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SUPPORT OF SYSTEM ANALYSES AND IMPROVEMENT IN INDUSTRIAL DESIGN TROUGH THE CONTACT & CHANNEL MODEL

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1. Introduction

Due to the increasing international competition, product development, production, assembly and vending supply are getting faster and more customer oriented. At the same time, lower prices for products are achievable. Thus, pressure on companies is growing so that they are forced to develop products fulfilling more and stricter requirements, perform better and on the other side minimize the effort of maintenance for the customer. Time for testing and validation of prototypes is getting shorter and the outcome is often inchoate. This leads to a higher amount of product recalls, e.g. occurring frequently in automobile industry. The second big task for design engineers is the improvement and cost-reduction of successful products to stay competitive in fast changing markets. In this case a target oriented analysis of the products is necessary for an efficient improvement in cost and function. One answer for these problems is a more consequent analysis of technical systems in order to avoid costs, caused by recalls or inefficient modifications of products before new solutions that are based on an insufficient understanding are implemented.

A large variety of tools and methods have been developed (e.g. QFD, CAD, FMEA and DOE) to improve and secure new roll outs. The Contact and Channel Model (C&CM) is basis for a method supporting designing engineers in their ability to solve technical problem more effectively. In this paper the C&CM is presented in a direct industrial environment. A project in which a procedure that enforced the C&CM-based modelling is applied in order to improve existing products. A special focus is set on the analysis of product failure.

2. Contact and Channel Model C&CM

Product development is searching and finding of solutions for complex technical problems. The procedure proposed in this paper is lined up to the SPALTEN problem solving approach [Albers, 2007]. For a successful solution of the problem the problem itself must be understood and comprehended as clear as possible. Thus, basis to successfully find and select solutions, which have the potential to innovate, is thorough situation analysis and problem containment. These two steps serve to found and reason the appointed solution. In addition, a reliable problem representation through an adequate model is essential for the problem solving process. Building models, internal (mental) and external (e.g. CAD or sketching), is a vital means for engineers to reduce the complexity of design problems. Models provide the intrinsic information necessary for the solution of the problem and omit the information dispensable. The act of building up the right model of the problem is thus essential for design engineering, because the way engineers formulate their problem (in a model) strongly determines how they search for solutions [Eckert, 2004]. Using the Contact and Channel

Model (C&CM) supports the internal and external problem modelling. The C&CM is a means to describe the problem on any level of abstraction in any level of detail in order to provide a representation of the product as the problem situation requires. Through a clear set of model building blocks, a free and dynamic modelling provides a language to argue systematically about design problems. Regardless whether designers want to generate a new solution for a component, make major modification to a component or change a very small detail, they can approach the problem in the same way and apply the same thinking steps.

2.1 Basis Principles

The C&CM approach relates technical functions and the shape in one model. This is achieved through the localisation of functions on the shape in at least two Working Surface Pairs (WSP) and a connecting Channel and Support Structures (CSS). Every function is situated in the physically existing product and every product has associated functions. The approach links abstract functions to concrete geometry, allowing designers to generate, modify or evaluate design in a very integrated way. The C&CM approach can be used in conjunction with existing product models when designers need to come up with a new idea or analyze the function of existing parts of the product. 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 any level of detail. Afterwards, the solution can be reintegrated and the effects of the changes on the entire system can be checked.

In the core of the C&CM there is a systematic function-component mapping [Matthiesen, 2002] that locates the functions on the components and thus makes functions visible. It provides a product model by means of Working Surface Pairs (WSP) and Channel and Support Structures (CSS) which are clearly defined on the abstract level of functions as well as on the concrete level of components. The key idea of this approach is that a function of any technical system can only be fulfilled through interaction with adjacent systems in terms of action = reaction (Basic Hypothesis I). Thus, an effect can only be obtained if a Working Surface (WS) is in contact with another WS and thereby creates a WSP. If this idea is systematized it becomes clear that a technical function requires a further WSP and a structure (CSS) that connects both WSP (Basic Hypothesis II). A technical function is defined in terms of the input- output relation of energy, material and information [Matthiesen, 2002]. A whole system is completely describable through a structure of WSP and CSS (Basic Hypothesis III), i.e. can be described with always the same elements on every level of detail. The functions are determined by the properties of the WSP and CSS.

