INTERNATIONAL DESIGN CONFERENCE - DESIGN 2006
Dubrovnik - Croatia, May 15 - 18, 2006.

DESIGN 2006

REFLECTING COMMUNICATION: A KEY FACTOR FOR SUCCESSFUL COLLABORATION BETWEEN EMBODIMENT DESIGN AND SIMULATION

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Keywords: human behaviour in design, human communication, design process improvement, CAD/CAE, collaboration, industrial case study

1. Introduction: Integration of CAD/CAE environments

1.1 Industrial need for integration

Simulation is taking on an increasingly important role during the engineering design process. It helps to reduce cost through early verification of design concepts, making greater numbers of physical prototypes obsolete. The industrial need for closer integration of CAD (computer-aided design) and CAE (computer-aided engineering) environments stems from the business priority to reduce product cycle times by reducing both iterations between the embodiment design department and the simulation department, and the time each single iteration takes.

This need for integration is exacerbated by the coexistence of two different paradigms: a topological one in embodiment design and a functional one in simulation. In other words, design engineers think in terms of their geometrical structure and focus on one component or module, whereas simulation engineers think in terms of functions and focus on the whole product or larger parts thereof. Given the industrial drive toward reducing iteration time this dualism, in turn, places increasing demands on immediate and thorough understanding of each other's 'object world' [Bucciarelli 1994] and thus human communication between design and simulation engineers.

1.2 Integration of product, people, tools, data, and process

There are different aspects that feed into successful collaboration. For the purpose of the study, these aspects are categorised thus: product, people, tools, and data. Interdependencies between the different elements of the four aspects generate the overall process. Several research projects have already attempted to shed light on data and tool integration. There has been substantial progress in these areas but many gaps in functionality remain [Armstrong et al., 2002]. Product data exchange is necessary for further integration but not sufficient.

As evidenced by a survey of approximately 50 engineers working in CAD or CAE environments in German automotive companies carried out by members of the Technische Universität München, success is not just a matter of getting the right CAx-system. The most important concern is information transmission and human communication between the different partners in the process, and this must be supported by clear, well-defined goals and team structures [Kreimeyer et al., 2005]. Therefore, this study diagnoses the communication situation by investigating the perception of factors influencing communication.

1.3 Methodical assessment of communication as enabler of integration

Findings in the literature support the perception that human communication is a crucial factor for efficient collaboration at interfaces in the design process, such as between the embodiment design and simulation departments [see for example Hales 2000]. At the automotive company where the study was conducted (see section 3), concepts such as simultaneous engineering are incorporated into daily activities: for example, certain meetings are termed ‘simultaneous engineering rounds’. This recognition of terminology developed in engineering design literature evidences the importance of adequate human communication in collaborative design projects.

A suitable method to diagnose communication is hence required to *reflect* communication, in both senses of the Latin word ‘reflectare’: to trigger active thinking about and consideration of communication, as well as to mirror perceptions of a given situation by the people collaborating at interfaces. Such diagnosis requires a method that performs a number of functions: raising participants’ awareness of factors influencing communication; making explicit their perception of the current as well as the desired status; enabling, thus, a gap-analysis; triggering reflection; and, lastly, providing the possibility to mirror back the answers in a quick, intersubjective way.

1.4 Outline of the paper

This paper reports on the construction and application of a maturity grid-inspired approach to diagnose the current and desired state of communication between design engineers and simulation engineers in the car body development of a German automotive manufacturer. In what follows, the method used is introduced and the objectives, conduct and result of the case study undertaken are then described. Different forms of evaluation as well as a discussion and an outlook are presented at the end of the paper.

2. Reflecting communication: Method development

2.1 Maturity grids: a brief overview

Maturity models for assessing processes originated from Quality Management. The basic assumption is that in order to improve product quality, the quality of the process has to be improved [Crosby 1979]. Crosby’s Quality Management Maturity Grid (QMMG) defines six aspects of quality management at five levels of ‘maturity’ [Fraser et al., 2002]. In the 1990s, the idea of process assessment via a maturity model was adopted in the software domain under the name Software Capability Maturity Model (S-CMM). The S-CMM combined both process assessment and capability evaluation to guide the control and improvement of software design. The S-CMM has now been superseded by the Capability Maturity Model Integration (CMMI) [Chrissis et al., 2003], which combines the S-CMM with a Systems Engineering Capability Maturity Model (SE-CMM) and an Integrated Product Development Maturity Model (IPD-CMM). In contrast to Crosby’s simpler ‘quality grid’, Capability Maturity Models are complex assessment tools which demand performance in baseline ‘key process areas’ (KPAs) in order to progress along the maturity scale [Fraser et al., 2002]. Maturity-based approaches have been applied to many different areas. However, there is as yet no attempt to apply the idea solely to communication in design.

