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Accessibility of the innovative principles to further levels of abstraction in product development

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Abstract

The paper introduces the transformation of the 40 innovative principles of TRIZ into a description with the Contact and Channel Model (C&CM). Reason therefore is the attempt to make the principles better applicable for the generation of new ideas in product development at any stage of the product development process. The paper in a first step introduces the C&CM. The core of the C&CM approach is an orderly assignment of the functions of a product to their shape, which enables designers to break up with rigid, pre-fixating representations of products. C&CM product models by means of Working Surface Pairs (WSP) and Channel and Support Structures (CSS) force users to think about products in a more abstract way. Designing with the C&CM is conducted on a meta level through (i) adding WSP, (ii) removing WSP, (iii) changing the properties of WSP and (iii) changing the properties of the CSS. The paper reflects the reasons for the transformation of the innovative principles of TRIZ into C&CM before the theoretical approach is explained. The paper closes with a case study where the coupling of the innovative principles to the C&CM meta-rules of designing is applied.

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Keywords: Innovative principles; Contact and channel model; C&CM;

1. Introduction

The development of technical systems is a complex process, where designers have to think ahead many steps at the same time. They have to consider many interdependent factors in order to prevent decisions which lead to unsatisfying solutions. The design process is determined by a permanent changing of steps of analyzing and synthesizing. Within this process the designer has to respect the abstract level of functions, which gives the objectives to the design process and the level of shape. The shape is the result of the design process, because only a real component can fulfill functions. Both levels have to be regarded parallel in order to find an optimal solution.

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Good designers mostly have a long lasting professional experience on which he/she can rely. Out of many successful and unsuccessful attempts of designing products he/she has developed a “feeling” for decisions and workflows. This experience can hardly be couched, thus can hardly be handed on to other designers.

To put these things right many manuals and instructions have been developed for creating products. Beginning with very general procedures within e.g. the VDI guidelines in Germany [13], continuing with many partly very specific process and rule descriptions, there is an endless repertoire for designers to find. Yet, rules and descriptions are formulated on specific levels of abstraction, i.e. somewhere on the way between a pure functional description and a pure geometric description.

Figure 1 shows that within the spectrum of function and form many methods and tools are developed. For each of these departments, which all contribute to the development of the product, rules, guidelines and principles are developed. Many of them remain hard to access for designers.

In order to support the passage of the different levels of abstraction in several research approaches continuous process models have been developed to describe procedures in product development on a generally understandable way (e.g. [3], [4], [5]).

![Figure 1: Different methods and models in the design process.](image)

The combination of the process models with the rules, guidelines and principles, which are all placed at different steps in the process, is a rarely supported issue.

In order to integrate the different methods models that are developed in the different departments of a company, the Contact and Channel Model (C&CM) [1] has been developed. Within this paper the C&CM is applied to improve the integration of the innovative principles of the TRIZ methodology into the product development process.

On the basis of the C&CM it shall become possible to represent the Innovative principles in any step of the design process, at any level of abstraction.

2. Background

During the development of products continuously new experience is generated. This experience that is not only suitable for the current project and can also be applied to other design activity in future projects. Specific experience may be applicable to only a small number of projects, whereas generally described procedures may be applicable to a huge amount of project. Yet, the general rules and principles must be adapted to the specific problem in order to benefit from their application.

In order to save the knowledge of experience and to make it also accessible for future projects out of the experience generally formulated rules, guidelines and principles are derived. Their allocation in knowledge-storages provides a useful support to inexperienced designers.

Numerous authors provide general but also topic- and technology based systems of rules. E.g. [14] represents a famous collection of many of these rules.

The concepts of the rules, guidelines and principles are not used consistently. Some authors use the term of guideline synonymously to principle or rule. Others applied these terms in an upside down hierarchy. There exist
guidelines that are named principles whereas rules in other works. An elaborate description of this issue can be found in [6].

Figure 2: Hierarchy of basic rules, principles, guidelines, and embodiment advices.

