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USABILITY IN INDUSTRY OF METHODS FROM DESIGN RESEARCH

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Abstract

Researchers in the engineering design domain have raised the question of why engineering design methods are poorly used in industry. This work investigates, instead, which methods have been accepted and are used in industry. Some significant attributes of methods used in industry have been found and are presented.

Keywords: empirical study, case study, introduction of methods, barriers to implementation

1 Introduction

Engineering design is a relatively young research field. Its aim is to find ways to support industrial companies in product development. As expressed by Blessing, Chakrabarti and Wallace: "*The aim of engineering design research is to support industry by developing knowledge, methods and tools which can improve the chances of producing a successful product*." [1].

Many methods and also tools have been developed within the area of engineering design for improvement of different parts of the design process in order to make more successful products. There are methods for creating and exploring new, potential designs/solutions (divergent methods) and methods for supporting decision making (convergent methods). As systems and products are becoming increasingly advanced and complex, academia expects industry to adopt progressively the methods developed through research in the engineering design field. However, this has not happened to the desired extent. Suh has stated "*…the effects on industrial practice and education is far less than expected*"[2] and Birkhofer, Lindemann, Albers and Meier have observed "*Most results end up in scientific publications rather than being transferred into practise*"[3]. López-Mesa has found through interview studies that "*the number of methods used in industry is relatively small*" [4].

Several researchers have sought an answer to why methods developed within engineering design are used so limitedly by industry. One of the most commonly found factors is that the environment in which the "academic" methods are developed and tested is different from the industrial environment in which they should be used. Blessing found that "*Many of the researchers seem to work in 'isolation', not investigating actual industrial needs.*" [5] and Stempfle and Badke-Schaub remarked "*Theory-building and research conducted under the normative strain has often neglected to look at what people actually do – simply prescribing a methodology may not meet the needs of designer 'out there'.*"[6].

In this paper, the needs of companies and its practitioners are the core from which the prohibiting and contributory factors of methods transfer are explored. In order to successfully implement methods in industry two barriers must be overcome: (i) methods acceptance, and (ii) successful use of methods. Methods acceptance means, here, that industry has to get interested in using a method. That happens when either management or engineers, or both, decide that a method should be tried in product development because they believe that its use will benefit company performance. Successful use of method means, here, that a company perceives a strong contribution of a method to product quality or reduced project lead-time. The distinction between method acceptance and successful use of method is made because there are methods that do not overcome either of the barriers, methods that overcome only the first, and methods that overcome both. Only the methods that overcome both barriers become permanently used and can be regarded as transferred from academia into industry. The distinction is also important because academics tend to lose motivation when a method gets accepted. Traditionally the first stage, 'methods acceptance' has been a responsibility of both academics and consultants, whereas the second, 'successful use of methods', has been exclusively considered a consultant's job. However, the unsuccessful transfer of methods calls for academia's attention to the issue. The research undertaken in this paper focuses on the contributory and prohibiting factors of acceptance of methods in industry, and the contributory and prohibiting factors of successful use of methods.

2 Methodology

All engineering design research (EDR) is by definition industry related [1]. This study concentrates on the actual use of methods in industry. All three researchers are located full-time at Volvo Car Corporation (VCC) and supervised by their universities. This possibility of observing industry from the inside has the potential of giving valuable input to research on a daily basis. In order to use and structure the research in an industrial environment, a research methodology is needed [5]. The methodology has to support and guide the research with respect to current theories in EDR and data gathering.

This paper reports a single case study of descriptive character [7]. The findings have been developed with an abductive approach, meaning that a combination of deductive research [8], i.e., going from a theory towards an explanation by logical reasoning, and inductive research [9], i.e., going from empirical observations towards formulating an explanatory theory has been used. The abductive approach is a continuous interplay between empirical investigation and study of theory. The theory guides and orients the empirical investigation, and the empirical observations guide the choice of theoretical framework. Dubois and Gadde emphasise *"This stems from the fact that theory cannot be understood without empirical observation and vice versa* " [8]. This abductive process goes under the name of systematic combining.

