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TRANSFER OF CREW RESOURCE MANAGEMENT TRAINING INTO PRODUCT DESIGN

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ABSTRACT
Product design is a complex reality domain with changing requirements on the engineer. Design processes are getting more and more complex mixtures of cooperation within and between different disciplines. The number and significance of projects is rising and thus teamwork with colleagues, superiors, other departments or even other companies increases and so does the importance of the designer's social skills. This development is not only valid in product design, but also in other complex reality domains. Due to increased demands on employees in the domain of aviation and due to problems related to communication and cooperation within the crews, airlines developed a program what was called Crew Resource Management (CRM) to train their airplane crews. CRM is focusing on non-technical skills such as communication, decision-making, stress and conflict management. These non-technical skills were formulated specifically for tasks and work in airplane crews. Behavioral Markers have been developed to assess the impact of the training in practice and in research. Behavioral Markers are observable, non-technical behaviors that contribute to superior or substandard performance. Other complex reality domains, such as medicine, adopted and slightly modified these systems. These Behavioral Marker concepts allow not only a better rating of performance, but also a better focus on relevant aspects in teamwork.
This paper presents four concepts of Crew Resource Management. An approach to transfer the Behavioral Marker concept into product design and accordingly develop a non-technical skills training for product design is formulated. Advantages and limitations of such a training concept are discussed.

Keywords: Product Development, Design, Training, Teamwork, CRM, Behavioral Markers

1 INTRODUCTION

„The ideal engineer is a composite. He is not a scientist, he is not a mathematician, he is not a sociologist or a writer; but he may use the knowledge and techniques of any or all of these disciplines in solving engineering problems." (Dougherty, 1955)

Times are changing and so do the requirements for the 'ideal designer': Product design processes nowadays are not single-handed design processes, but a complex mixture of cooperation and communication within and between different disciplines. As designers have to deal with content-related, process-related and relationship-related tasks, they often have to work on tasks that are not directly product-development related, such as organization or documentation [11]; approximately two thirds of the team communication deals with content, while the other third relates to the structuring of group processes ("2/3-rule") [12]. Thus, product designers need the so-called hard skill such as disciplinary knowledge or sketching abilities, but also soft skills, such as team willingness, flexibility, perseverance and many more [5,8]. The product design process is therefore - among other things - dependent on human factors, which can easily lead to errors and failures.
According to Cicero "to err is human", which is particularly valid for humans acting in complex reality domains, but errors can cost time, money and even human casualties. The last aspect is especially relevant in high-risk environments such as aviation. In the 1970's it was found that more than 70% of aircraft/airplane crashes involve human error. This might be a reason why, in this domain, the human factor gained earliest interest.

In 1981 United Airlines developed a training concept called "Cockpit Resource Management", which was refined several times and was recently renamed as "Crew Resource Management" (official acronym: CRM). This training program initially focused on the reduction of pilot errors and was later modified to fit and train the whole crew [2]. For approximately 10 years, CRM has been implemented as training program of most European airlines, such as the Deutsche Lufthansa AG, where pilots have to run through a CRM training every three years. CRM proved to enhance the performance of the crews' actions. As a result, CRM became interesting for other complex reality domains such as medicine [6,7,10] and also Fire Service, where new approaches were developed to reduce the number of critical incidents and to decrease the deaths of fire fighters in action [4].
Further development of the CRM led to the so called Line Operation Safety Audits (LOSA), which is another similar training program for crews in aviation [9]. All CRM or LOSA programs have – independent of the complex reality domain – the goal of minimizing errors by improving team cooperation. Although both domains aviation and product design pose partly different requirements there is some evidence that designers can also benefit from elements of CRM training. Transferred to the domain of product design, the aim should not be restricted to the reduction of errors, but such a training should lead to less troubleshooting and better cooperation and thus to improved quality of products and to time and cost savings.
However – as stated above – a direct transfer of CRM trainings into product design is not appropriate. On the basis of empirical analyses, but also based on existing studies, elements for such training have to be developed.
In a cooperation project **BEMAP** (BEhavioral MArkers in Product design) engineers at the Darmstadt University of Technology and psychologists at the University Bamberg are working together to develop an appropriate training on the basis of design-relevant Behavioral Markers. Whereas the emphasis of prior work of the cooperation between Darmstadt University of Technology and the University Bamberg (e.g. [11,12]) was on the analysis of successful and less successful mechanisms of design teams and leadership in design teams in different types of critical situations, the **BEMAP** project is mainly focused on the development of training and the evaluation of competencies.