The terms basic rules, principles, guidelines, and embodiment advices are shown in a coherent way (Figure 2). The hierarchy shows the categories of rules. Generally formulated approaches are located at the bottom. They can be applied to a wide range of design problems. On the top of the hierarchy concrete advices for specific embodiment problems are located. A specific embodiment advice is applicable to a smaller range of problems and requires a structured admission.

The “basic rules of designing” (explicit, easy, and secure) [14] are foundation for all other guidelines, principles, and rules. The “principles for design” are more generally formulated (here the innovative principles of TRIZ are associated) than the “guidelines of designing”. The “guidelines of designing” refer to specific topics like e.g. design for manufacturing or design for assembly. Embodiment advices already refer to very similar situations, low degree of abstraction and thus do not need to be interpreted in the depth of the principles.

2.1. Altschuller’s innovative principles (TRIZ)

This paper focuses on the innovative principles of the TRIZ theory. In the section before the innovative principles were classified to the class of “principles of designing” on a rather high level of abstraction, thus applicable to a very wide range of design problems but on the other hand give huge area of interpretation to the designing engineer.

The innovative principles are an all covering collection of interdependent principles for finding new solutions in design processes.

Genrich Altschuller documented in the middle of the 20th century his experience of analyzing about 40000 Patents [10]. His essential discovery at this was that on a certain level of abstraction the performance of innovation can be reduced onto 35 (later 40) basic principles. These principles are recurring in any innovation performed in any engineering design process [8].

For accessing these innovative basic principles Altschuller developed a theory which states that any problem that must be solved can be formulated as a contradiction. Any of these contradictions can be formulated as the combination of an improving and a worsening parameter. For any problem description there exist 39 technical parameters on whose basis the contradiction is formulated. The process is shown in Figure 3.
Yet, TRIZ does not only comprise the application of the 40 innovative principles based on a contradiction formulated with 2 of 39 technical parameters. The TRIZ philosophy comprises several other approaches that cover a huge area of engineering design, which are all not part of the paper in hand.

3. Problematic

The 40 innovative principles are a powerful tool. TRIZ claims that the principles can be applied to any kind of technical problem and find appropriate solutions.

Yet, the level of abstraction of the principles is very high. The designer has collect a lot of experience into the process, before the application of the principles leads to an optimal solution. The experience is needed to effectively interpret the principles according to the formulated problem. The abstraction of the problem and transformation of the principle solution (see Figure 3) into a concrete solution are process steps that need support.

This issue shall be exemplified by the application of the innovative principle number 12 (equipotentiality, remove stress). The principle states in the interpretation of [10]: “Change the conditions in such a way that the object can work with a constant potential of energy”. That means that the object should neither be lifted nor lowered. The principle makes clear, that a conventional piston combustion engine is not the ideal solution for transferring combustion energy into a mechanical movement. Indeed, for transferring this conclusion into e.g. a wankel engine with the aid of the principle number 12 a huge inventory performance in required. Therefore TRIZ does not provide support in any case.

The experience the designer has to collect to effectively transform the principal solution often concerns the knowledge about design decisions that limit the newly found concept. The concretization of the new innovative concept is limited by restrictions that stem from e.g. special knowhow in the electrical department of a company, whereas the new concept was discovered in the mechanical department. A key competence of the designer then is to transform the new concept into marketable solutions with respect to the limiting boundaries. As there is hardly any methodical support in integrating these conditions into the process of concretization the designer has to rely on his experience.

4. Approach of this work

The idea described in this paper is: through giving a more concrete reference to the abstractly formulated innovative principles, they become more easily applicable. A support especially in the abstraction and transformation steps is given through a concrete reference to the problem in hand. Although the finding of solutions can take place with very little description of a pre-fixating shape the transformation into the solution is supported by the location of the contradiction in a concrete Working Surface Pair (WSP) or Channel and Support Structure (CSS).
The Contact and Channel Model is a means to relate abstractly formulated functions to the shape which is designed for the fulfillment of the function. As the finding of principle solution with TRIZ is based on rather abstract functional descriptions the C&CM seems suitable to also here integrate abstract and concrete real descriptions.