2.2 Target orientated analysis – C&CM Compendium

Building up models is the only means by which humans can act and interact with their environment. As we are not able to catch the complexity of the world, we produce simplified pictures of our world and relate these to the perspectives and organisations, which structure our life [Stachowiak, 1973]. Models in product development representing the objects of the product development process are always generated relatively to the problem at hand. Different viewpoints of different people generate different problem representations. Based on the knowledge about certain areas of expertise, the issue becomes more complicated when enterprises make use of the knowledge of experts coming form different disciplines in engineering. In the authors' understanding, an applicable support for the designer must respect the individual successful problem solving strategies [Bender, 2004 and Lossack 2004]. But the designer must be able to argue about problem and solution in order to generate transparency his/her team mates or boss. Many methods fail under real working conditions, because they are too far away from the practical issues designers are dealing with.

Methods often suggest representing and analysing the whole complexity of a system. That is impossible, since the way a system is recognised is already subjective and any system can arbitrarily be particularised (section 2.1). Thus, a target orientated method is required, which allows the handling of design problems as they come along.

The C&CM is a way to reduce the complexity of a technical system while not neglecting the complexity of the problem, Using WSP and LSS to build up the model, a structural decomposition and documentation of the problem is generated. The C&CM connects the concrete world of geometries with the abstract world of functions and therewith provides a language for engineers to communicate

and work together on the same task, without losing context, the important tasks and the goal. The current research focuses on the transition of the model C&CM into a method.
Therefore ways in which engineers use the model are observed systematically. Based on the evaluation of the case studies, conclusions of successful strategies, which support the target oriented and efficient way of solving problems as well as ineffective applications are drawn. The conclusions are transferred into a compendium for the use of the C&CM. Ultimate goal is to find a set of rules or heuristics, making the use of the C&CM more easily applicable and learnable.
The following compendium was developed in order to enable people with few method experience and C&CM knowledge to work with the C&CM. All rules were created out of experience with using the C&CM tool in problem facing tasks, as appearing in industrial projects (e.g. the below described project with the Hilti AG). The summary of the experience of working with the compendium led to the up to now four rules, which do not prescribe a strict succession – theses rules describe successful strategies and can be recalled whenever necessary:

2.2.1 Definition of the relevant part of the system and its borders

The examination of a system can be conducted top-down or bottom up. In any case the system boundary can be drawn as the problem focus requires it. It is necessary to determine the part of the system, which is assumed to be the relevant part for the main function accomplishment which needs to be improved or corrected.

