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TOWARDS MANAGING TEAM INTERFACES: AN ELICITATION OF FACTORS INFLUENCING COMMUNICATION

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ABSTRACT

Many researchers and practitioners in industry have identified communication between people as a major determinant of success or failure in (design) projects. Our empirical investigations indicate that many non-technical problems are – mostly unintentionally – labeled 'communication problems'. Upon scrutiny, however, many appear to be caused by factors such as lack of 'overview of the sequence of tasks in the (design) process' or conflicting 'goals and objectives'. In such situations, a 'communication problem' might be the outcome rather than the cause. Communication is influenced by manifold factors related to information, representations, the individual, the team and the organisation. In this paper we argue that factors influencing communication provide levers through which communication can be improved. We introduce a descriptive record of influences identified through literature review and interviews in industry. Knowledge of such factors could aid researchers in generating hypotheses about communication and design performance, practitioners for management practices, and educators for teaching 'soft' competences.

Keywords: Communication, research and development management, empirical case studies in industry, collaborative design, influencing factors

1 INTRODUCTION: COMMUNICATION IN COLLABORATIVE DESIGN

Effective communication to coordinate work between design engineers and various stakeholders within and outside the company is crucial for collaborative product development [1-7]. A number of studies describe and analyse what impacts collaborative design and effective teamwork. To mention only a few, Hales [8] sets the design process in context with the project, company, market and external environment and provides a list of influences at macro-economic, micro-economic and corporate levels. Badke-Schaub and Frankenberger [6] extensively analysed four design projects in two companies. Their research identified what they termed 'prerequisites' to critical situations in the design projects, such as the individual, the group, external conditions, tasks, and the design process. Ostergaard et al. [9] present a taxonomy for the classification of collaborative design situations, including communication. Despite differing in terms of research aim and methodological approach, all papers agree that functioning communication between all stakeholders is crucial for a well-coordinated collaborative design process.

1.1 Objectives

In the studies listed above, communication is mentioned as one factor among others. In this paper, we now try to unpack what influences communication itself. In our own studies we observed frequently that any kind of non-technical problem is attributed to communication. People often intuitively sense that 'something' is going wrong. Yet, they find it difficult to ascertain whether communication as such is the cause of the problem or whether it is a manifestation of, for example, inadequate planning or personality issues [10], differing terminology [11, 12], lack of common goals or unclear responsibilities [13]. By presenting a record of factors elicited through literature review and empirical studies, this paper aims to allow engineers and engineering managers to be cognisant of and attentive to a number of influences affecting communication in collaborative design. The approach aspires to develop reflective practitioners [14, 15].

1.2 Outline

The remaining sections of the paper are organised as follows: Section 2 presents exploratory studies to illustrate the problem situation. Section 3 describes the methods used for data acquisition. Data presentation in Section 4 concentrates on describing the grouped list of factors in relation to literature findings. Section 5 mentions limitations. Section 6 shows implications for academic research and industrial practice. The paper ends with a conclusion and suggestions for further research in Section 7.

2. COMMUNICATION PROBLEM AS CAUSE OR SYMPTOM?

The following examples describe two reported communication problems in two different companies in the UK. Field research, using observation and interviews, was conducted in the UK (see Section 3: Methods): Firstly, between engineering and production at a strategic business unit of an aerospace supplier (Company 1) and secondly, between production/spares and service support within an engineering tools manufacturer (Company 2). These examples, together with other observed instances which were termed ‘communication problems’ in industry, fuelled our motivation to increase understanding of the specific circumstances.

The starting point for our observations and interviews in Company 1 was a reported (perceived) communication problem between engineering and production in general and in particular with respect to one-off ‘technology demonstrators’. Production would respond, if at all, in a noncommittal way to requests from engineering, according to the comments from the design engineers. Interview comments and observation yielded the following explanations (Figure 1).

Repercussions of the events of September 11 affected the development of the aerospace industry and altered business priorities. Together with a change in company ownership, it led to reorganisation of the company and redundancies occurred across several rounds. This, in turn, led to insecurity as to who else would be made redundant. Consequently, engineers would work primarily to their performance metrics, many of which appeared to be contradictory. In this case, production was assessed according to the speed and quantity of items produced and sent ‘out of the door’ in contrast to engineering who were encouraged also to work on one-off ‘technology demonstrators’ in order to gain a competitive advantage for the company in the marketplace. In addition, ‘science projects’ were only fostered when financed by a national funding body or the customer. This led to confusion on behalf of the engineers with respect to the product strategy. This confusion was not resolved; further, the engineers felt that as a combination of (i) changes in the aerospace market, (ii) shortage of resources and (iii) new ownership, decisions were taken purely for financial reasons. In summary, engineers perceived communication problems at the interface between engineering and production because both parties would not speak to each other enough. As could be inferred, this was the outcome of the interplay between a variety of factors and structural misalignments.