2.2 Construction and application of a maturity grid-inspired approach to communication in design

Communication can be defined as the cognitive and social process by which information is transmitted and meaning is created. It is seen as the vehicle by which acts are coordinated. Communication influences and is influenced by factors that also influence the design process, such as ‘understanding of requirement lists’ or ‘awareness of the sequence of tasks in the design process’. The factors that influence communication, and for which the perception of the participants in the study is elicited, are chosen based on empirical studies by the first author as well as a review of literature. There are five categories with two subfactors, each of which is in turn subdivided by 3-5 further factors. As an example the factor ‘information needs’ as part of the category ‘information’ is selected and discussed in the results section 6 (see figure 1).

Diagnosing communication in a company serves two goals. Firstly, to raise awareness of communication and its relation to the design process, and. secondly, to engage individual employees in an ongoing reflective learning process [Maier et al., 2006]. Learning is a dynamic concept and it emphasises the continually changing nature of organisations. The maturity levels in column A to D and the descriptions in the cells (see figure 2) are chosen based on an adaptation of the learning theory by Argyris and Schön .

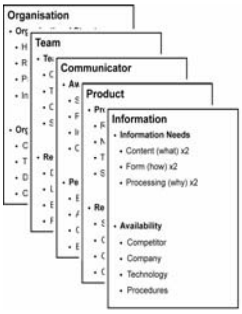

Figure 1. 'Communication Grid'

Understanding of information needs (content, form, processing)						
Factor	**A**	**B**	**C**	**D**	Current	Desired
Do you know which information the other party needs?	No	Sometimes, they learn from mistakes	Mostly since it is documented and communicated which information is needed	It is entirely clear to the other party what information we need and the information transmission process is continuously optimised	[ ]	[ ]
Does the other party know what information you need?	No	Sometimes, we learn from mistakes	Mostly since it is documented and communicated which information is needed	It is entirely clear to us what information the other party needs and the information transmission process is continuously optimised	[ ]	[ ]
Do you know in what form the other party needs information? (Drawing, Calculation...)	No	Sometimes, they learn from mistakes	Mostly since it is documented and communicated which information is needed in which format	It is entirely clear to us how the pther party needs information and the information transmission process is continuously optimised	[ ]	[ ]
Does the other party know in what form you need information? (Drawing, Calculation...)	No	Sometimes, we learn from mistakes	Mostly since it is documented and communicated which information is needed in which format	It is entirely clear to the other party how we need information and the information transmission process is continuously optimised	[ ]	[ ]
Does the other party know how you process the information you receive from them?	No	Sometimes, they learn from mistakes	Mostly since it is documented and communicated how we process information	It is entirely clear to the other party how we process information sent by them and the information transmission process is continuously optimised	[ ]	[ ]
Do you know how the other party processes the information they receive from you?	No	Sometimes, we learn from mistakes	Mostly since it is documented and communicated how information is processed	It is entirely clear to us how the other party processes information received from us and the information transmission process is continuously optimised	[ ]	[ ]

Figure 2. 'Information needs' grid sheet

2.3 Levels of maturity: Scale points

When completing cells in the 'communication grid', the analyst describes the degree to which the participants are aware of the influence and the relevance of individual factors to communication, and the degree to which these factors are reflected upon in the company. According to Argyris and Schön [1978], there are three types of learning. The first type of learning occurs when errors are detected and corrected, but firms continue with their present policies and goals. The second type of learning occurs when, in addition to detection and correction of errors, the organisation questions and modifies its existing norms, procedures, policies, and objectives. The third type of learning occurs when the first two types are incorporated and employees are aware of it.

'Communication grid' sheets adopt these three categories, and add a further preliminary stage. This additional stage, A, describes situations where companies do not even engage with the questions asked in the grid: i.e., they do not reflect on the connection between the factor in question and communication. The second stage 'B' corresponds with the first type of learning described by Argyris and Schön, and says that some action is changed in order to correct a mistake but other than that tasks are carried out as usual. The third stage 'C' corresponds to Argyris and Schön's second type of learning: people at this stage modify their actions, as well as thinking critically about existing norms, procedures, policies, and objectives that govern their actions.

This means that a mistake is not just corrected once, but that the general situation that led to a mistake is taken into consideration. The fourth stage in the grid 'D' corresponds to the third type of learning and signifies a stage where employees are aware of the influence of a given factor on communication and continuously check whether the way things are handled or set-up is still appropriate for the given situation. At this stage, learning does not only happen when a mistake needs to be corrected: participants have the general mind-set of continuously adjusting and improving the situation.