One could argue that the main objective of all research is in fact to compare developed theories with the real world. With the abductive approach, of systematic combining, this comparison process is accentuated continuously during the research. The continuous revision of the theoretical framework together with the revision of where to search and how to include the empirical data makes this approach fruitful when the research condition is not static, but changes during the study as in an industrial situation. The approach leads to an abundance of material and it is important to single out what is not central before presenting the final result. By no means should data be singled out in a biased way so that the findings are altered. But as Wieck [10] argues, *"many pseudo observers seem bent on describing everything and therefore describes nothing*". It is claimed by Yin [7] that the softer a research strategy is the harder it is to conduct. Soft would mean, here, something in opposition to a research strategy relying on quantitative, inactive [8] data taken from controlled experiments in a laboratory environment, treated mathematically. We believe that the benefits of using a research strategy permitting a wide range of data sources, including qualitative data, are greater than the risks.

The focus in the present study lies in understanding why some methods and related tools are sparsely used whereas others are used extensively in industry. This calls for a research approach able to bring out the mechanism that causes some methods and tools to be used and others not. The methods and tools originate both from academia and industry and can be found in different format [11], as a system of information, as structured knowledge and as an instrument in use. This multitude of theory and information sources calls for the abductive systematic combining approach to case studies.

2.1 Definition of methods and tools

Many definitions of what a method is and what a tool is have been reported. Hubka alone has given at least three (though similar) definitions of methods (1980, 1983 and 1987). See [11] for an extensive list of definitions. In this work a view is used stressing the difference between methods and tools, compatible with the views of Jones *"Methods are attempts to make public the hitherto private thinking of designers: to externalise the design process."* [12] and Hubka *"Methods are systems of methodological rules that determine classes of possible procedures and actions that are likely to lead on a planned path to the accomplishment of a desired aim."* [13]. For tools the view of Hurst is used. *"A design tool is an implement that you employ to facilitate the use of a method or an aid to the use of a method."* [11].

2.2 Data collection

The theoretical framework chosen to guide the data collection about the product development tools and methods is the Process-oriented Method Model, (PoMM) developed by Birkhoffer Kloberdanz, Berger and Sauer [14], see Figure 1. Engineers were asked about the inputs used for the methods, and outputs given and expected. They were also asked about other issues concerning users, working aids and general conditions, as illustrated in Figure 1.

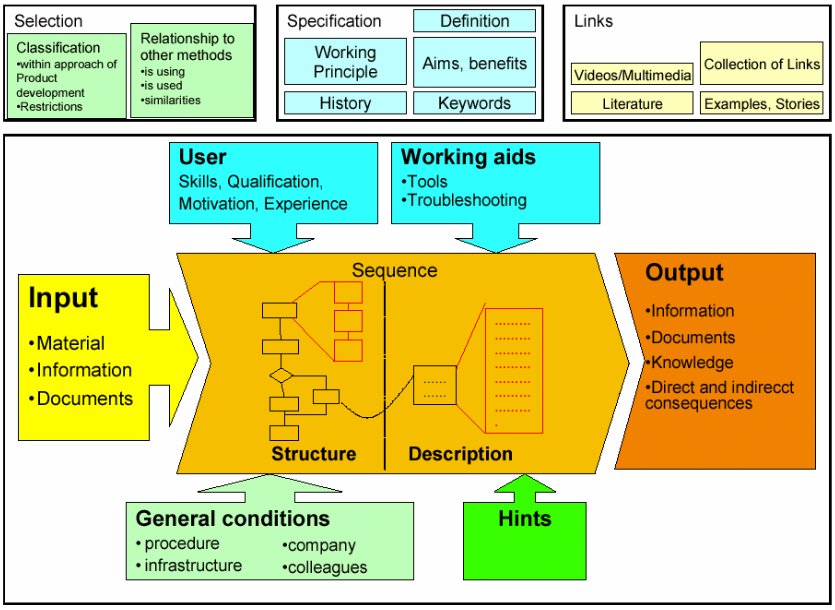

Figure1. Process-oriented Method Model (PoMM), by Birkhoffer et al.