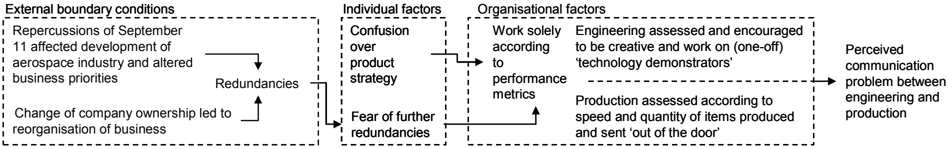

Figure 1 Perceived communication problem between engineering and production

The starting point for our observations and interviews in Company 2 was a reported (perceived) communication problem between production/spares and service support as they would not speak to each other as much as the job requires (according to people on the management team) and often only by carbon copying on email the whole management team . When asked where this problem would surface, we were pointed to the companies’ ‘Works Order’ process (Figure 2).

For every machine ordered by the customer, all departments within the company from sales to aftermarket support would meet, propose and commit to an offer. In order to produce a sound ‘Works Order’, each time a new product is produced, the full process, from the initial request to the actual contract, must be followed. In addition to requests for new products, an order for spares should trigger the same internal process if the financial value of the order exceeded the threshold for a ‘normal’ order of spares. As this was not documented in a procedure to order spares, people did not know whether to initiate a ‘Works Order’ process or not. This uncertainty led to inconsistent behavior from employees.

The 'sequence of tasks' needed clarification in cases where orders came in that were not clearly defined as new orders but by their financial value exceeded a 'normal' order of spares. In addition, the target for this year of managing spares was to minimise stock and to sell as many spares as possible. The target for the year for the service support department was to respond as quickly as possible to customer needs and repair or replace parts on already sold machines. Targets set by management contradicted themselves severely if each side were to take them to the extremes. Performance assessment and salary bonuses were based on the degree to which the different targets were met. The perceived communication problem may thus be seen partially to be an outcome of the different and misaligned underlying targets, set at the beginning of the year by management.

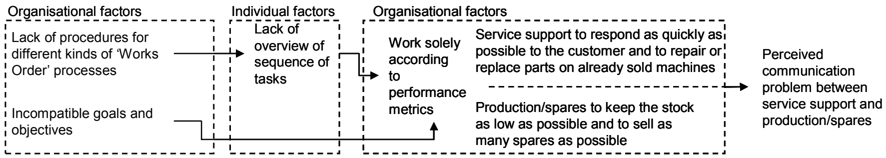

Figure 2 Perceived communication problem between production/spares and service support

3 METHODS: INTERVIEWS AND LITERATURE REVIEW

Elicitation of the list of factors from interviews and literature served the purpose of developing input for an assessment method of communication in engineering design, presented elsewhere, e.g. [16]. It is suggested there that factors influencing communication provide indicators through which communication can be assessed and tangible levers with which communication can be improved.

3.1 Interviews

63 staff from three companies in the aerospace, engineering tools, and information technology sectors were interviewed between 2003 and 2005. Two of the companies were the same as the two examples in Section 2. With the exception of one interviewee, the informants were all working as engineers or engineering managers. Interviews lasted between 30 minutes and one hour and followed the same format: The engineers were asked to describe their current position, followed by a description of the projects they were working on and the nature of interactions with other teams. Interviews were transcribed from audio-records where allowed and from field notes taken by the researcher. Transcripts were coded and findings were condensed into a list of 27 factors.