3. Conduct of the study: Application of method

3.1 Objectives of the study

A number of goals were to be achieved by the study presented:

- First, to capture the perceptions of the interviewed design and simulation engineers of selected factors which influence communication.
- Second, to identify where there were discrepancies in opinions between design engineers and simulation engineers for the selected factors; in other words, to get the users' point of view on problems of CAD-CAE integration.
- Third, to arrive at a detailed understanding of factors influencing communication, and, in this context, to identify a suitable focus and approach for initiating integration.
- Fourth, to evaluate the method used, especially focusing on clarity of presentation and individual handling of the grid-sheets by the participants of the study.

3.2 Set-up of the study

This case study was carried out in the context of a collaboration between two universities and a partner from industry, a car manufacturer that has led the market for several decades, and now has more than 50 000 employees, an annual turnover of more than 20 billion Euros, and more than five production sites worldwide. The project with the industrial collaborator focuses on the enhancement of collaboration between the design and simulation engineers for the development of car bodies. Until the start of the study, the engagement with the company had lasted for about 12 months already and included observation, interviews, a questionnaire, and workshops. Four weeks were allocated to this particular study on factors influencing communication.

The study looked at communication at the interface between design and simulation, and focused on the design of the so-called 'trimmed body' for the serial development of one of the vehicle series. The observed interface to simulation was that of engineers involved in developing the function 'Noise Vibration Harshness' (NVH). Due to the company's organisational matrix structure, the engineers interviewed were part of a virtual project team consisting of design and simulation, working at the same location but in different offices.

3.3 Conduct of the study

Eight people were interviewed individually for 1-1.5 hours each. Four design engineers and four simulation engineers, from novice to senior level, participated in the study. Grid-sheets were distributed to the participating engineers in interviews, and the purpose and method – to capture their perceptions of factors influencing communication – were explained. The interviewees were asked to make two marks for each factor: one to indicate the current situation, and one to indicate the desired situation. They were verbally reminded to think of the project team while answering, a detail also written on the grid-sheets below the headings. The follow-on workshop allowed the organisers to feed preliminary results back to the participants, to provide a forum for open discussion and to raise mutual awareness for the viewpoints of the others. Since the participants had filled in the grid sheets already the discussion could start right away.

4. Results: Analysing responses

4.1 Obtainment of results

For each factor, the individual interviewees were asked to choose a score from A to D (equated with 1 to 4) with respect to the current situation as well as the desired one. The mean value of the answers for the current and desired situations were calculated for each factor: once for all answers and once differentiating between design and simulation. The distance between the current and the desired situation indicates the need for action-planning relating to the respective factor. The greater the difference, the more evident it was that participants saw room for optimisation.

4.2 'Positive' and 'negative' consensus and discrepancies between design and simulation engineers

The answers given were analysed in two ways: first, to see whether there was consensus about the situation – 'positive' and 'negative' – and second, to identify discrepancies between the current and the desired state based on the answers given. This was done both for all answers gathered, and for the simulation engineers and design engineers as distinct groups. 'Positive consensus' refers to the fact that the distance between the current and the desired state is very small, i.e. under 0.5 steps, which in turn refers to the fact that the participants seem to be content and no action is required. 'Negative consensus' means that the distance between the current and the desired state for the factor under scrutiny is big, i.e. more than 1 step which in turn means that there is scope for improvement.

The answers to most of the approximately 50 factors elicited in the 'communication grids' show that there are few factors where the gap between the 'as-is' and the situation 'to-be' is very wide. In general, the answers given by the simulation engineers show a greater average distance between the current and desired status for each factor than the answers given by the design engineers. The trend reverses for the factors 'lessons learned' and 'best practices'. As far as positive consensus is concerned, the answers show that all participants are of the opinion that they receive enough 'company information' and that they are well informed about 'product specifications', and seem to be content with 'checking progress against objectives'. The factors that resulted in negative consensuses are listed in table 1. The following discussion concentrates on the factor 'understanding of information needs' (see parts table 1 and figure 2).