Figure 4: Proceeding of TRIZ with C&CM.

The approach has two aspects (fig. 4). First is a problem formulation on the basis of C&CM. A technical contradiction can then be formulated as the combination of two parameters in a WSP or CSS. The second aspect is the formulation of the 40 innovative principles according to WSP and CSS. Thus, solutions that are found through the application of the Innovative principles can be transformed more easily as they receive to a concrete location on the object of the problem solving process.

In order to explain the approach more concretely the basics of Contact and Channel Model are briefly introduced in the next section. After that the formulation of the innovative principles with the C&CM is shown up by the example of only two of the 40 principles. The other principles have been formulated with the C&CM, but are left away in this paper due to space restrictions. Subsequently the description of a concrete application of the procedure at “the fixation of a carriage of a turning lathe” should finally make the approach clear.

4.1. The contact and channel model (C&CM)

The core of the C&CM approach is an orderly assignment of the functions of a product to their shape, which enables designers to break up with rigid, pre-fixating representations of products. C&CM product models by means of Working Surface Pairs (WSP) and Channel and Support Structures (CSS) force users to think about products in a more abstract way [12].

How the C&CM works

By using C&CM it is possible to isolate an individual problem from the remaining technical system at any time of the design process and at any level of detail, to solve it and to integrate the solution into the entire system to check the effects of the changes on the entire system.

The Contact & Channel Model describes engineering products in terms of Working Surface Pairs and Channel and Support Structures Error! Reference source not found.. Every function of the product resides in a particular set of Working Surface Pairs (WSPs) and Channel and Support Structure (CSS), because a function cannot be applied other than through these interfaces. This enables designers to think about abstract functions in a concrete way, because they can picture them at a set of WSPs.
In terms of the C&CM approach, descriptions are generated for a particular problem through assigning a set of Working Surface Pairs and Channel and Support Structures to a specific function and searching for solutions on this clearly assigned level. The C&CM approach then picks and groups elements of the existing description in a new way, exploring the inherent ambiguity of how elements of a description are grouped.

For example the function of a ballpoint pen (Figure 5) cannot be fulfilled unless WSP0.1 between paper and pen, WSP0.2 between pen and hand and the CSS0.1/0.2 represented by the body of the pen exist. If one of these elements is not build up correctly the function cannot be fulfilled. For example if somebody tries to write on glass, WSP0.1 does not work correctly. Reasoning on a lower level of detail it remains to clarify why the function cannot be obtained. What effect prevents writing on glass? Is there not enough friction in order to turn the ball, or do the properties of the liquid ink prevent a wetting of glass through ink? Are there other reasons? To clarify such a case remains then in the hands of the designing engineer who might be given the task of creating a ballpoint pen for labelling glass-surfaces.

Thus, C&CM models can be applied on different levels of detail always in the same way, so that the same type of mental model can be applied at different levels of hierarchy. The CSS0.1/0.2 of the ballpoint pen can be split up into further WSPs and CSSs, which represent the structure of parts in relation to the structure of functions contributing to the principal function. The model can be dynamically adjusted in its degree of detail, according to the problem posed by a product.

Frame work for designing with C&CM
The sections before indicated that C&CM provides support in describing abstract functional issues and shape in a combined way.

This point of view allows the designer to facilitate keeping the overview over the interdependencies during the product development process. The C&CM allows switching very quickly between representations that provide a highly detailed insight into a very special issue and representations that give an overview to the designer in order to evaluate the consequences of the work at the detailed point (e.g. see Figure 5).

Further the description of a system with C&CM opens up the possibility to integrate different functional and geometric descriptions that are required during the design process (see Figure 1). These descriptions can be referenced with the C&CM, so that in case of iteration the evaluation of the consequences can be conducted more easily because the designer has a support to integrate the different descriptions.