2. CRM IN COMPLEX REALITY DOMAINS

According to Helmreich [3], Crew Resource Management does not primarily intend to improve teamwork, e.g. by preventing "superior errors" (such as superiors not listening to their subordinates). Improving these skills is a means, not an outcome itself.
To achieve effective and functional crew work aboard a plane, it is important that all crew members take part in a CRM training [1]. Although airlines mix their crews constantly, it is important that tasks and cooperation become a matter of routine.

2.1 Advantages of CRM

Crew Resource Management deals with issues such as communication, cooperation, stress management, decision-making, leadership and group behavior [1,9] by training and supporting the whole crew. CRM is a team training, which comprises interfaces to other teams and superiors/subordinates and is aimed to be understandable for everybody, by using illustrated examples, videos, role-plays and games for training methods. As trainings are conducted under non-competitive conditions and in a confidential atmosphere, high commitment and better results are achieved. Nonetheless, effects of stressors on performance (reduction of performance) are taken into account. The crews get training in coping with conflicts and managing stress by particular methods like thought-stop.
Initially developed as a tool for error management, CRM is based on the assumption that errors are inevitable [2,3]; thus, the CRM training focuses on error avoidance. Helmreich describes his model of the error troika [2] as a complete set of error countermeasures. In the first step, we should try to avoid errors. Secondly, errors should to be trapped before they occur and finally in the case if errors occur and cannot be trapped they should be mitigated. As CRM focuses on the issue of crew cooperation, it has to be included in existing training to complete them in that score.
Airlines have mixed crews with different backgrounds such as cultural differences [2], which may cause additional problems. Depending on society, culture and region, the understanding of team work differs. In his research, the Dutch Scientist Geert Hofstede discovered differences in team work

between different cultures [13] especially in terms of "power distance" – which means the discrepancy of power between two persons. Latin American countries, for example, have a much higher power distance than European countries. Results of high power distance are stress, latent conflicts, privileges and mistrust. It is obvious, that crew members can not cooperate properly, when the pilots are considered as "being of a different kind" by the crew and pilots have little faith in their subordinates. In CRM trainings, an atmosphere of trust and a non-punitive policy towards error is established and it is attempted to use the specific advantages in national culture, professional culture and team behavior [2,3] and reduce the problems caused by cultural differences. Essential for successful error management is (besides trust and the non-punitive policy) the commitment to take actions to reduce error-inducing conditions.
In summary, it can be stated that the great advantage of CRM is the focus on the team behavior and the communication of airline crews performing specific tasks. Additionally, the possibility to evaluate behavior (see also section 2.3) according to defined criteria allows the assessment of teams and the evaluation of training.

2.2 Limitations of CRM

Critique of CRM mostly concerns the lack of generalization which means, that it cannot easily be transferred to other cultures or organizations [3] and that it does not reach everybody due to cultural differences or because of rejections of participants (the so called "boomerangers" or "Drongos"). Further false promises like "zero-accident" harm the credibility of CRM [3]. In addition CRM has to face the general limitations of human beings, such as cognitive limitations, indifference, apathy and work overload. It is also mentioned that CRM emphasizing the acceptance of human errors can lead to a too positive attitude towards human errors with the consequence of less care and attention of the trained persons. Furthermore external problems such as inadequate training and procedures can also throw shadows on the achievements of CRM. According to Helmreich [3] CRM was even applied in completely different fields such as in marital and family therapy. It was assumed that CRM works in any kind of environment, situation and for any kind of group as long as it is about conflict, stress and communication.