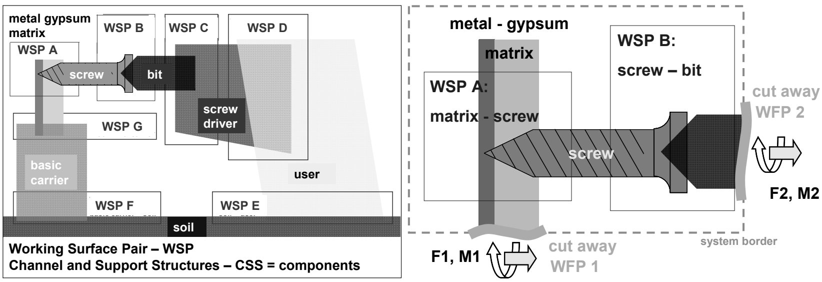

Figure 1. System Borders for the Screw Fastening Technology at Hilti

The examined main function is determined by the problem in hand. Thus, the relevant part of the systems is cut out, but still related to the surrounding systems through the WSP at the system boundary. It is recommended to perform the cut out through the material of the technical bodies (Channel and Support Structures - CSS), in order to avoid losing relevant information at the WSP. Such a cut out is shown in figure 1- right and can be conducted like a free cut in technical mechanics for the determination of inner forces. At the WSP at the cut out all influences of the surrounding are getting considered, but at the same time decisions must be made to disregard unimportant influences in order to keep the model as simple as necessary. The determination of the relevant part of the system and its border is not static and must be kept modifiable during the whole problem solving process. Thus, a higher level of detail can be necessary as well as the enhancement of the system border. Indicators for the right strategy would be the following: if inexplicable phenomena occur, a higher level of detail is advisable. But if the problem can not be solved within the system border, it might be adequate to explore influences from outside the system boundary. Exploration of influences from outside the regarded system thus means to enlarge the system border i.e. including other elements. System borders do exist in all levels of detail. There can be several system borders in one system, which also can overlap, i.e. one system can be a part of a bigger system or the upper system of many smaller and more detailed systems. It is important, that there are a minimum of 2 WSP and one CSS in each mode, conditioned by the minimum set for a function accomplishment (Basic Hypothesis II). In the example shown in figure 1, the task of the project at the Hilti AG Liechtenstein was, to improve drywall screws used for fixing gypsum boards on metal rails with high velocity and high reliability. The first step was building up the hole screwing system as shown in figure 1-left, in order to have an overview of all appearing and interacting parts of the system – with all WSP and indirect influences over the CSS. Due to the task to improve the penetration process in velocity and reliability and the design restricted parts like user, screw gun and underground, the screw itself was assumed to be the relevant part of the system. Having the screw as the main analysis object, the adjoined parts of the screw were considered as important as the screw itself: the bit and the metal gypsum matrix, including the WSP to these parts (see figure 1-right). Thus, the first relevant part, thus the system, has two WSP (WSP A matrix – screw and WSP B screw – bit, shown in figure 1) and three CSS (matrix, screw and bit). With the WSP cut through the matrix (WSP1) and the through the bit (WSP2), the bordering was performed.

2.2.2 Determining the locations of special interest for function accomplishment

Analysing the technical system within the previously drawn system border should start at the (assumed) most important point, normally a WSP (e.g. the WSP at the tip shown in figure 2).

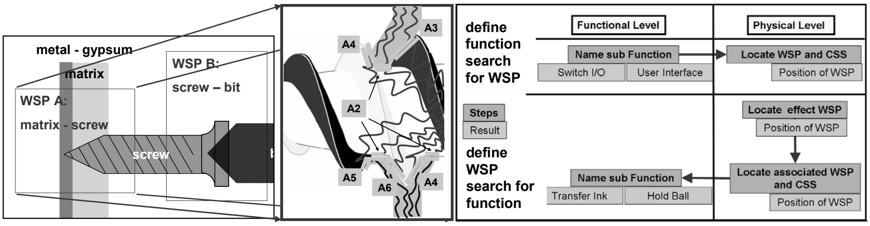

Figure 2. Place of special interest

The concentration on one single WSP is possible, when minimum a second WSP (WSP B in figure 2-left) is connected with the focused WSP A. For the time of a deep analysis of WSP A, the related WSP B is unattended, but remains connected. Thus, complexity is reduced, but not neglected. The location (WSPA) is set as the starting point for the analysis. It is recommended to start with *zooming in* this WSP (like shown in figure 2-left, red frame). Regarded in a higher lever of detail (basic hypothesis III) every macro WSP is built up by many micro WSP (WSP A can be split up into WSP A1, A2…). The goal of the analysis is to determine all relevant WSP and their interactions for the functions occurring at this place. This approach of *zooming in* must be repeated, until all operations at this point can be explained for the problem in hand.

At the screw project at Hilti, the *zooming in* at the WSP A (figure 2-left) showed that there are many WSP, which all contribute to different functions. In the first step the WSP for known functions were detected and in a second step also unknown functions were determined by exploring the found WSP.

Due to these method approach observations, two different strategies to detect WSP and functions were derived (figure 2-right):

- Starting from the form, what means to determine all occurring WSP and then explaining, what functions they fulfil and how they are related
- Starting from the known functions, what means to build up an function structure an then search for the locations the functions get fulfilled, i.e. determining the WSP and CSS

Both strategies describe possible ways in the model elicitation process. They can be used in any level of detail: there is no prioritisation of a strategy, but the two strategies are basic for the previously described rule of determining the system boundary and the following rule of comb approach.