The strategy chosen for the gathering of empirical data is guided by the notion of multiple sources of evidence [7], stating that a case study using various sources of evidence is more bound to be trustworthy than a study relying on one source only. The aim of multiple sources of evidence is not, as in quantitative research, to get a basis for statistical analysis but to get complementary views from different angles. These complementary views can be used for triangulation, e.g. if different sources point towards the same direction more confidence is gained. This has been achieved by using several informants from four different departments in VCC. The departments have different ways of working: the engine department and body department develop most of their designs from scratch, while the chassis department often uses suppliers both for development and production. The business strategy department decides what the other departments should design.

Dubois and Gadde [8] argue that two kinds of data exist, passive and active. The passive is the data that the researcher comes across when actively searching for data, e.g. by focused interviews. Unanticipated data that the researcher comes across when being an observer or overhearing a discussion is called active data. The active or unanticipated data coming from situations beyond the control of the researcher can give new insights that the researcher would not find if only relying on pre-formulated questions based upon the theoretical framework used in an interview context. Nevertheless, according to the systematic combining approach, active data can trigger a redirection of the choice of theoretical framework and the active search for (passive) data. In short, passive data is obtained with active searching and active data with passive searching. Our empirical investigation is accordingly based on multiple source of evidence in the form of observations, interviews (informant) and document search.

Their presence in the product development process at VCC for three years has provided the authors with active data both from planned observations on meetings and from informal "hang around" [15] within the development process. By using informants active in the everyday development process, the authors have been able to get insights into the development process from the view of skilled practitioners. When possible, records resulting from methods used have also been gathered and analysed.

3 Results

The results are given in two sections: the first, 3.1, addresses the factors that prohibit and facilitate acceptance of methods in industry and the second, 3.2, addresses the factors that prohibit and facilitate the successful use of methods.

3.1 Acceptance of methods in industry

In order to decide to undertake any kind of project three basic parameters are commonly considered: (i) the return on investments in that project, (ii) the risks assumed undertaking it, and (iii) the degree of certainty of the project usefulness. Such parameters have been used to study the factors that prohibit the acceptance of methods in industry. An analysis of how those factors are regarded by academics and by practitioners in industry has been undertaken with the aim of discovering why industry ignores academic design methodology to a large extent.

3.1.1 Return on investments

In order for industry to accept a method the value it adds must be worth its cost. Industry commonly measures the value in terms of reduced lead-time, avoidance of re-design, robustness, "hit rate" and increase in product knowledge. The cost includes purchasing cost, maintenance cost, training of the staff and, importantly, the amount of pre-work that a method needs as input. Methods that require abundant pre-work, which brings about costs for the company, should accordingly deliver high value. Many methods fail in use since they require input that does not exist and is impossible to produce. This was the case, for instance, with Quality Function Deployment (QFD). It was employed at VCC with much attention to detail requiring cross-disciplinary groups that had to gather abundant amounts of information. The perceived result was simple project specifications that were clear at the outset but which were highly susceptible to change during the design process. It is important that methods are developed according to the needs of industry to prevent this kind of mismatch with industrial conditions.

In contrast, academics tend to show greater trust in methods than practitioners do. Academics tend to believe that a method with a high potential provides a high value without considering the cost side of profitability. The lack of understanding of the costs of implementing methods from academia is an important prohibiting factor of methods acceptance.

3.1.2 Risk

An important parameter that a company looks at when considering to accept a new way of working is obviously the risk involved in adopting it. For instance, a risk exists that a tool never provides the value expected. This would result in bad solutions, re-design and eventually waste of time. Another risk assumed is that initially the tool does not provide as much value as it has the potential to do because the practitioners do not have experience with it. A failure situation with regards to these two kinds of risk has a great repercussion on the resulting products and lead-time, and therefore in the success of the product in the market.