2.3 Behavioral Marker Systems

In high-risk environments, the major interest is on the outcome. In medicine, for example, performance is measured in terms of the improvement of the patient's well being or in terms of saved lives. The process is often ignored [10]. However, arriving at a positive result without knowing how causes problems for the analysis, but also for the development of an appropriate training and education. Thus, the assessment of the process cannot be omitted. For example, the human interaction process in the cockpit plays an important role for team performance and thus for safety in aviation. But how can valid data of the process be assessed?
The latest generations of CRM and parallel developed training concepts such as LOSA are structured upon the concept of Behavioral Markers. Behavioral Markers (BM) are "observable, non-technical behaviors [of teams or individuals] that contribute to superior or substandard performance within a work environment" [9]. They are usually structured in a set of categories with sub-categories that are dependent on the system, called elements or markers (sometimes also called anchors). This structure allows describing, categorizing and evaluating behavior.
The University of Texas (UT) Behavioral Markers for aviation is rated by a digit scale with a range from one to four. NOTECHS (non technical skills system; see Figure 1), which was already used for CRM at Swissair, uses a verbal description scale from 'very poor' to 'very good' [9].
The UT Behavioral Marker System was extended by contextual factors (external/internal threats to safety, environmental and operational conditions, crew experience, etc.) and used for LOSA.
CRM (Swissair, Lufthansa) and LOSA (UT) were compared and analyzed regarding BM by the GIHRE project. The GIHRE (Group Interaction in High Risk Environments) project is an interdisciplinary project launched by the Gottlieb Daimler and Karl Benz Foundation in 1998. It consists of psychologists, associates of the University of Texas and employees of Swissair. As of 2001, approximately 100 crews from Swissair and Lufthansa CityLine had been analyzed in this project. The successful performance of CRM-trained crews was proven on the basis of the Behavioral Marker System of the UT and the NOTECHS. It turned out, that the UT Behavioral Marker System and the NOTECHS elements complement each other, because of their different perspectives.

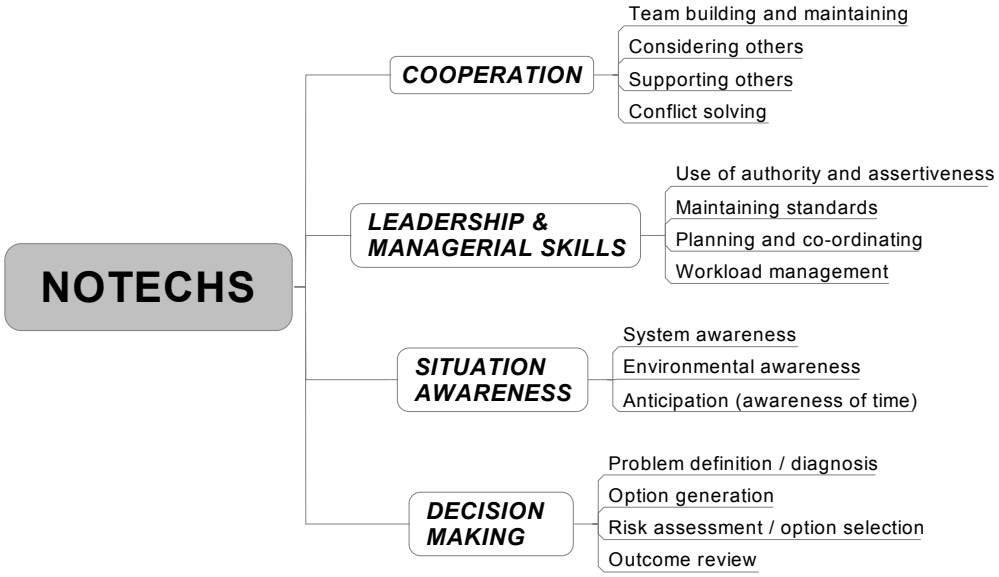

Figure 1. NOTECHS Behavioral Marker System with its categories and elements

It took several years until in medicine a similar system ('anesthetists' non-technical skills'=ANTS) has been developed on the basis of the Behavioral Marker Systems in aviation, aiming at the observation and assessment of non-technical skills of anesthetists in day-to-day practice. The transfer from CRM to ANTS was a bottom-up approach following three main phases:

1. Identification of the non-technical skills used by individuals in their routine practice.
2. Development of a prototype Behavioral Marker System for the identified skills.
3. Preliminary evaluation of the prototype (e.g. by videotaped scenarios).

Reported problems were the overlapping between non-technical skills and the requirement to focus on observable behavior [10]. Also, it was necessary to use a pragmatic approach, because the system should cover the non-technical skills in a complete and meaningful way, but should still be easy to use and observable.

Table 1. Behavioral Markers in group interaction training programs

CRM (Lufthansa)	NOTECHS (Swissair)	UT BM (LOSA)	ANTS (medicine)
communication	cooperation	planning	task management
leadership & group-behavior	leadership & managerial skills	execution	team working
stress management	situation awareness	review/ modify plans	situation awareness
decision making	decision making	–	decision making

Table 1 shows four different Behavioral Marker Systems in comparison. The Lufthansa CRM uses a BM system that has been derived from recommendations of the DLR [1] and is quite similar to NOTECHS. The category decision-making includes workload management and situational awareness.

