IMPROVING COMMUNICATION IN DESIGN: RECOMMENDATIONS FROM THE LITERATURE

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ABSTRACT

Communication permeates every aspect of an engineer's work – from clarifying product specifications to shaping social ties. This paper offers an overview of recommendations from literature to improve communication within and among engineering teams. We assume communication problems are often the outcome of underlying factors and that it is fruitful to study and improve these influences. Having been empirically elicited in prior research, 24 factors considered in this paper include, e.g., *availability of information about product specifications, roles and responsibilities,* and *overview of sequence of tasks*. To improve these factors in order to enable effective communication, this paper collates more than hundred recommendations from journal articles and textbooks published in the fields of engineering design, management science, sociology, and psychology. Recommendations include, for example, *identify priorities through risk and bottleneck analysis, give clear descriptions and role expectations,* and *employ effective process modeling tools.* Contributions of this paper are a list of recommendations for industry practitioners and an effort-benefit evaluation of individual recommendations.

Keywords: design management, human behaviour in design, collaborative design, design communication, success factors

1 INTRODUCTION

Researchers and practitioners point to the importance of communication in product development. On the one hand, suboptimal communication has potentially detrimental effects, e.g. resulting in late and costly modifications [1]. One the other hand, effective communication has its rewards, e.g. resulting in better processes and products [2], a more pleasant workplace for the engineer [3], and/or satisfied repeat customers [4]. Communication in this paper is conceptualised as co-ordination of behaviour [5] and thereby influencing and enabling collaboration in product development networks.

There are a number of complementary ways in which one can study communication in design with the aim to support and improve it. To point just to two: One approach starts with an analysis of the product structure and the steps in the design process and branches out to a suggested organisation structure [6]. This approach focuses on (ideal) information flow patterns and infers 'who needs to speak to whom' from tasks that need to be completed to develop the product. Another approach starts with the assumption that communication at team-interfaces is influenced by a range of factors, such as *availability of information about product specifications, roles and responsibilities, transparency of decision-making, representations,* and *overview of sequence of tasks.* This approach focuses on the perception and expectation of the individual engineer and teams of engineers on a range of factors and improving those will improve communication and thereby the product development process, e.g. [7]. In this paper, which focuses on eliciting published recommendations to improve communication, the focus is on the latter. This paper is part of a series of articles published in the preceding two ICED conferences. One records a set of empirically elicited factors influencing communication in new product development, another examines associations between these factors, and the current paper collates recommendations.

The objective of this paper is to provide recommendations that improve communication within and between engineering design teams. This paper is for researchers focusing on interventions in organisations and practitioners in industry managing engineering teams and asks: *How can practitioners improve communication through 'tackling' influencing factors?*

The remainder of the paper is structured as follows: Section 2 describes the methodological procedure employed. Section 3 presents and discusses the results. Section 4 describes implications for industry and academia and discusses limitations of the study. Section 5 concludes and suggests avenues for further research.

2 METHODS FOR DATA ACQUISITION: FACTORS, LITERATURE SOURCES

In this section, the selection of factors and rationale underlying the literature survey are explained.

2.1 Factors influencing communication in collaborative design

In research preceding this paper, 63 staff from three companies in the aerospace, engineering tools, and information technology sectors were interviewed. 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. The most frequently mentioned factors in interview were selected and findings were condensed into a list of 24 factors. Results from interview indicate that human communication between teams in new product development is affected by four major sets of factors, namely, information, individual, team, and organisation (for details see [8]). Each category is divided into a number of factors (Tables 1a and 1b). 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. [7].

2.2 Sources of literature for elicitation of recommendations

A number of search methods were used to systematically scan various sources of literature. As each method yields particular benefits and has limitations, various methods were employed in parallel to leverage complementarities [9]. This included: keyword search of an electronic database, targeted reading of selected academic journals and textbooks from relevant disciplines, as well as articles found through references from the consulted publications. In what follows, each method will be described in more detail.

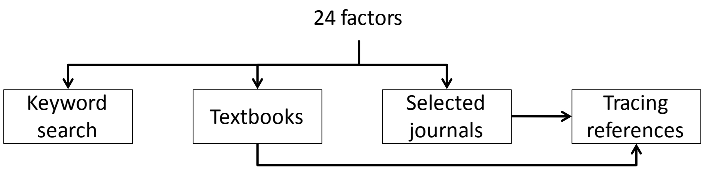

Figure 1 Procedure for systematic literature review

Searching keywords: The ISI Web of Knowledge database was keyword searched (latest search December 2009). All search strings were composed of the terms ‘communication’ and ‘engineering design’ or ‘design’. In addition, they were complemented by terms related to the specific factor. For example, the following search string was used for the factor ‘availability of information about product specification’: *(“engineering design” OR (engineering SAME team*)) AND communication AND (product* SAME information).* Only journal articles were considered.

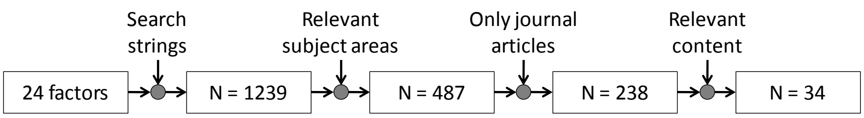

Figure 2 Keyword search process

Selecting journals: Sixteen journals were selected. They were on the one hand from the field of engineering design listed on The Design Society website (accessed October 2009). On the other hand, they were journals from the fields of engineering management and management science which achieved high scores across at least five of the 19 different rankings compiled by Harzing in 2009 (http://www.harzing.com/jql.htm).

Selecting books: In total, eight textbooks from relevant disciplines, e.g. engineering management, sociology, social psychology, human resource management and management science were chosen according to recommendations from reading lists published by leading academic institutions. Additionally, book citations were traced which were referenced by previously elicited relevant articles and/or other textbooks. Finally, thematically grouped shelves of university libraries were perused.