2.2.3 Comb approach – adapted zoom

The previous section explained the procedure of determining sets of WSP, CSS and their function. With the rule of the system boundary and thus the determination of the C&CM elements for a certain function, the basic hypothesis II reminds that there is at least one more location determining the accomplishment of the regarded function. In the case of the screw project any issue at the tip (figure 3: place 2) seemed to be explained clearly, but still certain screws did not behave as the analysis predicted. As the intrusion behaviour of the screw is also determined by the WSP B recess – bit (figure

3, place 3) the designers of the project concentrated on the second WSP and the CSS of the main function within this system border. *Adapting the zoom* at WSP B delivered the answer to the questions, which came up with the analysis of WSP A and which could not be answered logically.

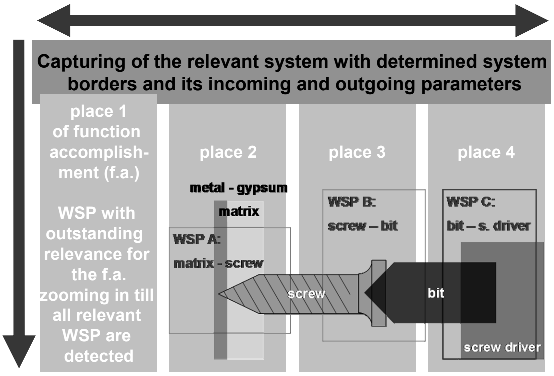

Figure 3. Comb Approach

The model can be dynamically adjusted in its degree of detail relative to the design problem in hand. During the detailed examination of the tip of the screw (WSP A in figure 2 and in figure 3, place 2) it became clear, that further influences can occur and must be considered (more than from WSP B). If e.g. the user improperly holds the screw gun, an intrusion failure might also be a caused. Thus, the modelling with WSP and CSS displays these systemic influences and give support in determining them. Experience recorded in the projects had shown that very often in these situations designers get trapped in focusing on details. The C&CM structure gives an aid to jump out of the fixated tracks by reminding on the functional interactions. For a complete capture of the problem it is required to analyse more than just one place of function accomplishment. This has a reason in the 2nd basic hypothesis which requests at least two WSP and a connecting CSS of a function accomplishment. Thus, every WSP and CSS within the system border can be a place of interest. If the problem requires it is recommended to zoom in all places of interest, which seem to be important. Then *zooming in* is to defining a sequence (see in the following section) or setting a new system border. The approach of *zooming in* at one place, *zooming out* and *switching to the next place* in order to determine more WSP and functions is called "Comb Approach". In the case the results are still not satisfying, even the system border can be enlarged (e.g. if the screw project will be extended onto the screw gun). In general the C&CM model can be applied on different levels of detail in always the same way (fractal character of the C&CM) so the same type of mental model can be applied at different levels of hierarchy.

2.2.4 Sequence model for dynamic operating systems

The following section introduces the part of the compendium for building up a model of dynamic events of technical systems: the "Sequenced Product Model", which allows temporally decomposition of design problems. The effective way to reduce the complexity with splitting up the design problem into smaller bits and pieces, is being used on the one side for function and form (as described in the previous chapters) and on the other side (in the same manner on every level of detail) for time. The temporal decomposing of the problem through the definition of sequences, in which only a certain set of WSP and CSS are regarded, additionally provides a support to manage complexity of design problems.

Sequences of states are determined by the operational mode of the product. Within each state several functions can be fulfilled in parallel. When one of the functions within a state breaks up through the dissolving of a WSP or a further function occurs through the forming of WSP, the subsequent state starts. A set of minimum two states then forms a sequence. A sequence is then a defined succession of states which is performed always in the same way. WSP and CSS can occur in several states. Since the technical functions are always based on minimum two WSP and one CSS, functions can also be fulfilled in different states and sequences, if they share WSP and/ or CSS. New states base on the addition, subtraction or variation of minimum one WSP, thus minimum one function less or an additional function emerges in a new state. The working operation of the whole technical systems is based on minimum one sequence, other sequences can be considered if the complexity of the problems requires so. Sequences can be repeated and take place in the same moment. This means the same chronology of states is performed in the same way. A sequence is fixed to a certain foregoing drawn system boundary. Of course sequences influence each other through an incidence occurring inside or outside the drawn system boundary (figure 4-left). The influences can excite a pause, a stop or the new start of an influenced sequence. Thus, with the sequencing of the operational modes of a product, the intended functions or the behaviour of the system in the case of malfunction or error situations can be modelled.