3. TRANSFER OF CRM INTO PRODUCT DESIGN

3.1 Development of DTRM (Design Team Resource Management)

In contrast to the CRM training usual team trainings are not developed with Behavioral Marker Systems. They are based on experience, not on results of a systematic analysis of requirements which contents and topics need to be addressed. Thus, there are trainings on system thinking, mental models,

shared vision, personal mastery (like loyalty to truth, power of choice) or on team learning (compare Senge [15]). The **BEMAP** project however aims to realize a holistic training that covers the relevant issues in design team cooperation. Thus it needs to be set on a sound basis. DTRM (Design Team Resource Management) will be based on a design-related Behavioral Marker System. This training is focused on collocated design teams (as defined by McDonough [14]) – which are observable regarding their behavior and/or communication – and relates to the specific behavior of design teams. Thus, an adaptation of the Behavioral Markers to the new domain is necessary that will follow a structured and explorative approach as described in Figure 2.

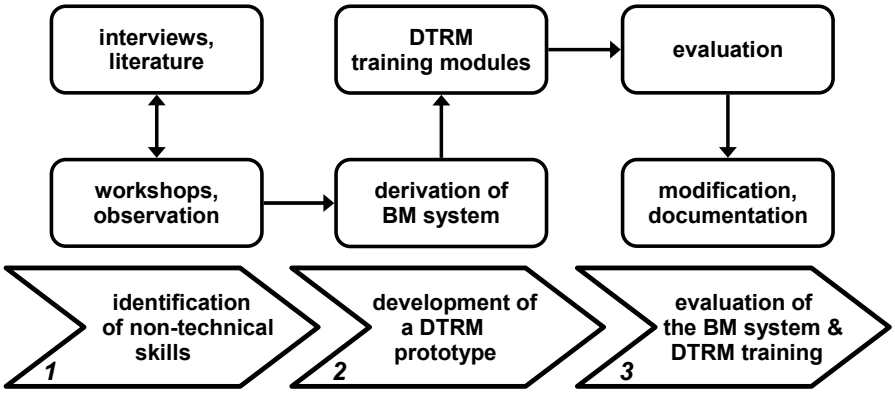

Figure 2. Approach of the development of a design-specific BM system

First phase: In the first phase the non-technical skills for product designers need to be identified. A combined bottom-up and top-down strategy merges the experience of existing systems with the empirical identification of relevant non-technical skills. Literature, interviews and existing systems can provide an idea about important elements of the system, while workshops and observation lead to the identification of the specific non-technical skills of the product developer.
Second phase: In the second phase – based on the results of phase one – a Behavioral Marker System will be set up. However, different to existing BM systems, the **BEMAP** project is categorizing and assigning the Behavioral Markers related to defined critical situations which describe situation-related successful and non-successful behavior. After setting up a Behavioral Marker System, modules for the DTRM will be developed that define the prototype of the training for product designers.
Third phase: In the last step, the effects of the training have to be evaluated, for example in studies which compare the non-technical skills before and after the training. Eventually, the concept has to be modified (and it can be necessary to go back to the second phase).

Currently, interviews in different companies are being carried out to collect the relevant non-technical skills of product designers. These companies vary in size (big and medium-sized companies), as do the positions and occupations of the interviewed participants. The collected data will be the basis for the development of the DTRM training, as – according to the expected results of the research described in Figure 2 – existing trainings may not cover all relevant characteristics and features of design teams.

3.2 Expected benefits of DTRM

Depending on an appropriate BM system, a specific designed DTRM corresponds to the needs of non-technical skills needed in product design. We assume that DTRM leads to an increase of the quality of the design process and the design product by improving teamwork, by better conflict and stress management and by introducing tools and methods for cooperation and communication in and between teams.
Thus, we assume that DTRM will lead to economical advantages, but DTRM would also have social advantages. Due to fewer problems in cooperation, a better working atmosphere is expected. Motivated, flexible and committed employees are the positive side effects of the improvements.

3.3 Expected limitations of DTRM

An adequate adaptation of the CRM concept into product design needs to take the differences between the domains of aviation and product design into account. Some of these problems are illustrated in Figure 3.