Tracing cross-referenced articles: Relevant articles referenced in publications elicited in earlier steps were also traced. For example, if an author described a recommendation citing a source that was important or added additional value, this source was also traced and taken, provided it met the same quality standards set earlier and contributed to the research questions.

3 RESULTS AND DISCUSSION

In a first step, recommendations were elicited from the literature (see Section 3.1 Compilation). In a second step, recommendations were evaluated in terms of their potential implications (effort) and outcome (benefit) (see Section 3.2 Evaluation). For each contribution, results are presented and subsequently discussed.

3.1 Compilation of recommendations: Results of literature analysis

The literature survey resulted in a list of 120 recommendations: 20 for factors grouped under the category ‘information’, 21 for factors grouped under the category ‘individual’, 39 for factors grouped under the category ‘team’ and 40 for factors grouped under the category ‘organisation’ (see Tables 1a and 1b). Elicited recommendations were stated directly and not inferred by the authors of this paper. The essence of findings for each category and factor can be summarised as follows (3.1.1-3.1.4):

Table 1a Overview of recommendations: Information and Individual

Information

Availability of information about product specifications

Shift effort to early project phases
(Smith D.G. and Rhodes R.G. Specification formulation – an approach that works. *Journal of Engineering Design*, 1992, 3(4), 275-289.)
Collect requirements carefully and thoroughly (Smith and Rhodes, 1992)
Pull together information from various departments
(Smith and Rhodes, 1992; Nellore, R., Söderquist, K. and Eriksson, K.-A. A specification model for product development. *European Management Journal*, 1999, 17(1), 50-63.)
Ensure good information transmission especially in the initial project phase (Nellore et al.,1999)
Create several specification lists; an official, and a stricter internal one (Nellore et al.,1999)
Ensure validation plans and feedback at all levels (Nellore et al.,1999)
Pay attention to adequately presented information (Nellore et al.,1999)
Use systematic and structured approaches to ensure broad input for product specifications
(Smith and Rhodes, 1992; Nellore et al., 1999; McKay, A., de Pennington, A. and Baxter, J. Requirements management: A representation scheme for product specifications. *Computers in Industry*, 2001, 33(1), 511-520.)
Identify priorities through risk and bottleneck analysis (Nellore et al.,1999)
Use computer-aided communication networks
(Söderquist, K. and Nellore, R. Information systems in fast cycle development: Identifying user needs in integrated automotive component development. *R&D Management*, 2000, 30(3), 199-201.)
Perform design reviews in early phases already
(Shooman, M.L. *Software engineering: Design, reliability and management*, 1983 (McGraw Hill, New York).

Availability of information about competitors

Share information early during product development
(Rouibah, K. and Caskey, K.R., Managing concurrent engineering with early supplier involvement: A case study, *International Journal of Computer Integrated Manufacturing*, 2005, 18(6): 509-521.)

Availability of information about the organisation

Establish a standardised terminology for inter-company communication
(Lin, H.-K., Harding, J.A., Shahbaz, M. Manufacturing system engineering ontology for semantic interoperability across extended project teams. *International Journal of Production Research*, 2004, 42(24), 5099-5118.)
Use only terminology accepted by all participating parties
(Lin, H.-K., Harding, J.A. A manufacturing system engineering ontology model on the semantic web for inter-enterprise collaboration, *Computers in Industry*, 2007, 58 (5), 428-437.)
Acknowledge the validity of questions and comments (
Frank, M.V. View through the door of the Sofia project. *IEEE Transactions on Reliability*, 2001, 54(1), 181-188.)
Answer questions in a simple, straightforward manner (Frank, 2005)
Don’t be arrogant or overly confident in your presentation. Point out assumptions, and uncertainties, including your limits of knowledge (Frank, 2005)

Availability of information about company procedures

Use sophisticated knowledge sharing tools
(Brandt, S.C., Morbach, J., Miatidis, M., Theißen, M., Jarke, M., Marquardt, W. An ontology-based approach to knowledge management in design processes. *Computers and Chemical Engineering*, 2008, 32(1), 320-342.)
Constantly reinforce information sharing
(Dawson, S. *Analysing organisations.* London, 1996 (Macmillan Press, London); Chang, W.-C. and Li, S.-T. Fostering knowledge management deployment in R&D workspaces: A five-stage approach. *R&D Management*, 2007, 37(5), 479-493.)

Individual

Overview of sequence of tasks in the design process

Employ effective process modelling tools (Culley, S.J., Boston, O.P. and McMahon, C.A. Suppliers in new product development: Their information and integration. *Journal of Engineering Design*, 1999, 10 (1), 59-75; Rouibah and Caskey, 2005)

Do you know what you need to know

Identify and prioritise knowledge needs (Ahmed, S. and Wallace, K.M. Identifying and supporting the knowledge needs of novice designers within the aerospace industry. *Journal of Engineering Design*, 2004, 15(5): 475-492.)

Best use of capabilities

Select team members for skill and skill potential (Mullins, L. J. *Management and organisational behaviour.* 2005, 7th edition (Prentice Hall: Essex); Katzenbach and Smith, 2005)
Maintain employees’ performance, knowledge, skills, experience, interests, and relevant personal characteristics in a data bank (Chen and Lin, 2004)
Maintain a friendly atmosphere (Goleman, D., and Boyatzis, R. Social intelligence and the biology of leadership. *Harvard Business Review* , 2008, 86(9), 74-81.)
Encourage team members (Nohria, N., Groysberg, B., Lee, L.-E. Employee motivation: A powerful new model. *Harvard Business Review* , 2008, 86(7), 78-84.)