This also means that the different departments can fulfill their part of the design task more independent form their colleagues, because the can rely on a common language and do not have to interpret the descriptions from another departments.
Therefore designers have to organize their mental work differently. All kind Information is saved as properties about WSP and LSS without completely being assigned to one special shape. In the course of the design process this information is consolidated through the legwork of the different departments, and in the end leads to the concrete shape. Whereas today e.g. the different departments often have to face pre-fixated design decisions that limit their room for searching solutions.

The description with C&CM leaves the liberty to the designer to not stringently make decisions. The final shape can be defined when information of all departments come together. Thus, Iteration, rework and revision of stringently made decisions can be reduced.

![Diagram](https://via.placeholder.com/150)

**Figure 6: Support in the "transformation" steps**

On the other hand the space of solution is not limited arbitrarily by one department based on their partial decision. The space of solution can be narrowed down with the respect to the information from the other departments. Thus, the chance of choosing a solution of higher quality can be improved.

Figure 6 shows in which cases the support to the application of the innovative principles of TRIZ is of greatest benefit. The abstractions with C&CM as well as the concretization step when a solution is found are the mainly supported steps. All the information about the problem description can be referred to the WSP and LSS. For the step of searching solutions this information can optionally be neglected in order to be “free” from limiting restrictions.

Yet, when the solution found has to be concretized all the information and input from other department has to be considered. Thus, an effective selection of solution according to the boundary conditions is supported.

**Meta-rules of designing with C&CM**

Principles and guidelines that are included into the C&CM can be divided into different groups, depending on which changes are made and how they are carried out in order to improve the result: One group only concerns the WSP of a technical system. This includes among others the principle of assembly-oriented design, wear-oriented design and corrosion-oriented design. A further group only influences the Channel & Support Structures of a technical system. It contains creeping and relaxation-oriented design, deformation-oriented design as well as some of the principles concerning energy and force transmission.

Apart from that there is a group which concerns the complete Working Structure of the technical system, i.e. the Working Surface Pairs essential for the function as well as the Channel and Support Structures. This group is relatively big and contains e.g. the principles of nearly flawless design, the principles of safety engineering, the principle of self-help and the risk-oriented design.
For the paper in hand the following generally described proceedings are relevant. An important organising criterion overlapping with the research work in this paper is the way the changes concerning the application of the principles and guidelines in the technical system are realised. In general, there are four possibilities for changing a technical system:

- Meta-Rule 1: Adding Working Surface Pairs or Channel and Support Structures,
- Meta-Rule 2: Removing Working Surface Pairs or Channel and Support Structures,
- Meta-Rule 3: Changing the properties of Working Surface Pairs, including their relation to other Working Surface Pairs or Channel and Support Structures and
- Meta-Rule 4: Changing the properties of Channel and Support.

From these rules all changes of any technical system can be derived. However, as the rules are so general a designer with some experience is required to guarantee a safe application in the design process and derive the correct measure from these very generally put rules. The combination of the meta rules with the innovative principle of TRIZ concretizes the application of the meta rules.

Innovative principles and the meta rules

Similar to the proposed procedure with C&CM the formulation of a contradiction is the description of the problem on a more abstract level.

The approach of this paper is: with formulating the problem contradiction on the basis of C&CM and through formulating the innovative principles with C&CM the integration of the found solution into the overall design process is improved.

Finding solutions with C&CM is conducted through applying one of the four meta rules, that were introduced in the section before. These meta rules give an abstract framework for proceeding in the design process but lack to give innovative food for thought. In order to integrate the innovative principles into the process with C&CM the innovative principles have been reformulated on the basis of the four meta rules.

4.2. Applying the C&CM to the innovative principles of TRIZ

The problematic of applying the innovative principles is their absolute dissociation from the specific problem. Thus, the step of concretization becomes the core performance of the designer. Integrating the newly found innovative solution is a hardly supported step that is based on experience.