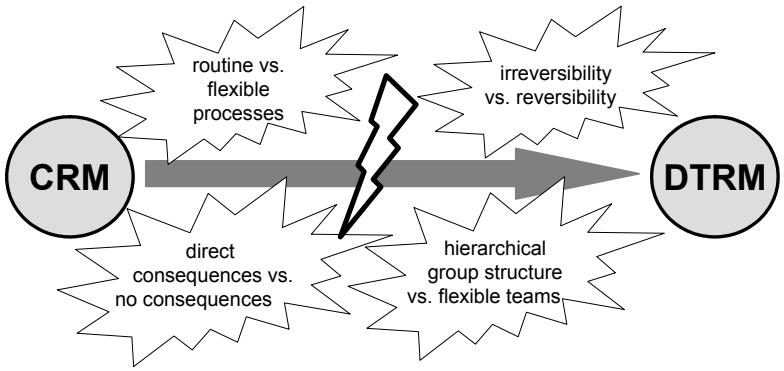

Figure 3. Potential problems with a transfer of CRM

Operating procedures: In contrast to design, aviation has a lot of standard operating procedures which define the means and actions for many different problems. A product design process, however, is very dynamic because of changing requests; also the context of one design process is never identical to another one. Therefore, in product design it is difficult to work with extended checklists. The training has to be much more focused on flexibility in the design process.

Responsibility: There are also differences with regard to responsibility. If the design of a machine has flaws, in most cases there are no direct consequences for the individual, because many people are involved in the process and often it is not possible to identify the responsible person. This can lead to a low level of own responsibility concerning decisions and actions.

Reversibility: Decisions in aviation are of short-term character with direct (often irreversible) consequences (like a crash in a worst case scenario), while in design consequences are of long-term character and are to a certain degree and time reversible. This can lead to thoughtlessness and immature solutions that have to be reworked and improved.

Group structure: Hierarchical structures in flight crews are clear and leadership is precisely defined. Although crews rotate regularly they keep their structure and thus everybody knows his position and responsibilities in the crew. In industry project teams often vary in size and members. Sometimes it is not possible to assign responsibilities to a person. Leadership is often not clearly determined, especially when different departments or companies are involved.

3.4 Content of DTRM-Trainings

CRM trainings focus on four topics: leadership and group-behavior, communication, decision behavior (incl. workload management & situational awareness) and stress management. An extension to fit the new domain will be the topic ‘design-methods,’ which adds an important process component. However, the final selection of topics will be a result of the interviews, the workshops and the literature review (see Figure 2).

A model of a product design process is depicted in Figure 4. A lot of factors, elements and mechanisms affect and influence the whole process. The exemplary internal factors (non-technical skills) are basically derived from existing Behavioral Marker Systems (see Table 1) extended with specific tasks in product design, such as analysis or documentation. The internal factors have to be determined in the first phase; then training modules will place defined situations as reflections of external factors and relate both to process structures in the DTRM training.

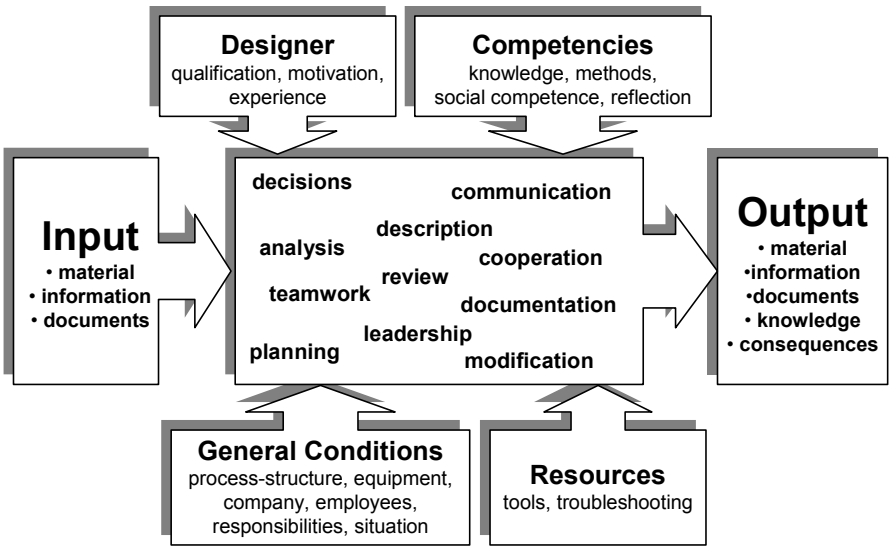

Figure 4. Examples of factors, elements & influences on product design processes

A training concept elaborated and transferred from CRM into DTRM will consist of three modules (see Figure 5) such as the steps of the DLR recommended CRM training [1].