Table 1. Topics identified for action planning

Topic	Overall			Simulation			Design		
	*Ø Distance**	*Ø Current*	*Ø Desired*	*Ø Distance*	*Ø Current*	*Ø Desired*	*Ø Distance*	*Ø Current*	*Ø Desired*
Orientation									
Overview of sequence of tasks in design process	1.50	2.25	3.75	1.50	2.25	3.75	0.75	3.00	3.75
Implementation of common goals	1.00	2.87	3.87	1.00	2.75	3.75	1.00	3.00	4.00
Clarity of roles and responsibilities	1.12	2.75	3.87	1.50	2.50	4.00	0.75	3.00	3.75
Reflection									
Lessons learned	1.37	2.50	3.87	**1.00**	2.75	3.75	**1.75**	2.25	4.00
Best practices	1.37	2.50	3.87	**0.75**	3.00	3.75	**2.00**	2.00	4.00
Understanding of information needs									
Content: (x,y)	-	-	-	**1.50**	2.50	4.00	**0.50**	3.25	3.75
Content: (x,y,x)	-	-	-	**2.00**	1.75	3.75	**0.75**	3.00	3.75
Form: (x,y)	-	-	-	1.00	3.00	4.00	0.75	3.00	3.75
Form: (x,y,x)	-	-	-	1.75	2.25	4.00	0.75	3.00	3.75
Processing: (x,y)	-	-	-	1.50	2.00	3.50	0.75	3.00	3.75
Processing: (x,y,x)	-	-	-	1.75	1.75	3.50	1.00	2.75	3.75

** Average distance between the current and the desired state*

4.3 Understanding of information needs: Knowing what information is needed and in what form?

A necessary condition for functioning communication is to understand the information need of the respective communication partner. Here, the question was whether design engineers would understand what the information needs of the simulation engineers in the car body development were and vice versa. To this end, the factors 'knowledge about information needs' (see figures 3 and 4), 'knowledge about the form of information', and 'knowledge about the processing of information once transmitted' were tested.

Both parties were asked two questions for each factor (content, form, and processing of information). The first was to test for the interviewee's perception of the partner's needs for information, the second to probe for his self-perception of what the other might know of his needs. This arrangement allows for a comparison and matching of the self-assessment with the perception of the respective other part of the interface. Answers possible were: A: 'No', B: 'Partially, we learn when mistakes happen', C:

‘Mostly, since it is documented and communicated which information are needed’, and D: ‘It is completely clear to us what kind for information the ‘other party’ needs and the information transmission process is continuously optimised.’

It becomes clear that the average distance between the current and the desired situation differs greatly if the answers are grouped into design and simulation engineers (table 1). Answers to the first question show the results depicted in figures 3 and 4. For the simulation engineers (figure 3) the desired situation is clear. The current situation seems to be that there is no real clarity with regards to what information exactly the design engineers need. Yet, the answers of the design engineers’ show that they seem to know what information the simulation engineers need (figure 4).

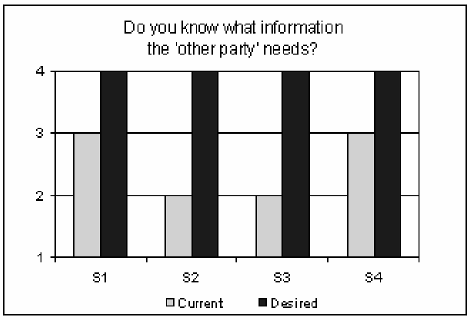

Figure 3. Does Simulation know what information Design needs? Answers given by the Simulation team members

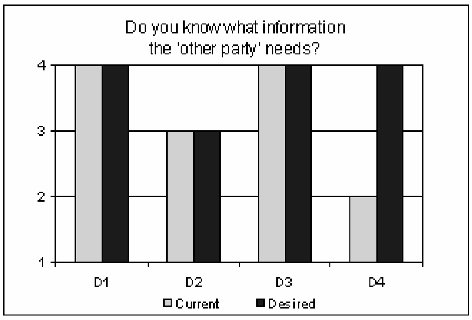

Figure 4. Does Design know what information Simulation needs? Answers given by the Design team members

When asked the second question - whether X (simulation engineer or design engineer) thinks that Y (design engineer or simulation engineers) knows what information X needs - the answers given by the simulation engineers show that the average distance between the current and the desired state is two steps. The simulation engineers perceive that the design engineers do not really know exactly what information the simulation engineers need. A gap of two steps clearly shows room for improvement. The answers by the design engineers, however, show that they are overall satisfied with the situation, believe they know what the simulation engineers need, and believe that the simulation engineers know what information the designers need.

The same questions were asked with respect to understanding and awareness of the desired form/representation of the information, and the understanding and awareness about how the respective other party processes information after it has been transmitted to them. Overall, the results show the same tendency. The average distance of the answers given by the simulation engineers is always greater than the answers given by the design engineers seem to suggest. Most of the time, the value for the current situation is at stage 2 (‘partially, we/they learn once mistakes have occurred’), whereas the value for the current situation perceived by the design engineers is at stage 3 (‘mostly, since it is exactly documented and communicated, which information is needed in what form’).