Autonomy of task execution

Do not become involved in the problem-solving process of the engineering team (Kratzer, J., Leenders, R., Van Engelen, J. The social structure of leadership and creativity in engineering design teams: An empirical analysis, *Journal of Engineering and Technology Management*, 2008, 25(10), 269-286.)
Facilitate rather than direct and help workers to manage themselves
(Walton, R.E. From control to commitment in the workplace, Harvard Business Review, 1985, 63(3), 77-84.)
State your expectations clearly (Rosenhead, J. *Rational analysis for a problematic world: Problem structuring methods for complexity, uncertainty, and conflict*, 1989 (John Wiley & Sons: Chichester, UK).)
Change the company culture rather than just schedules (Marquez, J. Changing a company's culture, not just its schedules, pays off, *Pensions & Investments*, 2008, 36 (1), 21-22.)
Reward for results, not time spent working (Pink, D.H. *A whole new mind: Moving from the information age to the conceptual age*, 2005 (Riverhead Books: New York).)
Use negative incentive schemes (Gürerk, Ö., Irlenbusch, B., Rockenbach, B. Motivating teammates: The leader’s choice between positive and negative incentives. *Journal of Economic Psychology*, 2009, 30(4), 591-607.)

Education and training

Include work/life issues into education and training
(Kossek, E.E. and Hammer, L.B. Supervisor work/life training gets results. *Harvard Business Review*, 2008, 86(1), 36.)
Exploit the power of positive feedback, recognition, and reward
(Katzenbach, J.R. and Smith, D.K. The discipline of teams. *Harvard Business Review*, 2005, 83(7), 162-171.)
Design training plans (Arnold, J. *Work psychology*, 2005 (Pearson Education: Essex).)
Follow a training cycle and repeat it regularly (Arnold, 2005)
Consider to source out training (Arnold, 2005)
Make education and training standard activities (Chang and Li, 2007)

Roles and responsibilities

Give clear job descriptions and role expectations (Brotherton, C. *Social psychology and management: Issues for a changing society*, 1999 (Open University Press: Buckingham); Bandura, A. *Self-efficacy: The excercise of control*, 1997 (W.H. Freeman: New York).)
Consider a quantitative representation of team member characteristics
(Chen, S.-J. and Lin, L.. A project task coordination model for team organization in concurrent engineering. *Concurrent Engineering: Research and Applications* , 2002, 10 (3), 187-202.)
Communicate objectives very clearly (Hamm, J. The five messages leaders must manage, *Harvard Business Review*, 2006, 84(5), 115-123.)
Do not underestimate the ability to change personnel - focus more on training and development activities
(Manning, T., Parker, R. And Pogson, G. A revised model of team roles and some research findings. *Industrial & Commercial Training*, 2006, 38 (6/7), 287-296)

3.1.1 Information: Sharing information to improve communication

Most of the recommendations for factors grouped under this category were found in publications about *availability of product specifications*, suggesting shifting to early design phases when putting specifications together or emphasising thoroughness when collecting requirements within and across departments. Recommendations to improve *availability of information about competitors* for benchmarking purposes or merely to keep abreast with what is happening are not concrete. Similarly, *company information* and the knowledge about *procedures* were not covered to a great extent by the literature. The importance of terminologies when sharing information (especially across functional boundaries) is stressed. In terms of knowledge sharing tools and methods it is suggested to use them in a way that is adequate to organisational needs. Reinforcement of their use is also regarded as being important.

3.1.2 Individual: Orientation and building context

In order to gain an *overview of the sequences of tasks* in the design process, it has been argued that most current process modelling methods may not be adequate. However, adequate process modelling is a prerequisite for adequate communication in complex engineering projects and thus, we can infer a fruitful research focus for future work in engineering design. Scarce material about how to improve *knowledge about information needs* stresses the importance of the issue and calls for prioritisation of research in this area. In terms of the use of *employees' capabilities* it has been argued that the factor has strong links to employee motivation, which is fostered through maintaining a friendly atmosphere and encouragement. Authors agree that employees should be selected according to their skills in order to allow them to use their capabilities. Some also acknowledge employees' potential to develop skills and thus extend their capabilities according to the job description. While some authors argue that employees should be left with as much *autonomy* and flexibility as possible to design their job, others promote incentive schemes to control output. A general consensus seems to exist according to which the more autonomy engineers have, the better the creative results. Results for the factor *education and training* suggest that this topic should not be left to chance but approached consciously and in a controlled manner. Methods to evaluate training needs are as important as continuous awareness of training issues. While *roles and responsibilities* can be interpreted in different ways, it is important to give employees clear job descriptions in order to achieve clear communication lines.

3.1.3 Team: Structuring collaboration

In terms of *lessons learned* and *best practices* authors point to the importance of reliable feedback following completed projects. Authors recommend providing process guidelines, using tools that enable collaboration, collecting process data, institutionalising disciplined reflection, as well as capitalising on overview and expertise of experienced designers. They stress that it is important to ensure that managers and designers both have an overview of the entire design project and that knowledge and skills of experienced designers should be used to help coordinate tasks for less experienced employees. Authors also point to the positive effect of appraisals. One author recommends fostering knowledge exchange through the formation of informal networks and effective communication, in particular communities of practice. Research on *collaboration* returned a vast amount of findings, acknowledging collaboration as an essential part of teamwork, but also warning not to underestimate collaboration costs. A number of authors stress to encourage teams and to provide a common purpose for their work, as well as a sense of community (*team identity*). Employees need to be provided with the necessary skills to collaborate, but also with feedback, mentoring, and coaching. It is also important for team leaders to act as a role model by collaborating themselves. Authors addressing the factor *design reviews* suggest performing them especially in the specification phases of the design, and setting specific goals that are measurable. This is necessary to maintain sufficient control over the project outcome. Also, ambiguity in communication should be reduced by using an agreed set of annotations. While literature about *common goals and objectives* was not found with regard to engineering, general management suggests a long-term approach to communicating company values and objectives. This is done by frequently engaging in persuasive talks with employees and constantly reinforcing values in order to change employee attitudes and behaviour.