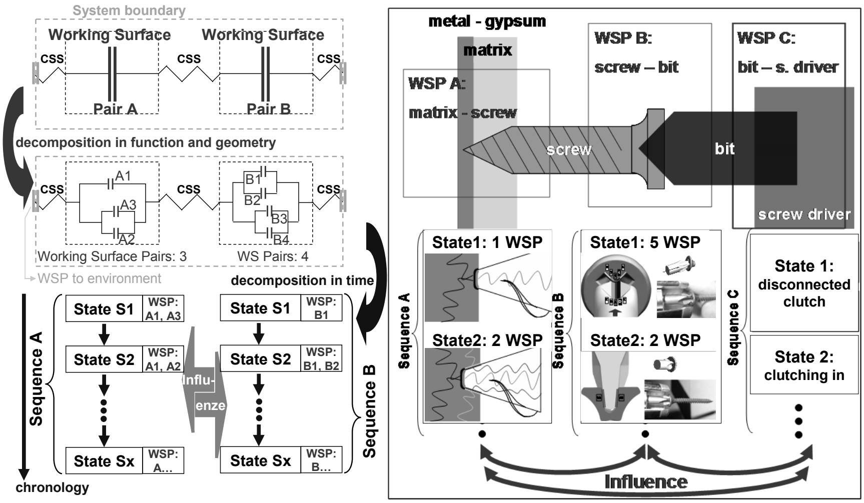

Figure 4. Temporal decomposition

In both cases the states building the sequence help to define the temporal succession of the functions, thus trace the impact for the whole system. E.g. screws were claimed to fail due to dull tips. But the analysis with the temporal decomposition showed clearly, that the screws failed at a time, where the tip had no influence, since the tips have already been broken through the metal.

Every place of interest and respectively function accomplishment can change its amount of operating WSP over a period of time with several states. It is recommended to build up a sequence for each dynamic system. In the screw case, 6 states were determined for the WSP A (figure 4-right, sequence A). After building up the relevant model at WSP A with all WSP and the sequence, the second analysis followed at WSP B (figure 4, sequence B). So zooming in at WSP A also meant building up a model with a sequence before switching over to the next place of interest. Tracking the sequences with their states for all relevant places (comb approach) in order to combine all sequences and states to each other within the system (e.g. figure 4: place 3) is immense important to reach a system understanding. Out of that approach the connections between the functions and the WSP become visible and understandable. The comb approach is conducted until the model is build up to the point, where the analysis results satisfy for solving the problem: e.g. to clarify the failure mode, the working process of the system or the elements or a cost reduction.

3. Conclusion

With the decomposition of a design problem in time, the last part of the compendium is given which supports the model building process for the detection, reasoning about and structured containment of design problems. A thoroughly boarded search for solutions is prepared. It becomes visible, which part in what moment is fulfilling which functions – positive and negative ones. So the C&CM is supporting in clearly dividing between source and effects of problems. Furthermore the systematic way of modelling will produce new ideas for the evolution of the product and builds the basis for decision-making in the following selection of solutions, when required.

4. Industrial Examples

The following section describes the application of the C&CM as the basis for typical design tasks determining the all day work of designers. These problem solving processes are often unstructured and chaotic, because at a first sight the problem seems to be obvious so that the solution can be found easily. In the end an obviously easy to handle design problem can cause huge difficulties and cost a lot of time and money.

4.1 Screw Development Technology - Hilti AG, Liechtenstein

Industrial construction is a big business for screw selling companies. Most of the industrial buildings have a roof made out of profile metal sheets. These metal sheets are getting connected by screwing along their edges (lapping).