The results of the ‘communication grid sheets’ match the answers given in the interviews and in the workshop. Rare exceptions noted, it seems generally that each group of engineers is uncertain about what information the respective other party needs and in what form it should be presented.

5. Evaluation

5.1 Validation of results

Two sociological techniques for validating the results, as described by Bloor [1997], were used, i.e. the so-called member-validation and triangulation. In contrast to the natural sciences, where findings are validated or verified by their replication by a second independent investigator, in sociology validation cannot occur through subsequent replication, since identical circumstances cannot be re-created outside the laboratory.

Firstly, the results were fed back to the participants of the study through a workshop, a final presentation and a written report by the researchers. At each stage, feedback from the participants was encouraged. So far, all statements about the evaluation were greeted very positively by the participants who felt the statements accurately represented the actual status of communication between CAD and CAE engineers. Secondly, the results were cross-referenced ('triangulated') with a questionnaire on the same topic, answered by about 50 participants in the same context as the study subjects (more than 40 of this second group work in the company in question). From the individual comments on single questions in the questionnaire especially, a picture very similar to that obtained in this study can be derived. Yet, communication was only one of many aspects analysed, as the questionnaire was targeted at CAD-CAE-integration as a whole.

5.2 Evaluation of method used

Whether the method is of value for reaching case study and research objectives (see section 3.1.) is indicated by the degree of user approval, which in turn determines the acceptability of the results and implementation of suggestions. The method used to diagnose the current and the desired state of communication, which was inspired by a maturity-grid approach, has been evaluated through one-on-one interviews. The interviewees were asked to comment on individual terms that needed clarification, on the factors chosen, on handling of the grid sheets, and on whether they learned something new about communication in design. The comments were duly noted for further refinement of the method.

6. Summary, conclusions and further work

This study presented a method, inspired by maturity-grid approaches combined with an adaptation of a learning theory, for gauging perceptions on factors influencing communication in design. The method proposed enables assessment of the gap between the actual and preferred state of communication, and its underlying conditions. It can deliver adequate insight into the current state of communication, as well as eliciting gaps to be bridged in order to achieve successful communication.

The method was applied to the problem of rendering collaboration between embodiment design and simulation more efficient. Several techniques were used to validate the results, illustrating a remarkable precision even on a small population of participants for the communication study. The results show that – particularly for larger teams of development engineers – communication is crucial.

By looking at a specific (departmental) interface, the method is able to deepen mutual understanding in an intersubjective and goal-oriented manner. This helps in understanding communication in general and its role in the design process in specific. This is especially achieved through consensus on selected identified discrepancies. In engaging different departments, the method was also able to highlight the differing self-conceptions of embodiment design engineers and simulation engineers. Whereas the former see them as the driving force in product design, second to none, the latter see themselves as equal partners.

As the method captures individual answers as well as group averages, it both sheds light on the general state of company communications and on to the particular experience of each participant. However, the results tend to depend on personal answers, which often incorporate a subjective point of view and therefore need to be critically questioned in every case. Generally, people with a broader outlook or more experienced participants tend to judge a situation differently to the novice engineers.

The objectives set out in section 3 were fulfilled. First, the study captured design and simulation engineers' perceptions of factors influencing communication in the current and desired situations. Second, discrepancies in opinions between design engineers and simulation engineers for the selected factors were detected. This in turn enabled the identification of the user's point of view on problems of CAD-CAE integration. Third, it arrived at an identification of issues that provides the basis for action planning towards CAD-CAE integration. Fourth, the method has been evaluated through mirroring the answers of the participants of the study back to them, and eliciting their comments on the accuracy and adequacy of the picture painted.

Communication is simultaneously influenced by multiple factors on various levels. These cannot be viewed as independent, but rather as mutually intensifying or counterbalancing each other. Yet, the method presented shows only a snapshot of the set of factors most relevant for the observed situation.

The observed interface of design and simulation engineers was characterised by different paradigms for accessing product information, i.e. geometric structuring of components and modules for embodiment design and a functional perspective for simulation engineering.
So far, studies with regards to all five aspects mentioned (data, tools, product, people, and process) have been conducted in order to enhance CAD-CAE integration. Future research will examine how these aspects are interlinked. This will function as a basis for the formulation of different suggestions for improvement.

Acknowledgements

The authors acknowledge support from the industrial collaborator and the UK Engineering and Physical Sciences Research Council. The work of AM was partially supported by a DAAD Doktorandenstipendium.

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