Table 1b Overview of recommendations: Team and Organisation

Team

Lessons learned

Provide reliable and prompt feedback (Busby, J.S. The neglect of feedback in engineering design organisations. *Design Studies*, 1998, 19(1), 103-117; 1998; Mullins, L.J. Management and organisational behaviour . 2005, seventh edition. (Prentice Hall: Essex).)

Remember that learning works best with encouragement and praise (Mullins, L.J. Management and organisational behaviour . 2005, 7.ed. (Prentice Hall: Essex); Goleman, D., Boyatzis, R. E. (2008). *Social intelligence and the biology of leadership, 2008,* 9 .ed., vol. 86, 74-81. (Harvard Business Review: Boston, MA).)

Form communities of practice (McMahon, C. , Crossland, R., Lowe, A., Shah, T., Williams, J.S. and Culley, S. No zero match browsing of hierarchically categorized information entities. Artificial Intelligence for Engineering Design, Analysis and Manufacturing (AI EDAM), 2002, 16(3), 243-257.)

Collaboration

Remind people of having a compelling purpose (Henley, D., Power of collaboration, *Leadership Excellence*, 2009, 26(8), 4.)

Hire the right people (Henley, 2009)

Provide the right job design (Henley, 2009)

Deal with failures optimistically (Henley, 2009; Allen, N.J. and Hecht, T.D., The 'romance of teams': Toward an understanding of its psychological underpinnings and implications, *Journal of Occupational and Organizational Psychology*, 2004, 77 (4): 439-461.)

Use appreciation (Henley, 2009)

Demonstrate your commitment to relationship practices (Gratton, L. and Erickson, T.J., 8 ways to build collaborative teams, *Harvard Business Review*, 2007, 85 (11): 100-109.)

Be a role model (Gratton and Erickson, 2007)

Practice mentoring and coaching (Gratton and Erickson, 2007)

Ensure soft skills for communication (Gratton and Erickson, 2007)

Support a sense of community (Gratton and Erickson, 2007)

Strive for task- and relationship-oriented team members (Gratton and Erickson, 2007)

Build on heritage relationships (Gratton and Erickson, 2007)

Understand role clarity and task ambiguity (Gratton and Erickson, 2007)

Set clear rules for behaviour (Katzenbach and Smith, 2005)

Offer team-based rewards (Hauptman, O. and Hirji, K.K., Managing integration and coordination in cross-functional teams, *R&D Management*, 1999, 29(2), 179-192.)

Implement job rotations (Hauptman and Hirji, 1999)

Use 360-degree feedback (Polzer, J.T. Making diverse teams click. *Harvard Business Review*, 2008, 86 (7/8), 20-21.)

Consider alternative non-collaborative activities (opportunity cost (Hansen, M.T., When internal collaboration is bad for your company, *Harvard Business Review*, 2009, 87(4), 82-88.)

Constantly evaluate the value created through collaboration (Hansen, 2009)

Don't underestimate collaboration costs (Hansen, 2009)

Design review

Perform design reviews especially in the specification phases (Shooman, 1983)

Define specific goals (Katzenbach and Smith, 2005)

Set concrete values and measures for goals (Katzenbach and Smith, 2005)

Use a set of agreed symbols and terms for annotations in the design (Hisarciklilar, O. and Boujut, J.-F.: An annotation model to reduce ambiguity in design communication. *Research in Engineering Design*, 2009, 20(3), 171-184.)

Common goals and objectives

Reinforce organisational values on a constant basis (Garvin, D.A. and Roberto, M.A. Change through persuasion, *Harvard Business Review, 2005, 83(2),* 104-112.)

Strive for a change of behaviour – not just of thinking (Garvin and Roberto, 2005)

Design and run a persuasion campaign in phases (Garvin and Roberto, 2005)

Best practice

Capture knowledge properly (Fruchter, R. and Demian, P. Comem: Designing an interaction experience for reuse of rich contextual knowledge from a corporate memory. Artificial Intelligence for Engineering Design, Analysis and Manufacturing (AI EDAM). 2002, 16(2), 127-147.)

Provide process guidelines, tools that enable collaboration, collect process data, and institutionalise disciplined reflection (Edmonson, A.C. The competitive imperative of learning. Harvard Business Review, 2008, 86, (7/8), 60-67.)

Use the overview of experienced designers (Flanagan, T., Eckert, C., and Clarkson, P.J. Externalizing tacit overview knowledge: A model-based approach to supporting design teams. Artificial Intelligence for Engineering Design, Analysis and Manufacturing (AI EDAM), 2006, 21(3), 227-242.)

Encourage formal interactions in the form of meetings (Flanagan et al., 2006)

Coordinate less experienced employees through the use of more prescriptive plans (Flanagan et al., 2006)

Ensure managers and designers have an overview of the entire design project (Flanagan et al., 2006)

Use best-practice cases from other company units and previous innovative projects (Hansen, 2009; Durand, M.-G., Renaud, J. and Boly, V. Past projects memory: Knowledge capitalization from the early phases of innovative projects. Concurrent Engineering: Research and Applications, 2009, 17 (3), 213-224.)

Team identity

Understand that people should have similar problem-solving styles (Lopez-Mesa, B. and Thompson, G. On the significance of cognitive style and the selection of appropriate design methods. Journal of Engineering Design, 2006, 17(4), 371-386.)

Establish urgency, demanding performance standards, and direction (Katzenbach and Smith, 2005)

Pay particular attention to first meetings and actions (Katzenbach and Smith, 2005)

Spend lots of time together (Katzenbach and Smith, 2005)

Organisation

Activity at interface with other party

Seek information within the organisation; team members should try to solve problems through horizontal communication rather than through management (Griffin, A. and Hauser, J.R. Patterns of communication among marketing, engineering and manufacturing - a comparison between two new product teams. *Management Science*, 1992, 38 (3), 260-273.)