First phase: Participants have to realize the importance of the influence of human factors on performance and get motivated to do the training properly. This is especially important, because the training gives advice on team and individual behavior, which might be problematic with persons that see themselves as "lonely fighters braving the elements" – as it is stated in CRM trainings [2,13]. Lone wolves, as well as dominant persons, have to learn confidence in others and must be convinced that this kind of teamwork will lead to an improvement compared to existing processes.
Second phase: Practical exercises plus feedback have to be accomplished. The described skills, such as group-oriented behavior or methodical knowledge are to be trained here. Feedback is given by the group referring to personal attitudes and behavior during a problem solving process. In the DLR-CRM a LOFT (Line Operations Flight Training, similar LOSA of the UT) role-play without a simulator is advised. Transferred to product design, interactive role-plays with fictitious problem definitions and changing parameters and conditions adapted to the Behavioral Marker Systems would be the corresponding procedure.
Third phase: To guarantee that the positive learning experiences are put into practice, the trained behavior has to be consolidated by specially designed courses (refreshing / deepening) in the third phase. Advanced courses, including tasks with implementation of specific requirements help to extend and deepen DTRM knowledge.

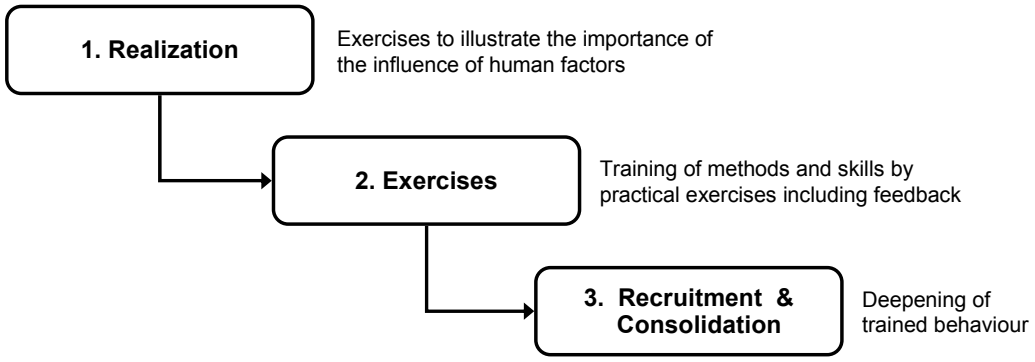

Figure 5. Training phases recommended by the DLR

As described in section 2.3, Behavioral Marker Systems do not only serve as a frame for training contents, but are also developed to assess successful behavior and thus team performance. Therefore, an evaluation of the quality and success of the training can be carried out either through a comparison

of team work in a design team before and after the training or by comparison of trained groups with control groups.

4. CONCLUSION

Product Designers are knowledge specialists in their complex reality domain. In former times, teamwork was not very common as a lot of development tasks (e.g. building a CAD model) were tasks to be done alone. Nowadays, design projects include many different parties, other departments or even other companies, so that cooperation becomes more and more important. Domain-specific knowledge is not enough when working together in a project team. Usual problems occur because of difficulties with interfaces, what in fact means problems in communication and cooperation.
CRM is a system to prevent errors by training and assessing the whole crew in cooperation, stress and conflict management, communication and factors such as leadership or decision-making. Step-by-step, other complex reality domains, such as medicine and fire services, took over this concept and it can be expected, that other domains will follow in the future. Product design can gain ideas and principles from the existing systems. Thus, an adaptation of CRM into a training for product design (called DTRM) is conceptualized.
The roadmap to an appropriate training is to first analyze existing systems. In the next phase a Behavioral Marker System will be set up, defining non-technical skills that contribute to successful teamwork in product design. The **BEMAP** project aims to design a situation-specific Behavioral Marker System for collocated design teams. Based on the BM system – which additionally allows team performance to be assessed– a profound training concept has to be developed that supports the relevant elements. In a third phase the acquired skills have to be refreshed and improved.
We assume that a sound DTRM training can improve product design considerably by reducing errors and further improving team work, which ensures successful results for the future.

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