If the innovative principles are formulated in a way that these can be assigned to WSP and LSS a reference to the specific problem persists and the transformation of the innovative principles is facilitated, because the principles can be referred to a concrete location.

Further it is interesting to transform the innovative principles into C&CM for generating a basis to apply the principles to all kinds of changes of technical systems. In the following the conversion of the innovative principles is formulated as general as possible according to the introduced meta rules.

In this paper the formulation of the innovative principles is exemplified by only two of the 40 principles due to space restrictions. Yet, the goal of the paper is to principally explain the approach and lay a cornerstone for the immersion of the research work.

4.3. Exemplification of the innovative principle with C&CM

Principle Number 2: Extraction, Separation, Removal, Segregation

“Hiving the disruptive part of the object or in contrast hiving the only part essential”[10]. Explanation: the principle describes the possibility of separating a technical system in two or more parts if these fulfill different functions. The subsystem fulfilling the required function shall be retained whereas the subsystem fulfilling the unwanted function shall be removed.

Example for this is non-metal contaminations in metals. For removing those contaminations the metal material can be transferred into cast. Contaminations can then be removed, because they are still solid or are swimming upon the surface of the cast.

Description of principle no.2 with C&CM
A system should be broken down into its sub functions according to the subsystems fulfilling the wanted and unwanted functions. For each of these functions the WSP and LSS shall be determined as clearly as required. The clear determination of unwanted and wanted/required elements allows an easy separation.

Interdependencies between WSP and LSS of wanted and unwanted functions shall be uncovered. If the WSP and LSS of wanted and unwanted functions are not depending on each other meta rule 2 can be applied: unwanted WSP and LSS shall be removed.

If the WSP and LSS of wanted and unwanted functions are depending from each other meta rule 1, 3 and 4 shall be applied in order to abolish the interdependencies. Meta rule 4 “Changing the properties of the LSS” can be applied in order to transfer the metal into its cast (changing the property of aggregation state) by melting. Afterwards the unwanted function of the non-metal contamination can be removed.

**Principle Number 4: asymmetry**

“The symmetric form of an object shall be transferred into an asymmetric form”. If the object is already asymmetric, the degree of asymmetry shall be increased” [10].

Explanation: Symmetry can be understood with respect to symmetry of geometric features as well as in a figurative sense, e.g. the symmetric assignment of functions. The dim light of cars stronger illuminates the clipping of the drive lane than the middle of the street, in order to create a compromise between good illumination and blinding of oncoming traffic.

**Description of principle no.4 with C&CM**

“Change the alignment of WSP and LSS of a function in such a way, that they are arranged asymmetric“. There can be added WSP and LSS in order to realize asymmetry; there can be removed WSP and LSS in order to realize asymmetry. There can be changed the properties of the WSP and CSS in order to realize asymmetry.

In the case of the dim light of the car the two functions “illuminate drive lane” and “blinding the oncoming traffic” are fulfilled by the same WSP and CSS. Those are the WSP between headlamps and the light beam and the WSP between the light beam and the drive lane respectively the eyes of the driver in the oncoming car. The CSS is determined by the extension of the light beam in front of the car. Asymmetry is realized through focusing the beam on the WSP on the drive lane and minimizing the WSP on the eye of the oncoming driver as far as possible.

**5. Case study**

Figure 7 shows a device that was build for the objective of being able to quickly and easily adjust the tool carriage of the a turning lathe. The device consists of a lever and a screw (shown in fig. 8) that fixes the lever to the carriage.
Therefore the device fulfills several functions. In a functional state 1 (Figure 9) the “fixation of the carriage can be locked and unlocked”: the function is fulfilled through the WSP 1 between user and lever and WSP 2 between lever and screw. The “lever needs to be fixed and guided” through the WSP 2, 3 and 4.

A second functional state (Figure 10) is when the carriage is fixed (WSP 2 and WSP 5) and when the lever is not activated, when WSP 1 is not active. And also here the “lever needs to be fixed and guided” through the WSP 2, 3 and 4.