The size of the implementation required for a method determines to a great extent the scope of risk. When a method requires the whole company to be involved in its use, e.g. Six-sigma, management assumes the responsibility of accepting the method. Even though management is not fully familiar with design methods, they have to be able to estimate the risk of implementing them. If information is not provided to do this estimation, they are often reluctant to introduce new methods. This is a prohibiting factor for the methods that require a top-down implementation in the organisation and that cannot be introduce step-by-step by engineers, and also for methods requiring heavy investments.

3.1.3 Degree of certainty of method usefulness

Academia is traditionally content with small examples that prove the value of a method. A method from academia that shows usefulness in small-scale examples can, by the shear effect of scale, be useless in an industrial situation. For instance, in the case of the prioritisation matrix, authors tend to include between 5-10 criteria to prioritise, but in the VCC chassis department the number of criteria can be up to around 100. Using a prioritisation matrix with five criteria engineers have to make ten value judgements, while a prioritisation matrix of thirty criteria requires over four hundred value judgments.

For this reason, practitioners are becoming more reluctant to use methods tested by small samples; success stories that ensure that methods work in real product development are important and preferable. In order for success stories to become reality, some company must be the first one to accept and try a method. So another prohibiting factor for the acceptance of methods in industry may be the low-risk attitude of companies, especially for methods that require heavy investments. On the other hand, people in industry are extremely sceptical regarding methods that do not have support tools. For instance, the method called "Seven Management Tools" (7MT) is promoted on the VCC intranet. It is composed of seven different design methods that are described on the intranet but not supported by any specific software tool. The result is that most engineers and managers are not even aware of the existence of this VCC "official" way of working. Tool support is regarded as crucial in industry [16, 17, 18]. It seems that this is building a gap between the academic development of methods and their industrial use. In academia it is the principle of the method that is interesting while in industry it is the application of it, and if this is not supported industry often disregards the method. This reluctance from academia to pursue its research until a working tool, or at least a demonstrator, able to really show the potential has to be questioned, together with the little amount of credit given to researchers that do finalise their methods by making tools.

It is usual that working methods of high value to companies are kept confidential to avoid other companies copying them. Academia often ignores this and may therefore be ignoring the industrial methods that are in fact more sophisticated than realised, even if they do not have specific names. A prohibiting factor is that the unawareness in academia of the existence of valuable ways of working in industry prevents them from developing methods that suit existing well-working processes. It has for instance been revealed by an informant that academia prefers linear processes while most real development situations need a lot of iteration.

3.2 Use of methods in industry

The use of methods was investigated with the PoMM method developed by Birkhoffer Kloberdanz, Berger and Sauer [14]. The methods have all been accepted at VCC and are presented in Table 1 but not all of them have been successful in use. A distinction is made between methods "used" and methods "seldom used". The methods labelled seldom used, are not officially sanctioned by the company and not used on a daily basis, but occasionally used by engineers. The way of using the methods at VCC has been compared with the use that academia prescribes. This shows whether the methods are used as intended by academia or used differently.

Table 1. Methods used at VCC

Method	Used	Seldom Used	Applied as described	Differently applied	Tool Support
Finite Element Method, FEM	●		●		●
Failure Mode Effect Analysis, FMEA	●		●		
Computer Aided Design, CAD	●		●		●
Brainstorming	●			●	
Pugh evaluation		●		●	
Paired comparison		●		●	
Brain writing	●		●		
Axiomatic design		●	●		
Multi Body Dynamics	●		●		●
Controls simulation	●		●		●

As the table shows, the use of methods at VCC is heterogeneous. Some of the parameters above, together with a supplementary one, serve as a basis for further analysis and discussion: (i) intensity of use; (ii) way of application and (iii); the method should fit well into the company’s modus operandi.