Interview coding procedure

Coding in this research project evolved as follows. Initially, the researcher identified codes emerging from the material and assigned them to the appropriate sentences or paragraphs of the transcript. This is referred to as open coding by Strauss and Corbin [17]. These initial, very detailed codes were then merged and grouped in a tree structure. In general, the researcher started with a long list of initial codes which was then reduced in subsequent rounds of coding. The hierarchy of codes was established using a mixture of bottom-up and top-down coding. In most cases, the 'children' codes were identified first and the 'parent' codes last. To give an example, an interviewee would explain the importance of timely and accurate 'bill of materials' or 'dimensions of a certain component'. In the first round of coding these codes would be listed individually. In the second round of coding the researcher assigned these comments to the code 'availability of information about product specifications'. In the third round of coding, five levels and groups of codes to which individual codes related to were discerned: information, representation, individual, team and organisation. Borders of the five levels of influence are not rigid and overlap in parts. As the research progressed, the number of codes evolved from several hundred to less than fifty, the rationale for which is now presented.

Rationale for selecting factors

Transcriptions and field-notes of all 63 interviews and eight weeks of observation formed the basis for the coded material. A list of factors was extracted from the acquired data. Frequency of occurrence was counted. Counting proceeded according to the following criteria:

- A factor mentioned several times by the same interviewee was only counted once, even if it occurred more than once throughout the interview;
- A quote from an interviewee could be associated with one or more codes;

- In Company 1 (aerospace supplier) a questionnaire that investigated information transmission and availability of information was distributed to 28 people, responses in interviews were added to the frequency of occurrence of the respective factor and in cases where the respondent of the questionnaire and interviewee denote the same person, the respective factor was counted once;
- Only factors mentioned by at least three interviewees were taken into account.

For the purposes of this study, factors that are outside the control of individual team members or their managers, such as 'economic and legislative changes', 'workload', 'cultural differences' [18], 'product complexity', 'experience' [19], 'team composition' [20], 'personalities' [21], 'power distribution' [22], 'gender', and 'emotions' were not taken into consideration. For a review of factors in the New Product Development (NPD) literature that concludes communication is affected by factors related to the project, the project manager and the external environment, see Belassi [23].

3.2 Literature review to support empirical findings

As new product development in general and design research in particular is a multidisciplinary field [24], literature from adjacent disciplines was taken into consideration to support the selection of factors. Various fields of literature were consulted, such as engineering design, new product development, management science, computer supported collaborative work, work psychology, and sociology. In reviewing this literature, one encounters a broad range of factors that influence the success of human communication. Table 1 in Section 4 shows a selection of key references. Further, it should be noted that factors are listed individually. Yet, interrelations and potential hierarchies between these factors contribute to the specific context of design – a topic covered elsewhere [25].

4 ELICITED FACTORS THAT INFLUENCE COMMUNICATION

Results from interview indicate that human communication between teams in new product development is affected by four major sets of factors, namely, information, representation, individual, team and organisation. Each category is divided into a number of factors (Table 1). Due to the complexity of communication and design (and human beings for that matter), the list of factors is extendable. Within the criteria presented under 'Rationale for selecting factors' above, the most frequently mentioned factors in interview were selected, shown in (Table 1) and described below. Each factor is introduced by its 'title' written in italics. This is a merging of interview data and existing literature.

4.1 Information

Due to the inherent complexity of many design products and processes, design engineers spend a significant amount of time searching for, prioritising and handling the information available. Rectifying errors due to lack of information is a costly way to learn, yet it happens in most design processes. In general, designers deal with a vast amount of information at every stage of the design process [26, 27]. Searching for information can take up considerable time and acting on incomplete or false information can lead to suboptimal decision making.

- *Availability of information:* Engineers' communication is affected by the availability of information, specifically of product specifications, procedures, competitors' products and strategies and availability of information about their own company. The different nature of these types of information requires various different representations.
- *Knowledge of information needs:* While availability of information is an information retrieval process from the point of view of the beneficiary, for effective communication team members also need to know what information other people require. In order to know what information is needed, engineers need to make their personal preferences and assumptions known [28].

By guaranteeing availability of information and sharing information between members dependent on individual needs and preferences, a team is able to make best use of its pooled knowledge – the focus of knowledge management in engineering design [29].

4.2 Representation

The teams observed in the first two companies were both technical experts within the companies to which other project teams referred when they needed advice. Giving advice entailed translation of their knowledge and terminology to people with less detailed technical knowledge.

- *Product representations:* A number of representations of the product, such as a drawing, a requirement list or a physical prototype serve visualisation purposes and are used to derive information [30-32].

The wide variety of means used to represent the product require, for example, understanding of the technical language (terminology) and drawing conventions (notation) [11].