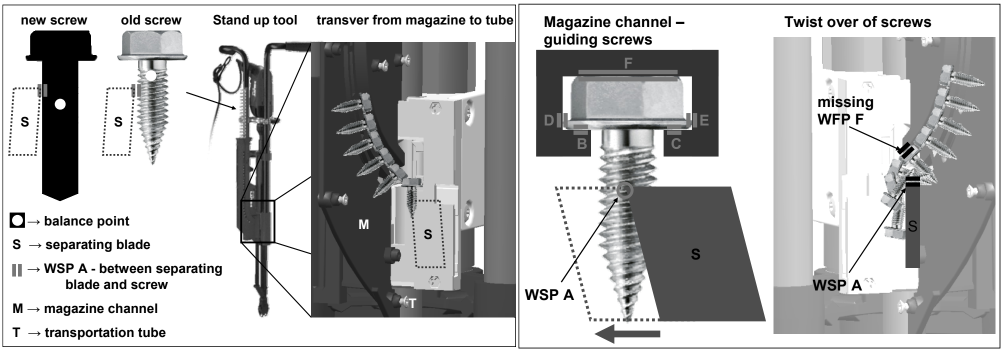

Figure 5. Twisting screw in stand-up-tool

Therefore a stand-up-tool of Hilti (figure 5) can be used, wherein screws are getting reloaded automatically with every up and down movement. In the run of the evolution project of the stand-up-tool the problem occurred that new screws twisted when falling from the screw magazine into the transport tube of the stand-up-tool (figure 5). Five days were given to find and proof a solution, since it was planed to use the stand up tool for the presentation of the new screws.
So about every 10th screw was laying up side down (figure 5 – right hand side) and caused a failure in the screwing system. The first analysis was made by an engineer observing and taking the system apart. Since the tool used to work with the old screw, the focus of the engineer was on the new consumable. He found out that the new screw had a different balance between body and head: the head is relatively heavier ("balance point" in figure 5) - he assumed that this was the reason for the failure. The screws are getting separated by a sideward moving piece of metal blade that touches the screw right in the middle, below the balance point of the new screws ("S" in figure 5). So the upper part with the head, which lies over the point where the separation blade touches the screws (WSP A), is heavier than the lower part. Being separated at this point it was assumed, that the new screw flips over due to the disproportion of the weight. Also tests by hand showed, that the dislocation caused the flip over. The solution implemented was a modified blade, which touches the screws at the head, what means that production tools had to be changed. Testing the new solution on the 3rd of 5 days, the prototypes showed that even with the new separation tool new screws were still flipping over and hanging up side down in the tube. So the solution did not work.

At this time the point was reached, where the engineer was willing to use the C&CM model, since time was short and a reliable solution had to be found in time. The analysis of the whole system using the four rules of the C&CM compendium for a thorough problem containment showed, that there was not just a difference in the CSS of the screws (the changed balance point), but also one WSP was missing in the system with the new screws. The difference in the two ways to find the reason for the failure was the consequent search for all occurring WSP, CSS and their functions, combined with an adequate temporal decomposition. Not until the analysis of the system and its WSP and CSS the information was found, that the point of time the failure occurs is, when the screws fall from the magazine channel (“M” in figure 5) to the transportation tube (“T” in figure 5). Due to this approach, which used the same analyse techniques as before (e.g. observing and taking the system apart), it was detected, that the screws flip over when falling into the tube and in comparison to the system with the old screws one guiding WSP (A) was missing. This lack of a WSP and thus a function made the screws twisting to up side down while falling from the magazine into the transportation tube. The screw did not flip over due to the separating blade, even though the chance of the balance point facilitated the flip over. It was WSP A between the upper side of the screw – head and the magazine as shown in figure 5. This missing WSP caused by the minimal lowering of the head of the new screws enables the screws to fall front side down as shown in figure 5. The whole problem was granted by the changed balance, but caused by the missing WSP. After the problem was clearly argued the solution was quite simple. The screw holding device and the screw leading part of the magazine were merged together more closely, so screws have no chance to twist, because they are now being guided by all WSP of the magazine channel (WSP A, B, C, D, E and F) into the transportation tube. This solution costs a small metal ring and is reliable.

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