Employ a third party expert during first meetings to coordinate communication issues (Skepper, N., Straker, L. and Polloc, C. A case study of the use of ergonomics information in a heavy engineering design process. *International Journal of Industrial Ergonomics*. 2000, 26(3), 425-435; Neumann, W.P., Ekman, M. and Winkel, J. Integrating ergonomics into production system development – the volvo powertrain case. *Applied Ergonomics*, 2009, 40 (3), 527–537.)

Everyone should have the freedom to communicate with anyone. It must be safe for everyone to offer ideas (Catmull, E. How pixar fosters collective creativity. *Harvard Business Review*, 2008, 86(9), 64-72.)

Invest in cross-divisional ties and encourage the mobilisation of organisational resources (Kleinbaum, A.M. and Tushman, M.L. Managing corporate social networks. *Harvard Business Review*, 2008, 86 (7/8), 26-27.)

Usage of procedures

Employ engineers with high levels of project work experience (Zika-Viktorsson, A. and Ingelgård, A. Reflecting activities in product developing teams: Conditions for improved project management processes. *Research in Engineering Design*, 2006, 17(1), 103-111.)

Establish high levels of time pressure and extensive managerial support (Zika-Viktorsson and Ingelgard, 2006)

Hierarchies

Recognise that entire support systems must be in place to support team performance (Allen, N.J. and Hecht, T.D. The 'romance of teams': Toward an understanding of its psychological underpinnings and implications. *Journal of Occupational and Organizational Psychology*, 2004 77 (2004) 4: pp. 439-461.)

Adopt a management style that is more collegial than supervisory (Despres, C. and Hiltrop, J.-M. Human resource management in the knowledge age. *Employee relations*, 1995, 17(1), 9-23.)

Share information, delegate responsibility and encourage upward and horizontal communication (Despres and Hiltrop, 1995)

Handling of technical conflicts

Manage for parameter consistency and provide context- and reader-independent semantics (Wang, W.-M., Hu, J., Yin, J.L. and Peng, Y.-H. A knowledge-based parameter consistency management system for concurrent and collaborative design. *Journal of Engineering Manufacture*, 2007, 221(1), 97-107.)

Use one-to-one talks to resolve conflicts of interpersonal aspects of group work (Bass, B.M. and Stogdill, R.M. *Handbook of leadership*, 1990 (The Free Press: New York).)

Approach conflicts pro-actively (Heifetz, R.A. Leadership without easy answers, 1994. (Harvard University Press: Cambridge, Massachusetts); Arnold, J. Work psychology. 2005 (Pearson Education: Essex).)

Generation of innovative ideas

Create an atmosphere where people are awarded for their contribution of ideas (Edmonson, A.C. The competitive imperative of learning. *Harvard Business Review*, 2008, 86 (7/8), 60-67.)

Create a psychological attachment to the organisation (Walton, R.E. From control to commitment in the workplace. *Harvard Business Review*, 1985, 63(2), 77-84.; Organ, D.W. and Ryan, K. A meta-analytic review of attitudinal and dispositional predictors of organizational citizenship behavior. *Personnel Psychology*, 1995, 48(4), 775-802.)

Do not mistrust your workforce (Thompson, P. and Warhurst, C. Workplaces of the future, 1998. (Macmillan Business Press: Basingstoke).)

Use brainstorming sessions (Perttula, M. and Sipilä, P. The idea exposure paradigm in design idea generation, *Journal of Engineering Design*, 2007, 18 (1), 93-102.)

Share only the most unusual ideas instead of always exposing people to the most common ones (Perttula and Sipilä, 2007)

Create a pool of ideas to draw from (Perttula and Sipilä, 2007)

Do not dominate the problem-solving process (Kratzer, J., Leenders, R. and VanEngelen, J. The social structure of leadership and creativity in engineering design teams: An empirical Analysis. *Journal of Engineering and Technology Management*. 2008, 25 (10), 269-286.)

Mutual trust

Have team members make their personal preferences and assumptions explicit (Foley, J. and Macmillan, S. Patterns of interaction in construction team meetings. *CoDesign: International Journal of CoCreation in Design and the Arts*, 2005, 1(1), 19-37.)

Repair trust through eliminating negative emotions and account for things that went wrong (Tomlinson, E.C. and Mayer, R.C. The role of causal attribution dimensions in trust repair. Academy of Management Review, 2009, 34(1), 85-104.)

Practice threat-reducing behaviour in order to influence positive emotions (Williams, M. Buildung trust interpersonal emotion management: A threat regulation model of trust and collaboration across boundaries. *Academy of Management Review*, 2007, 32(2), 595-621.)

Demonstrate concern for the fears and threats that counterparts may experience (Williams, 2007)

Use close communication to enable purposeful and powerful cooperation (Miles, S.A. and Watkins, M.D. The leadership team. Harvard Business Review, 2007, 85(4), 90-98.)

Express authenticity when building strong trust in relationships (Brockner, J. Why it's so hard to be fair. *Harvard Business Review*, 2006, 84(2), 122-151; Williams, M. Building trust through interpersonal emotion management: A threat regulation model of trust and collaboration across boundaries. *Academy of Management Review*, 2007, 32(2), 595-621.)

Application of vision and values

Communicate with many persons (Rouibah and Caskey, 2005)

Transmit visions and values authentically (Weinberger, D. Authenticity: Is it real or is it marketing? *Harvard Business Review*, 2004, 86(4), 33-43.)

Transparency of decision making

Give employees the feeling to be part of the decision making process (Brockner, 2006)

Invest in training and impression management (Brockner, 2006)

Identify and prioritise the decisions that must be made (Davenport, T.H. Make better decisions. *Harvard Business Review*, 2009, 87(11), 117-123.)

Follow a clear guideline through the decision making process (Ullman, D.G. Robust decision-making for engineering design. *Journal of Engineering Design*, 2001, 12 (1), 3-13.)