- *Terminology:* Terminology refers to all terms used within a specific technical area where the assigned meaning is different from the everyday commonsensical usage of the word. According to the Oxford English Dictionary, 'terminology' means "the system of terms belonging to any science or subject; technical terms collectively; nomenclature" [33].
- *Notation:* Notation is defined as "the explanation or exposition of a term in accordance with its etymology", and "the process or method of representing numbers, quantities, etc., by a set or system of signs; hence denote things or relations in order to facilitate the recording or considering of them" [34]. In the context of this paper, this primarily applies to drawing conventions.

4.3 Individual

Successful communication between designers is influenced by a variety of factors which could be positioned on the level of the individual communicator. Designated as important factors by the design engineers interviewed across the three companies, they are: 'generation of innovative/alternative ideas', 'best use of capabilities', 'education and training', 'overview of sequence of tasks', and 'task autonomy'.

- *Generation of innovative/alternative ideas* and *best use of capabilities:* Engineers in the companies observed all seemed to be highly motivated and committed to the projects they were working on. An often heard comment was that people would stay and work until they solved the problem or finished the task they were pursuing, no matter how long it took. From observation and comments at interview, the engineers' 'commitment and motivation' seemed to stem from application of their 'technical skills and use of their capabilities' which contributes to successful designing the end product. They were enthused by the problems they solved and many engineers would be enticed to continue by being allowed to experiment with 'alternative and innovative solutions' to a problem. Especially in the software engineering company, most staff had written their own problem-specific software tools. The tools were then used by the group to fulfill their set tasks. Freedom to pursue innovative ideas [35] and best use of individual capabilities [36] function as motivational forces and influence communication.
- *Education and training:* To keep abreast with new technological developments and deepen their expertise, engineers interviewed mentioned that education or training is an important factor that influences the way they communicate with their peers. Knowing what training someone has helps them address the right person for information. Furthermore, receiving training is seen as a source of motivation for the team members [37].
- *Overview and awareness of sequence of tasks in the design process:* Awareness of the work of others facilitates communication and is therefore a basis for engaging in any kind of collaborative activity [38]. Awareness and communication are related. Lack of awareness can cause communications to diminish. Positively phrased, communication can lead to awareness. Overview and understanding of others' activities and the sequence of tasks in the design process enables one to understand the context for one's own activities, goals and motives [39, 40].
- *Autonomy of task execution:* Engineers stated that they need sufficient time and latitude to carry out their tasks autonomously whilst collaborating with others. Interviewees often mentioned this in connection with knowledge about their and their colleagues' roles and responsibilities. Communication improves when the roles of the individual team members are defined yet team members are given freedom in how to achieve their individual tasks [41, 42].

4.4 Team

Design engineers interviewed across the three studies pointed towards a 'supportive environment' as affecting the way they communicate and perform their daily design tasks. What the term denotes is to a certain extent the researcher's informed estimation which was shaped during the case studies.

Characterisation of a 'supportive environment' includes comments on, for example: 'collaboration', ‘team identity’, materialisations of team reflections, e.g. ‘best practices’, ‘lessons learned’, and ‘project reviews’, and ‘common goals and objectives’.

- *Collaboration:* Collaboration has been shown to promote productivity by helping individuals perform more effectively [43]. Collaboration is conceptualised as the degree, extent and nature of working together and the mutual help between project team members [44-46].
- *Team identity:* A key to effective project teams is developing a sense of community that demonstrates sensitivity to differences, thereby establishing ground rules and agreement among team members for how the team will work together [47-49]. Creating a sense of community or belonging leads to commitment to the team and common goals and objectives while doing individual tasks.
- *Best practices/lessons learned/project reviews* are materialisations of team reflection. Engineers referred to ‘best practice’ databases, ‘lessons learned’ sessions and ‘project reviews’ as helpful to critically reflect on what and how design tasks should be performed. This reflection would shape the way they communicate as they would approach a colleague better informed. Ideally, reflection would also happen on a regular basis and without active external encouragement outside this institutionalised or structured reflection [50, 51].
- *Common goals and objectives:* Classical organisation theory originally established the importance of goals in organisations [52]. Since that time much has been written on the concept of an organisational goal, the purposes served by goals, the multiplicity of goals in organisations [53], and the hierarchical nature of goals [54]. Studies on high-performance teams have found out that for successful teams, team members identify with common goals, for example timeliness, cost and quality and with the greater vision driving the project. This results in higher motivation and is a key enabler for team members to act responsibly [55, 56].