These two functional states allow the easy and quick adjustment of the carriage.

Problematic of this solution is that through the fulfilling of the function “lock and unlock the fixation (Figure 9, WSP1 and WSP 2) WSP 4 and WSP 3 are dissolving, so that the function “fix and guide lever” in both functional states lever is not fulfilled any more. Thus, the objective of the design process is not achieved any more.

In order to make the system fulfill the functions again the screw has to be fixed all the time. In case of emergency the turning process is interrupted and the work piece can be destroyed.
Searching for solutions with the TRIZ C&CM approach

Searching for a solution with the approach introduced in the sections before the problem is formulated as a contradiction based on WSP and LSS that are responsible for the fulfilling of the functions, in order to find a suitable innovative principle.

The function that is dissolved „fix and guide the lever“ gives a first hint onto a contradiction. The WSPs 2, 3 and 4 have to make sure that on the one side the lever is fixed, but on the other side have to grant space for motion in order to be able to “guide the lever”.

The cropping up problem is that the “stability of the object’s composition” (technical parameter no. 13) decreases with the dissolving of the WSP 4 and WSP 3.

Thus, the parameter that needs to be improved is “stability of the objects composition”. WSPs 2,3,4,5 are not being obtained. The parameter can be referred to the mode of action in these WSPs. These parameters represent the stability of composition of the object.

The loss of stability lies in the dissolving of the pressure in the WSP 4. Through WSP4 the movement of the lever is transfused into the screw and cause the breakup of WSP3 at the tread.
Thus, the contradiction can be localized to the WSP 4 between the head of the screw and the upside of the lever. Here the unwanted movement is transferred.

Improving the parameter no.13

According to TRIZ the approach must then be to improve the parameter no 13 in order to reestablish the stability. Obvious solutions for re-increasing the stability of the composition of the WSPs could e.g. gluing the WSP4 or welding the WSP4 or strongly attaching the screw. Yet, these solutions would change the “shape” of the WSP 4 in such a way that WSP 4 cannot guide the lever any more. The technical parameter no 12 is decreased.

Accessing the table of contradictions

Taking the contradiction of technical parameter no 13 (improving) and technical parameter no 12 (worsening) to the table of contradictions, beneath others the innovative principle no 4 (asymmetry) can be chosen.

The principle formulated with C&CM ends in “Change the alignment of WSP and LSS of a function in such a way, that they are arranged asymmetric”. As the WSP 4 is mainly responsible for the problem, the contradiction is formulated for this WSP 4 in order to apply the principles here.

Finding solutions through the table of contradictions

Meta rule 1 of the C&CM proceeding states that “WSP and CSS” can be added in order to solve the problem. Thus, there should be WSP and CSS added in order to find an asymmetric solution.

This leads to the solution shown in Figure 11, where WSP 6 is introduced. WSP 4 and WSP 6 are asymmetric in their geometric extension. The increased contact pressure in WSP 4 in contrast to WSP 6 leads to ductile deformation and causes different friction coefficients in WSP 4 and WSP 6, thus the screw will probably not join the motion of the lever.

Further, applying meta rule 3,”Changing the properties of the WSP” can lead to another solutions with “asymmetric friction coefficients in WSP 4. WSP 4 could be a teflon-steel WSP that prevents the transmission of the motion into the screw.

6. Summary and future work
Designers in industry projects complaining the too abstract level of searching for solutions with the TRIZ innovative principles, difficulties of students applying the method to concrete design tasks has led the authors to think about a way to make the innovative principles more easily accessible for newcomers. Designers in industry produce fantastic new ideas with the method, yet the transfer of these ideas into concrete solutions that can really be implemented are very rare. Also students produce promising ideas but mainly fail to transfers the ideas to their problem. Unfortunately this leads to a “method shock” that convinces mechanical design students that they are better off with a conventional way.

Yet, the paper and the research work represent only the beginning of making the innovative principles better accessible. Another paper in this conference describes the improvement of the accessibility through creating real touchable artifacts (TRIZ-box) for the innovative principles. Thus, the problematic shall be abolished through the generation of analogies.