Have a clear understanding of the issue (Ullman, 2001)

Examine the factors involved in each decision (Davenport, 2009)

Develop a set of objective criteria (Ullman, 2001)

Design the context (i. e. roles, processes, systems, and behaviour) to improve decisions (Davenport, 2009)

Evaluate alternative decisions (Ullman, 2001)

Institutionalise the new approach through training, refined data analysis, and outcome assessment (Davenport, 2009)

Do not be afraid of changing your mind before employees in later conversations (Bass, B.M. and Stogdill, R.M. Handbook of leadership, 1990. (The Free Press: New York).)

3.1.4 Organisation: effective operations

Authors addressing *activity at interfaces* encourage that information is proactively sought within the organisation and team members should try to solve problems through direct, horizontal communication rather than through top-down management. Another suggestion found recommends an environment which encourages freedom to communicate with anyone and safety for everyone to offer ideas. Management should invest in cross-divisional ties and encourage the mobilisation of organisational resources. In order to optimise *usage of procedures*, authors suggest that engineers with high levels of project work experience should be employed. Some found an increase in reflective actions and co-workers' initiatives for using procedures when high levels of time pressure are established and extensive managerial support is provided. In order to use organisational *hierarchies* to facilitate communication, authors recommend adopting a management style that is more collegial than supervisory and to share information, delegate responsibility and encourage upward and horizontal communication. *Technical conflicts* can be handled best when conflicts are approached pro-actively. Team leaders should manage for technical parameter consistency as far as possible in order to prevent the emergence of (personal) conflicts, and provide context- and reader-independent semantics, i.e. a shared understanding by all parties involved. Many authors address the issue of increasing *generation of innovative ideas*, particularly those with a background in management science. They recommend that team leaders and management should create an atmosphere where people are awarded for their contribution of ideas. Employees should be trusted and given a psychological attachment to the organisation in order to increase their motivation to innovate. Technically, the use of brainstorming sessions is recommended, as well as the creation a pool of ideas to draw from. It is important, however, for team leadership and management, not to dominate the problem-solving process. Since *mutual trust* is a universal topic, which is relevant for any kind of team, most literature on it is found outside the domain of engineering. Authors suggest that trust is essential for teamwork and can be created when team members make their personal preferences and assumptions explicit. Few authors addressed the issue of translating company *vision and values* to design engineers. Those who did, mentioned the need to transmit visions and values authentically. Authors also mention the challenge of having to include many people when making visions and values known and understood. To achieve *transparency of decision making*, authors suggest that employees should be given the feeling to be part of the decision making process. Besides stressing the importance of transparent processes, many provide in depth recommendations on how to improve the decision making process itself. Decision makers should start by identifying and prioritising the decisions that must be made and follow a clear guideline through the decision making process. They should have a clear understanding of all issues and factors involved in a decision, develop objective criteria, and evaluate alternative decisions without being afraid of changing their mind in conversations with employees. If necessary, decision makers should invest in training and impression management to better communicate their point of view. It was also mentioned that a design of the context (i.e. roles, processes, systems, and behaviour) can help to improve decisions.

3.2 Discussion of compilation

Comparatively more recommendations were found for factors grouped under the categories 'organisation' and 'team' than for 'individual' and 'information'. When looking at the number of suggestions found per factor, they vary between one (e.g. for the factor improving communication through heightened *overview of sequence of tasks within the design process*) and 20 (for the factor improving communication through increased *collaboration*). For some factors there are a high number of recommendations and when looked closer, many of them come from one study where authors were particularly articulate in giving recommendations, such as for *collaboration,* where eight recommendations are drawn from one article. Often, there is only one study from which a number of recommendations are drawn, e.g. for factors *usage of procedures* and *common goals and objectives*.

Looking for explanations, one could argue that firstly, the selection and groupings of factors and the definition of search strings had an influence, secondly, it could be down to the relative importance of factors in different research communities from which literature was drawn, and, thirdly, results of this paper point to the possibility of a need for further research in some areas relative to others. The selection and groupings of factors followed extensive empirical research, as documented in articles from the authors, e.g. published in the two preceding ICED conferences and search strings were formulated accordingly. It might be speculated that for categories 'information' and 'individual' for which recommendations came more from research articles in engineering, authors were on the one hand a little more hesitant in giving specific and direct suggestions which also perhaps resulted in vague or abstract suggestions. The purpose and focus of most research articles consulted is perhaps on description and understanding and less so on specific suggestions. To reiterate, recommendations were directly taken and not inferred by the authors of this paper - where it was merely implied in the text and could have been inferred, it was not listed. Another point worth mentioning here is that these possibly "hidden" recommendations in findings might also be a function of journal papers. Authors might be a little more forthcoming in conference publications which we decided not to consider for international visibility and traceability reasons. With respect to fewer recommendations in the categories 'information' and 'individual', we might conclude that there is a need for research or a need for translation of research results into clear recommendations for industrial practitioners.

3.3 Evaluation of recommendations: Effort-benefit analysis

In Section 3.2.1, a framework to evaluate individual recommendations according to their potential effort-benefit structure is presented, whereby higher effort induces higher cost. For illustration purposes, Section 3.2.2 applies this framework to recommendations elicited for the factor 'availability of information about product specifications'.

3.3.1 Presentation of evaluation framework

Recommendations have implications. They incur effort and also yield benefit. For example, performing a risk analysis during the design process requires effort, such as collecting additional information. This takes time and resources and is hence noted on the effort side. On the benefit side, a recommended risk analysis may lead to a better outcome, such as improved decision making or the discovery of avoidable uncertainties. This may be a desirable and anticipated outcome that signifies added value. As it develops engineers' ability to perform tasks better and thus contribute to an overall greater productivity, acting upon recommendations can be seen as an increase in an engineer's intellectual (or human) capital. Ulrich [10] suggests intellectual capital be composed of competence and commitment.