4.5 Organisation

Being even more general in their remit, factors pertinent to the team within the organisation and the whole organisation affect communication at team-interfaces. Looking at a team within an organisation, engineers frequently mentioned the influence of ‘mutual trust’, ‘roles and responsibilities’, ‘handling of technical conflicts’, ‘activity at interface with the other party’, and ‘transparency of decision making’.

- *Mutual trust:* The majority of interviewees mentioned trust as another factor that influences communication. The design engineers interviewed stated that trust in each others’ technical skills, experience and goodwill is vital in order to build good working relations. Trustful behaviour generates benefits, such as improvements in communication. As Clark and Fujimoto [2] point out, “mutual trust on both the product and process sides seem to be the basis of a foundation for effective communication”. This is beneficial to information sharing. Conversely, lack of trust can lead to information hiding [57]. The technology management literature adopts the concept of trust in relation to risk of information leakage [58]. Many functions are attributed to trust [59]. It is regarded as a basis for present and future co-operations [60], an important basis for teamwork in the design process [61], and a mechanism that enables reduction of the complexity of social interaction systems [62].
- *Roles and responsibilities:* The interview data suggests that clarity of roles and responsibilities is another important factor according to designers’ perceptions of communication in their work environment. Design engineers suggested that a clearly defined role eases communication. It relieves engineers from the pressure of guessing what information is expected from him/her and who he/she possibly has to go to in order to receive the relevant piece of advice and information. Communication and collaboration are eased when the roles of individual team members are clearly defined. Without such clarity, team members are likely to waste too much energy negotiating roles or protecting turf, rather than focusing on the task in hand [42].
- *Handling of technical conflicts:* Many conflicts in the work place occur between individuals who share similar goals but disagree over the means by which they can be achieved. There are basically two types of conflict. The main distinction in the literature on work psychology and management science is made between a ‘task conflict’ (technical) and a ‘relationship conflict’ (personal) [63] or ‘task conflicts’ and ‘process conflicts’ [64]. It is hard to separate the two, which makes it difficult to gain the benefits of task conflicts without the negative effects of

relationship conflicts. Handling and management of conflict is connected to the topic of handling of mistakes also found as 'error correction' or 'team culture' in the literature e.g. on organisational behaviour and high performance teams. A characteristic of successful high performance teams is a certain way of handling the fact that someone made a mistake or error. When errors are discovered, they are quickly and reliably corrected. It is not focused on the question of who caused the error but how it can be resolved [65]. This 'organisational culture' influences the way engineers communicate. A 'blame-culture', for example, may lead to information hiding in case of a mishap.

- *Activity at interface with the other party:* A large body of research indicates that the more the product development team members are connected to each other and to key external parties, the more successful the project is going to be [66]. Inter-departmental understanding is thus a strong correlate of new product success [67, 68]. As observed in an IT company, the nature of interactions between teams, whether predominantly reactive or proactive influences communication patterns between teams. For instance, when software is released to the customer, code ownership changes from the software development team to the service support team. The software development team moves on to work on the next new release whilst the support team is still predominantly concerned with a previous release and will be exposed to issues connected to the new code only after significant time has passed. This asynchronicity in terms of involvement time affects communication.
- *Transparency of decision making:* One of the major activities of organisations is decision making [69]. Organisational decision making theory has been strongly influenced by the computational approach. Currently, work in artificial intelligence, multiagent analysis, and electronic commerce is influencing organisational decision making models. Computational organisation theory focuses on understanding the general factors that affect individual and organisational behaviour. There are mainly two topics of concern within the research on organisational decision making. The first is the way decisions are made [70] and the second is the issue of transparency [71]. Transparent decision making ensures that members understand the reasons for decisions which eases communication and creates a deeper understanding of and buy-in of common goals.

Looking at how an organisation is run, engineers acknowledged that a multitude of organisational factors influences the way they communicate. Interviewees noted that they often expected their direct managers to address these factors within the constraints that the company imposes.