3.2.1 Intensity of use

The most extensively used methods are the Finite Element Method (FEM) and Computer Aided Design (CAD); they are used on a daily basis and are virtually irreplaceable. The use of FEM reflects the use of CAD: extensive use is concentrated to the late phases to minimise the need of expensive complete vehicle testing. The Multi-Body Dynamics (MBD) method is also extensively used to simulate chassis behaviour and Controls' Simulation (CS) to simulate active systems. All the methods mentioned are supported by a computer tool and often the name of the tool is used instead of the name of the method. For example, engineers say that they are going to use ADAMS to make an analysis and not that they are going to use Multi-Body Dynamics, or CATIA and not CAD when they design the geometry. This can be seen as an indication of how important an adequate support tool can be for the success of a method. These methods also have their counterpart in the experimental world: e.g. a chassis can be tested dynamically, a car body can be built according to the CAD drawings, and components or systems can be tested with experiments closely reflecting the FE analysis. This strong coupling between the virtual world (method and tool) and the real world (experiments) make it possible to continuously check the quality of the results from the method used. The return on investment by using these methods can be calculated fairly easily. The cost of the software, training and use, as well as the money saved by decreasing the number of physical tests and shorter time to market, are all figures possible to find. Two other methods used frequently are explorative: Brainstorming and Brainwriting, which although used regularly the use may not be what is expected by academia, as further described in section 3.2.2. More sporadically used are the convergent methods, Pugh [19] and Paired comparison [20]. Common to these methods are that the cost and savings from using them are not easily calculated, meaning that the return on investment can not be readily calculated. In [11] it is stated that in most companies' paper methods are considered to have no cost, since the books have an insignificant price compared to the price of computer tools. But when the savings are so difficult to calculate, the methods are not introduced with great enthusiasm.

3.2.2 Way of application

The CAD, FEM and MBD methods are all used with corresponding computer support tools. The user does not alter the CAD tool but uses it in its original form; updated versions are introduced by training courses. The analysis tools on the other hand permit some alterations by the user, and skilled users develop and extend the usability range of the methods. The validity of an alteration is verified against experimental results and care is taken to preserve a good correlation between the analytical results and the experimental results. The company has people at PhD and associate Professor level to develop the analysis methods and tools and keep in contact with the tool-making companies.

Brainstorming and Brainwriting are used without specific tools and by engineers without specific education in the use of the methods. Their use differs substantially from the use prescribed by academia. Brainstorming, for example, is seen to be used without the participants being sufficiently oriented on the condition of the problem to be solved and criticism is made during the brainstorming phase. Convergent methods, such as the previously mentioned Pugh and Paired comparisons, are sometimes supported by Excel sheets. The methods are frequently altered, as in the engineering domain the tradition is that quantifiable knowledge reigns. See, as an example, Figure 2. It is a Pugh-like method as used at Volvo Cars to select an engine suspension. Figure 2 represents four different solutions, but the real example contained twelve! It has been simplified to make it legible, and confidential data has been deleted. The Pugh method was used because the solution performance was not known with precision, and it was more sensible to evaluate the alternatives in terms of better or worse with respect to a reference. The engineers soon wanted to introduce weighting, trying to reflect importance of attributes. This led to numerical results that were difficult to trust. This type of misuse of the Pugh method is very common and completely destroys its goal, i.e. permitting comparison without detailed quantifiable knowledge of the solutions. Similar experience exists from introducing pair comparison [20] where a 10 graded scale was adapted instead of using 'better', 'equal' and 'worse'. This lead to confusion, and pair comparison was never successfully used.