These both approaches will be evaluated systematically in real design projects in order to improve them.

The application of the C&CM in several industry projects e.g. described in [1] and Error! Reference source not found. showed that relating abstract issues to the concrete objects of the design task through WSP and CSS is valuable way of improving product development. Thus, also the abstract issues of the innovative principles can be supported through the relation to a concrete WSP.

References

[1] Albers A., Alink T., Thau S., Matthiesen S., 2008, “Support of Design Engineering Activity through C&CM temporal decomposition of design problems”, Proceedings of the Tools and Methods for Competitive Engineering, TMCE, 21-25 April, Izmir, Turkey, 2008a.
[2] Albers A., Alink T., Matthiesen S., Thau S., 2008, “Support of System Analysis and Improvement in Industrial Design through C&CM”, Proceedings of the International Design Conference, DESIGN 2008, 19-23 May, Dubrovnik, Croatia, 2008.
[3] Hubka, V., 1973, „Theorie technischer Systeme: Grundlagen der wissenschaftlichen Konstruktionslehre“, Springer-Verlag, Berlin, Heidelberg, New York, ISBN 3-540-06122-3.
[4] Roth, K., 1982, „Konstruieren mit Konstruktionskatalogen, Systematisierung und zweckmäßige“ Aufbereitung technischer Sachverhalte für das methodische Konstruieren, Springer-Verlag, Berlin, Heidelberg, New York, ISBN 3-540-09815-1.
[5] Suh, N.P., 1990, “The Principles of Design”, Oxford University Press, New York, 1990. Pahl Beitz Engineering Design.
[6] Marz, J., 2005, „Mikrospezifischer Produktentwicklungs-prozess (μPEP) für werkzeuggebundene Mikro-techniken“, Dissertation, Forschungsberichte Institut für Produktentwicklung.
[7] Zobel, D., 2001, „Systematisches Erfinden – Methoden und Beispiele für den Praktiker“, Expert-Verlag, Renningen, 2001, ISBN 3-8169-1959-6.
[8] Herb, R., Terninko, J., Zusman, A., Zlotin, B., 2000, „TRIZ Der Weg zum konkurrenzlosen Erfolgsprodukt“, Verlag Moderne Industrie, Landsberg / Lech, 2000, ISBN 3-478-91920-7.
[9] WOIS Linde, H., Hill, B., 1993, „Erfolgreich erfinden. Widerspruchsorientierte Innovationsstrategien für Entwickler und Konstruktore“ Hoppenstedt Technik Tabellen Verlag, Darmstadt, 1993, ISBN 3-87807-174-4.
[10] Orloff, M., 2002, Grundlagen der klassischen TRIZ, Springer-Verlag, Berlin, Heidelberg, New York, ISBN 3-540-66869-1.
[11] Albers, A., Ohmer, M., Eckert, C., 2004, “Engineering in a different way: A cognitive perspective on the contact and channel model approach”; In: Third international Conference on Visual and Spatial Reasoning in Design, MIT Cambridge; USA.
[12] Matthiesen, S., 2002, Ein Beitrag zur Basisdefinition des Elementmodells „Wirkflächenpaare und Leiststützstrukturen“ zum Zusammenhang von Funktion und Gestalt Technischer Systeme, Dissertation, Institut für Maschinenkonstruktionslehre und Kraftfahrzeugbau, Universität Karlsruhe (TH), Karlsruhe, ISSN 1615-8113.
[13] VDI-Richtlinie 2221, 1993, „Methodik zum Entwickeln und Konstruieren technischer Produkte“, Beuth-Verlag, Berlin.

[14] Pahl, G., Beitz, W., Feldhusen, J., Grote, K.-H., 2007, Pahl/Beitz Konstruktionslehre, Springer-Verlag, Berlin, Heidelberg, New York, ISBN 978-3-540-34060-7.