- *Application of corporate vision:* Individual project goals and objectives must be clearly defined and aligned with the overall goals and vision of the company. This includes the general overall purpose definition as well as specific performance targets to provide clear directions for the team members [56, 65, 72]. Every organisation and every manager has more than one goal that guides activities and actions. In theory, different functional areas within an organisation should possess complementary goals that are derived from a set of general, organisation-wide goals. In practice, however, overall goals are often broken down into specific functional objectives that might conflict with each other [45].
- *Usage of procedures:* In the companies investigated, engineering as well as quality procedures that are supposed to be followed were available on a document management website or filed accurately in folders and placed on shelves openly available to all. Procedures, capturing and depicting the desired way to approach certain tasks, are seen as important in engineering design communication. According to the interviewees, procedures regulate the flow of information and determine who becomes involved in particular topics. Following procedures eases communication.
- *Hierarchies:* As indicated by the interviewees, hierarchies affect information flow and communication. Hierarchy can be an enabler as well as a barrier. The position a designer is in can constrain or create opportunities in terms of information and communication. Comments suggest that hierarchies are specifically used for communicating between designers, particularly if they don't know each other in person, as well as between designers and design managers, partly as a technique to address conflict.

Table 1 Record of factors affecting communication: definition and literature references

	Factor	Definition	# in interview*	Key references
Information	Availability of information about Product specifications, Procedures, Competitors and the Company	How often information about product specifications, procedures, competitors and the company is distributed to the interviewee.	 43 39 33 33	[26, 29]
	Knowledge of information needs	Degree of the awareness of the other party's needs and preferences.	18	[27, 28]
Represen-tation	Product representations	Degree of understanding and adequacy of the different types of representations of a product (*e.g.* bill of materials, drawings)	27	[30-32]
	Terminology	Degree of understanding of specific technical terms used.	13	[11]
	Notation	Degree of understanding of for example drawing conventions.	7	[11, 12]
Individual	Generation of innovative/alternative ideas/ Best use of capabilities	How generation of innovative and alternative ideas is supported and rewarded. How one's capabilities are realised and utilised.	8 14	[35, 36]
	Education and training	To what degree training and education plans are tailored and executed.	12	[37]
	Overview of sequence of tasks in the design process	Degree of everybody's overview of the sequence of tasks in the design process according to their own job description.	38	[38-40]
	Autonomy of task execution	Freedom in one's own decisions and task execution in alignment with one's responsibilities and co-ordination with others.	12	[41, 42]
Team	Collaboration	Regularity of collaboration and of the effort to improve collaboration.	17	[43-46]
	Team identity	Strength of belonging to the team and degree of reflection how team identity can be strengthened.	11	[47-49]
	Reflection Best practices/ Lessons learned/ Project reviews	How often 'best practices' and 'lessons learned' are considered and how 'best practices' and 'lessons learned' are communicated within the team and to other teams for future task execution.	 11 18 17	[50, 51]
	Common goals and objectives	Knowledge and pursuit of common goals and objectives.	16	[53, 54]
Organisation	Mutual trust	Degree of interpersonal trust and effort to create trust within the project team.	14	[49, 59-61]
	Roles and responsibilities	Knowledge about someone's own and the other's roles and responsibilities and the use of it while communicating.	20	[42]
	Handling of technical conflicts	How often technical conflicts are addressed and resolved.	14	[63-65]
	Activity at interface with the other party	Degree of activity with regard to the interface with the other party.	41	[67, 68]
	Transparency of decision making	Transparency of decision making and involvement of the right people in the decision making process.	12	[69-71]
	Application of corporate vision and values	Knowledge and application of corporate vision and values.	13	[45, 53, 54, 56, 65, 72]
	Usage of procedures	Effort to improve design procedures and the usage of procedures.	25	
	Hierarchies	Understanding how hierarchies can be called upon to achieve clear communication.	19	

*number of times mentioned in interview

5 LIMITATIONS OF THE STUDY

The purpose of this research is to identify influences on communication in new product development. Data was taken from 63 interviews and subsequently mapped to literature. Therefore, the list is biased towards the answers given by engineers in industry. Project characteristics, characteristics of the team members and factors external to the project are not taken into consideration in this paper. Further, the list is extracted in an indirect manner. Interviewees were asked to describe their daily interactions with colleagues from other teams as opposed to asking directly what in their opinion influences this very interaction. The factors elicited are defined in a rather broad sense without suggesting any hierarchy (a topic explored here [25]). The list in Table 1 does not prescribe procedures to conduct communication effectively within an organisation, nor does it attempt to measure the causal relationships between influences and outcomes. However, it does offer a foundation upon which such investigations can be carried out. Lastly, the record was extracted with the purpose of developing an assessment method. Thus, the list is a means to an end.