	Criteria	Importance acording to PJMF	CURRENT SOLUTION	Type A							
				I	I weighted	II	II weighted	III	III weighted	IV	IV weighted
Company wants	A	0	REFERENCE	0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	B	8,9		0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	C	5,5		0,5	2,8	0,0	0,0	0,0	0,0	0,0	0,0
	D	7,3		0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	E	4,7		-1,0	-4,7	-0,5	-2,4	0,0	0,0	0,0	0,0
	F	10,9		-0,5	-5,5	0,5	5,5	0,5	5,5	0,5	5,5
	G	4,7		-0,5	-2,4	-0,5	-2,4	0,0	0,0	0,0	0,0
	H	3,3		-1,0	-3,3	-1,0	-3,3	0,0	0,0	0,0	0,0
	I	0		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	J	4		-0,5	-2,0	-0,5	-2,0	-0,5	-2,0	-0,5	-2,0
	K	6,4		-0,5	-3,2	0,0	0,0	0,0	0,0	0,0	0,0
Customer wants	L	8,2		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	M	8,2		0,5	4,1	0,5	4,1	0,5	4,1	0,5	4,1
	N	8,2		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	O	6		0,5	3,0	0,5	3,0	0,5	3,0	0,5	3,0
	P	4,9		0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Q	5,6		-0,5	-2,8	-0,5	-2,8	-0,5	-2,8	-0,5	-2,8
	R	3		0,5	1,5	0,5	1,5	0,5	1,5	0,5	1,5
AUTO SUM	Company wants	99,8		-3,5	-18,3	-2,0	-4,6	0,0	3,5	0,0	3,5
	Costomer wants			1,0	2,6	1,0	5,8	1,0	5,8	1,0	5,8
	No of 0			7	7	9	9	13	12	13	12
	Total			-2,5	-12,5	-1,0	1,3	1,0	9,3	1,0	9,3
		TOT SUM								-1,5	7,3

Figure 2. Pugh-like method as used at VCC

In quantitative methods, often both the decision criteria importance and concepts' performance are quantified. In early stages of the development process, very little reliable quantifiable data (experimental results, simulation results) exists. It is dangerous to try to quantify uncertain data because quantified data, although taken from extremely rough estimation, looks more exact than it really is. Because of the often non-exact input, the outcome will render results that are counter-gut feeling, meaning that the decision-maker will not use the results from the method, anyway. Or worse, a decision will be taken according to the number that just pops up through the method. In both cases, this leads to decreasing trust in using selection methods.

Much of the force in using selection methods lay in the probing that is made during the use of the methods. One of the informants who has tried various selection methods at Volvo during daily work, argued that by using methods the discussion around the concepts is more structured and thorough, which has also been observed by Pugh [19]. In other words, one could more easily see how prepared the decision group were to take the decision.

3.2.3 The method should fit well into the company's modus operandi

In academia each method is seen mostly as a way to enhance a certain phase in the product development. How a method should be used in an existing development process in a company is seldom addressed by academia. Our observations at VCC have shown that the boundary between especially convergent methods and the organisation in which they are used is not easily distinguishable. At VCC a multi-disciplinary team, in the spirit of concurrent engineering, is formed when a selection between concepts is to be made. Sometimes a method from academia may be used, sometimes a method developed at the company, and sometimes no use of a method can be seen. For a decision to be valid, the management in the hierarchy as well as informal key people throughout the organisation known for their competence, have to agree on the decision. At this stage we have found evidence that decisions are not taken at a discrete moment but rather seep into the organisation and get accepted. This practice of concept selection is not without problem. Some informants claim that the participants sometimes emerge from a meeting with different views on what has been decided and that this creates divergent development.

4 Conclusion

Academia is poorly considering the methods from a return on investment perspective. This is crucial for acceptance in industry. There is a gap between the academic aim in developing methods and the industrial aim when using methods. One reason is that academia tend to be satisfied with published methods tested in small-scale examples, while industry requires the methods to be demonstrated on industrial sized problems (success stories).

In industry, product development is done in an existing organisation structure, methods frequently used fit into that structure. Academia on the other hand often sees methods like stand-alones not considering the link with the organisation structure and the interplay between the persons using the method. When developing a method it should address a clearly defined problem situation and take into account the surrounding organisation.

The widespread use of methods in late phases shows that well developed tools together with easily verifiable and understood results of a method (e.g. by experiments) encourages its use. The late phase methods are used by experts with a high control over the tool that supports the method. Early phase methods are, on the contrary, used by generalist users without tool support. This often leads to misuse of design methods. Mechanisms to avoid misuse of the design methods should be provided that ensure the successful use of methods.

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