Recommendations collated in this paper are firstly evaluated in terms of expected implications (effort) and expected outcome (benefit). Secondly, implications and expected outcome are furthermore differentiated in terms of competence and commitment (Table 2). The impact of an implemented recommendation is estimated to be either positive or neutral (negative is omitted as it is assumed that authors formulate recommendations as yielding positive outcomes). A positive impact is depicted with the arrowhead pointing upward and a neutral impact is represented by a horizontal line (Table 3). A positive impact is stated if one of the criteria in Table 2 is fulfilled. A neutral impact is stated if none of the criteria in Table 2 apply. The resulting framework is to be seen as a reference point against which individual recommendations can be evaluated bearing the specific task-, project- and company context in mind.

Table 2 Framework of evaluation criteria

	Effort (Implication)	**Benefit** (Outcome)
Competence	• Team members have to acquire **additional skills** and knowledge and may face **training** costs. • The team will need to **rely on specialists** amongst its members or hire new specialists.	• Employees acquire **planning competences** (e.g. to make better estimations on the duration of a task or on the potential impact of changes). • Team members acquire **inter-personal competences**. • **Decisions** will be more informed.
Commitment	• **Workload** will increase and implementation of recommendation might take too long. • Risk of discomfort due to changing **habits and attitudes**. • Ambiguity and **uncertainty** will rise.	• **Organisational engagement** of employees will increase. • The team members' **motivation** or job satisfaction will increase. • **Knowledge and experience sharing** will increase among colleagues.

Table 3 Evaluation of recommendations

Effort (Implication)		**Benefit** (Outcome)	
Competence	Commitment	Competence	Commitment
-	$\uparrow$	$\uparrow$	-

3.3.2 Exemplary listing and evaluation of recommendations for 'product specifications'

What follows is an exemplary illustration of the evaluation framework applied to recommendations concerning 'product specifications' (Tables 4a and 4b). When applying the framework, expected return on investment just after implementation was taken into consideration instead of long-term implications months or years after implementation. The effort-benefit structure of particular recommendations might vary depending on the specific task-, project-, and company context.

Product specifications aggregate all relevant input for the design of the product. Extension of enterprises across geographical spaces, increase in technical sophistication, in other words, an increase in complexity makes it even more important to ensure collection and 'availability of information about product specifications'. In what follows, the first three recommendations from Table 4 are discussed.

To support good communication and to prevent potential conflicts through ensuring a comprehensive and reliable list of specifications, Smith and Rhodes (1992) suggest *shifting effort to early project phases*. This reduces overall cost, speeds up product development, and, although requiring more attention at first, eases later development phases and simplifies later communications, so Smith and Rhodes. Implementing the recommendation, we anticipate an increase in needed competences, such as detailed knowledge about user and market situations for the new product once designed – hence, an increase in effort. On the benefit side, we anticipate an increase in planning competencies. Similarly for another recommendation by Smith and Rhodes which reads *collecting requirements carefully and thoroughly,* we anticipate a neutral effect on competence but an increase in workload on the effort-side. On the benefit side, we anticipate an increase in competencies as decision-making is better informed and in terms of commitment an increase in knowledge sharing. With respect to *pulling together information from various departments*, a further recommendation by Smith and Rhodes and Nellore et al. (1999) (see Table 4a), evaluations according to the suggested framework (Tables 2 and 3) result in neutral impacts on the effort-side as no additional technical skills are required and workload remains relatively unaffected. On the benefit-side, decisions may be better informed and cross-functional collaboration will be encouraged. Effort-benefit trade-offs have to be judged against the specific situation at hand.

All in all, evaluations help judge implications of potential implementation of recommendations from the literature. Yet, recommendations accentuate what do to and leave room for detailed 'how-to-instructions'. In order to properly judge the effort-benefit ratio, recommendations need to be mapped against potential ways of how to specifically implement them.

Table 4a Recommendations for the factor
'Availability of information about product specifications'

Summary of recommendations	**Source** (Table 1 for reference)	**Evidence**	**Inference from articles, *our interpretation (italic)***	**Effort** (Implication)		**Benefit** (Outcome)	
				Competence	**Commitment**	**Competence**	**Commitment**
Shift effort to early project phases	Smith and Rhodes, (1992: 275)	*"Analysis of a number of design projects"*	Reduces overall cost; speeds up and eases later phases	↑ Additional knowledge about market environments has to be acquired early on	- Overall workload will decrease, as argued by Smith and Rhodes (1992)	↑ Planning competences will be acquired	- Motivation may be not directly affected
Collect requirements carefully and thoroughly	Smith and Rhodes, (1992: 275)	*"Analysis of a number of design projects"*	Simplifies later communication, requires more attention at first	- Additional technical skills are required	↑ Workload will increase	↑ Decisions will be better informed	↑ Knowledge sharing will increase
Pull together information from various departments	Smith and Rhodes, (1992: 275); Nellore et al., (1999)	*"Analysis of a number of design projects"*, case studies in one auto and one aircraft OEM (Original Equipment Manufacturer)	*Prevents conflicts*	- No additional technical skills are required	- Uncertainties may decrease as workload remains relatively unaffected	↑ Decisions may be better informed	↑ Cross functional collaboration will be encouraged
Ensure good information transmission especially in the initial project phase	Nellore et al., (1999)	Case studies in one auto and one aircraft OEM	Requires communication between all stakeholders (e. g. involved departments)	- Additional skills are needed	- Uncertainty may decrease	↑ Decision making will be improved	- Motivation may not be directly affected

Table 4b Recommendations for the factor
'Availability of information about product specifications' continued

