suggested by the authors in this paper, requires the designers to use the formal vocabularies of functions and flows. The advantage is that ambiguity is avoided, especially in interdisciplinary teams common in cognitive product development. Further, the identification of cognitive functions becomes trivial. However, the designers need to agree on, learn and use a common vocabulary to model the product (idea) and the associated stakeholder actions.

The authors used Microsoft Visio to create the presented cross-functional flowcharts. The advantage is that Microsoft Visio is a widely known modelling software which is available in many companies and intuitive to use. Nevertheless, the modelling can not be considered absolutely formal. By shifting to a formal modelling language, e. g. the Systems Modeling Language (SysML), in combination with the mentioned vocabularies of functions and flows a formal functional modelling is feasible.

To date, the approach to integrate cognitive functions has been applied only in one company that is producing capital goods and in few academic development projects carried out by students. So far, the application of the approach was very successful and led to several working prototypes, a patent application and a lot of positive feedback from experts in the area. Disabilities could not be identified during the initial application in industry and academia. Nevertheless, further evaluation is necessary before the universality of the approach can be assumed. It is important to test the approach in different lifecycle-phases as well as with different and multiple stakeholders in different industries. Currently, a project with a big company applies the approach to derive new concepts for intelligent construction tools. An evaluation of the second industrial application will be carried out in 2014.

7. Conclusion

The procedural model and the supporting methods in this paper extend the existing method for the integration of cognitive functions and provide a holistic approach for new product development, product improvement and hybrid development approaches. Central to the procedural model is the functional modelling of the product or the product idea for all relevant lifecycle-phases and the activities of relevant stakeholders. The models support the identification of meaningful and valuable cognitive functions and allow the derivation of cognitive product concepts based on an evaluation among the identified functions. Previous shortcomings and challenges have been addressed and enable the systematic application of the approach in an industrial context. The application of the approach was illustrated and discussed using an example of a company producing capital goods. Future research is necessary to evaluate the applicability of the approach in different industrial contexts. An evaluation of the approach together with a company in the area of intelligent construction tools just started. Furthermore, an extension of the approach detached from the stakeholder actions is desirable, especially for the top-down approach dealing with new cognitive product development.

Acknowledgement

This research is part of the Cluster of Excellence, Cognition for Technical Systems -CoTeSys (www.cotesys.org), funded by the Deutsche Forschungsgemeinschaft (DFG). The authors want to thank all involved people in the project that have been interviewed, questioned, shared their ideas and experience and encouraged the authors to do this research.

References

Dumitrescu, R., "Entwicklungssystematik zur Integration kognitiver Funktionen in fortgeschrittene mechatronische Systeme", Heinz Nixdorf Institut, Universität Paderborn, 2010.

Panshef, V., Dörsam, E., Sakao, T., Birkhofer, H., "Value-chain-oriented service development by means of a 'two-channel service model'", Int. J. Services Technology and Management, Vol. 11, No. 1, 2009.

Hepperle, C., Orawski, R., Nolte, B. D., Lindemann, U., "An integrated lifecycle model of product-service-systems", 2nd CIRP Industrial Product-Service-Systems Conference, Linköping, 2010.

Pahl, G., Beitz, W., Feldhusen, J., Grote, K.-H., "Engineering Design: A Systematic Approach", 3rd ed., Springer, 2007.

Metzler, T., Jowers, I., Kain, A., Lindemann, U., "Development of Cognitive Products via Interpretation of System Boundaries", C.A.P.R.V., ICoRD'13, Springer India, Neu Delhi, 2013a, pp. 163-174.

Metzler, T, Schmid, H., Lindemann, U., "Bewertungsmethodik zur systematischen Integration kognitiver Funktionen in Produkte", Stuttgarter symposium für Produktentwicklung, Stuttgart, 2013b, pp. 1-10.

Metzler, T., Shea, K., "Cognitive Products: Definition and Framework", In: 11th International Design Conference – DESIGN 2010, Zagreb, 2010, pp. 865-874.

Metzler, T., Shea, K., "Taxonomy of cognitive functions", International conference on engineering design (ICED11), 2011a, pp. 330-341.

Metzler, T., Shea, K., "Lessons Learned from a Project-Based Learning Approach for Teaching New Cognitive Product Development to Multi-Disciplinary Student Teams", ASME IDETC/CIE, Washington DC, USA, 2011b.

Sharp, H., Finkelstein, A., Galal, G., "Stakeholder identification in the requirements engineering process", In: Proceedings of the Tenth International Workshop on Database and Expert Systems Applications, Florence, Italy, 1999, pp. 387-391.

Stone, R. B., Wood, K. L., "Development of a Functional Basis for Design", In: Journal of Mechanical Design, Vol. 122, December, 2000, pp. 359-370.

Vernon, D., Von Hofsten, C., Fadiga, L., "A roadmap for cognitive development in humanoid robots", Springer, Berlin Heidelberg, 2010.

Torsten Metzler, Research Assistant
Product Development
Technische Universität München (TUM)
Boltzmannstr. 15, 85748 Garching, Germany
Telephone: +49-89-289-15154
Email: torsten.metzler@pe.mw.tum.de
URL: http://www.pe.mw.tum.de