6 DISCUSSION AND IMPLICATIONS OF RESULTS

6.1 Discussion

Acknowledging that some factors are beyond any individual's control, e.g. change of ownership, this paper, therefore concentrated on factors that are within the remit of the individual design engineer and his or her line manager in connection with top management. Not everybody, however, has the power to affect all factors as influence rests at certain levels. For example, company management at the top level may define the basic structure of organisation (hierarchies) and may set the goals and vision of the company. Within these constraints, teams may decide how they apply and contribute to the company vision within their own remit of tasks. Functions, such as human resources or process excellence groups develop procedures and guidelines which help individual engineers understand how they are meant to interact with each other. These guidelines also have an influence on how a team works and how certain tasks are to be approached, e.g. best practice or lessons learned are factors often defined by the organisation but left to the discretion of a team as to how they carry them out. Team managers can foster collaboration within a team. They may generate conditions within which an individual works. However, how an individual works often depends on his or her willingness to engage with the process. Individuals themselves need to understand what is expected of them and what they need from others. They are also responsible for acquiring and providing information. Responsibility for representations rests on all levels. Whilst individual engineers may decide which notations and terminologies are most suitable for the task and interaction partner, the basic choice of software tools and thus representations they provide is often decided at the corporate level.

Communication is never perfect. In each communication situation something could be better. However, detrimental effects of, for example, lack of formal structures or leadership are often compensated by the enthusiasm and social skills of individuals. Similarly, individual idiosyncrasies can be mitigated by other team members' facilitation skills. Yet, this only works to a certain extent. If some factors are completely dysfunctional it is very different to establish effective communication. For example, if team members do not trust each other, open sharing of tentative or sensitive information is very difficult. Similarly, if lessons learned are not in place, or procedures are not adhered to and there is high staff turnover, information will be lost and the company is likely to repeat mistakes that have already been made in the past.

Managing communication can sometimes be achieved by removing obstacles that can easily be identified, e.g. ambiguous representation can be disambiguated (e.g. Eckert, 2000) or incompatibilities of software tools can be removed. In general, however, a big step towards improvement of communication can be taken if individuals and teams understand their own responsibilities with respect to paying attention to factors influencing communication and thus help generating a climate in which the listed factors are in balance.

6.2 Implications

Similarly to Moray [73], in analysing new product development processes it is claimed here that the performance of a company is affected both by engineering characteristics of the design and the design of communication within and between groups and teams. Research presented here provides a set of empirical results aiding interface management. Therefore, this paper should be of interest to engineers, engineering managers and researchers.

- Engineers: The record of factors affecting communication in product development identified serves as a checklist for design engineers and can reduce uncertainty.
- Engineering managers: Although developing new products is affected by many uncontrollable external factors, managers can improve the way they evaluate their practices by understanding the factors that influence communication and thus hopefully reduce these factors' negative impacts. In other words, results presented here furnish a checklist of considerations to keep in mind when designing or evaluating communication practices.

- Researchers: Researchers can look at the effects of all the factors simultaneously to uncover the relative contribution of each factor in new product development communication and can study the interactions amongst the factors.

7 CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

This study is descriptive in nature and as such, we avoid drawing explicit normative conclusions. Factors are not differentiated into 'enablers' and 'barriers' as they can act as both.

7.1 Conclusions

Organisational theorists as well as social and work psychologists have repeatedly affirmed the importance of interpersonal working relationships and communication to goal accomplishments within a company [74]. Communication is crucial in new product development. However, observations suggest that it is often unfairly 'blamed' when things go wrong. This paper suggests that communication problems can be the effect of factors related to information, representations, the individual, the team and the organisation. By delineating factors that influence communication in new product development, the study lays a foundation for systematic development and evaluation of communication problems. This foundation can also stimulate the formulation of issues and hypotheses for investigation by researchers.

7.2 Future directions

There are a number of directions for future research, a number of which are listed. Firstly, analysing drivers for team member satisfaction, factors, such as clear project goals, for example, have been found to be important [75]. Future research can investigate how the findings in this study map on to research on team effectiveness. Secondly, additional factors that have been found to be important such as 'team composition' and 'leadership' were not investigated here. Future research can examine what role they play in addition to the factors examined here. Thirdly, as there are rapid changes occurring in the business environment, criticality of factors might change. Therefore, future research can investigate whether individual factors change in importance over time. Lastly, to judge completeness, correctness and validity, future research will compare results presented here with results from other empirical studies, e.g. on competences.

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