Summary of recommendations	**Source** (Table 1 for reference)	**Evidence**	**Inference from articles,** ***our interpretation (italic)***	**Effort** (Implication)		**Benefit** (Outcome)	
				Competence	**Commitment**	**Competence**	**Commitment**
Create several specification lists; an official, and a stricter internal one	Nellore et al., (1999)	Case studies in one auto and one aircraft OEM	Ensures quality	- Similar work is required	↑ Additional workload is created	↑ Planning may be improved	- Knowledge sharing might not increase
Ensure validation plans and feedback at all levels	Nellore et al., (1999)	Case studies in one auto and one aircraft OEM	Can prevent conflicts / increases effort	- Existing skills will be needed	↑ Changed work patterns and additional effort may be needed	- Planning competences may not be increased but be used more extensively	↑ Knowledge sharing may increase
Pay attention to adequately presented information	Nellore et al., (1999)	Case studies in one auto and one aircraft OEM	*Prevents misunderstandings*	↑ Details may have to be understood better	- Effort to clarify issues may decrease, as may uncertainties	- Planning skills may be unaffected	↑ Knowledge sharing will be encouraged
Use systematic and structured approaches to ensure broad input for product specifications	Smith and Rhodes, (1992: 275); Nellore et al., (1999); McKay et al., (2001)	Case studies in one auto and one aircraft OEM, *"Analysis of a number of design projects"*, one case study of a valve assembly.	Helps making important information available and can facilitate collaboration	↑ Approaches may have to be explored	- Workload may remain unaffected	- Planning may remain unaffected	↑ Decisions may be better informed
Identify priorities through risk and bottleneck analyses	Nellore et al., (1999)	Case studies in one auto and one aircraft OEM	Creates knowledge about desired direction of effort	↑ Skills may have to be acquired	↑ Workload will increase	↑ Decisions may be better informed	- Motivation or knowledge sharing may not be affected
Use computer-aided communication networks	Söderquist and Nellore (2000)	Case studies in the auto industry	Facilitates knowledge sharing and competences across functional boundaries	↑ Skills may have to be acquired	- Uncertainty may decrease through communicatio n	- Planning may remain unaffected	↑ Knowledge sharing may be encouraged
Perform design reviews already in early phases	Shooman (1983)	Experience of the author	Fosters better collaboration during later stages	- Different knowledge may be needed	↑ Change in the work process is suggested	↑ Decisions may be better informed	- Knowledge sharing or motivational factors may be unaffected

4 IMPLICATIONS AND LIMITATIONS OF THE STUDY

4.1 Implications for industry, research and education

There are two important implications of this work for practitioners in industry. The first implication relates to the use of recommendations found in literature to improve factors affecting communication in product development. The list serves as inspiration and decision aid for 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 set of evaluated actions to consult when attempting to improve communication practices. Researchers can look at the effects and trade-offs of all the recommendations simultaneously to test them in terms of usefulness for product development cycles. Recommendations can be used when teaching integrated product development as suggestions for managing communication to co-ordinate collaboration.

4.2 Limitations

The purpose of this research is to elicit recommendations to support managers and team leaders of engineering design teams. Due to the specific search rationale, the selection of recommendations is contingent on the literature consulted. Recommendations are listed with respect to their sources of origin. Suggestions are results of particular projects in particular industry sectors will have to be adapted to the specific situation. Comparison and juxtaposition of recommendations might therefore be difficult and the list has to be seen as a compilation of experience and insights from different authors. Also, as impact might vary, recommendations and their evaluations presented here need to be validated in industrial practice – beyond their sources of origin and this also applies to the suggested evaluation framework (Section 3.3.). Last but not least, prior to implementation, recommendations need to be assessed bearing ethical and legal issues in mind.

5 CONCLUSIONS AND FUTURE DIRECTIONS

5.1 Conclusions

This paper is seen as one part among three. The first offers a detailed description of elicitation and definition of factors via literature and empirical elicitation. The second provides a statistical analysis network of associations between factors. This third part offers recommendations elicited in literature. All papers are based on the premise that effective communication facilitates an effective design process which contributes towards a good product and that complex development projects need consideration of context- and project-specific socio-technical configurations.

This paper offers two main contributions. The first is a set of 120 recommendations to improve communication in engineering projects collected and mapped to factors influencing communication. This list gives engineers and engineering managers an overview of possible actions to attain effective communication and perhaps sensitises for actions which might otherwise not have been considered as they would perhaps not be found in one and the same publication. Despite the large number of recommendations found, the authors of the respective articles have been rather hesitant to give specific recommendations. Where authors did suggest improvement actions, they mostly resulted from a small amount of case studies. Testing in other settings or extrapolations for wider applicability was mostly left for future work. This led us to suggest an evaluation framework for recommendations which we applied to the elicited collection. The second contribution is a framework to evaluate recommendations. This can be used by industry personnel to assess recommendations found in the first step against the background of their specific situation. The framework allows an evaluation of each recommendation in an effort-benefit structure with effort and benefits both being evaluated in terms of competence and commitment. Further, the framework aids in 'testing' recommendations found in literature for applicability and usefulness within product development and to inform selection and potential use.

Suggesting actions to improve communication within and between engineering design teams is not a straightforward task. Products are different, processes are different, and people are different. Further, recommendations vary in scope and potential resource requirements. This said, individual studies have been conducted and recommendations have been documented in the literature and the task of this paper was to bring them to our attention and thus facilitate transfer of insights.

5.2 Future directions

The compilation of recommendations to improve communication presented here can be seen as a broad collection of options with possibly significant impact. There are several directions for future research, a number of which are listed. Firstly, additional factors should be considered. Factors frequently mentioned in relation to communication in the literature are, for example, 'shared ontologies', 'motivation', and 'attitudes'. Secondly, a detailed examination of individual factors and implications of specific recommendations will be worth undertaking. Thirdly, interdependencies of recommendations need to be examined as a project, a team and an organisation are situated in a wider network. Finally, validation of recommendations in industrial practice will contribute to work of industry practitioners in general and engineers in specific.

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