Cross-Border E-Collaboration for New Product Development in the Automotive Industry

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Abstract

In highly globalized industries such as the automotive industry, product development is strongly dependent on e-collaboration tools that hold the potential to capitalize on specialized-knowledge across nations, organizations and professions. This paper focuses on the determinants and impacts of e-collaboration tools in geographically distributed product development teams. Preliminary results from an empirical study conducted among members of three new product development teams suggest that the determinants of the level of use of e-collaboration tools seem strongly biased towards human-related factors (language differences, training, professional background differences) and that the overall impact of these tools is positive but not significantly related to cost reductions.

1. Introduction

This paper focuses on cross-border collaboration in the context of product development activities. More specifically, we propose to investigate the relative importance of determinants of the use of computer-mediated collaboration (e-collaboration) tools in geographically distributed product development teams and to assess the perceived impacts of these tools. This line of inquiry seems relevant for several reasons. First, product development represents a knowledge-intensive, high-value-added strategic activity which is increasingly conducted among geographically-dispersed teams [14]. Second, past research in the specific context of product development remains scarce and the empirical evidence limited (for exceptions, see [38], [29]). Third, the emergence of 3D viewing technologies, Internet-based virtual project rooms, advanced conferencing tools and other e-collaboration tools is creating the virtual environment for collaborative product development work. In addition to some technical difficulties with compatibility, some challenges arise from the adoption of e-collaboration tools: e-collaboration is viewed as less effective than face-to-face collaboration; it tends to frustrate specialists, who are spending more and more time managing product data at the expense of "real" work [36]; and it creates some coordination problems among team members in different time zones [38]. The potential benefits of e-collaboration may be outweighed by these challenges. This warrants further investigation.

The paper is organized as follows. We will first provide some theoretical background and then outline the sequential methodology adopted for the pilot study design, i.e. the focus groups, the panel of experts, and the survey. The main results will be presented, followed by a discussion of the implications of the empirical evidence.

2. Theoretical background

2.1. Product development

As noted by Reich [24], "products are international composites. What is traded between nations is less often finished products than specialized problem-solving (research, product design, fabrication), problem-identifying (marketing, advertising, customer consulting), and brokerage (financing, searching, contracting) services, as well as certain routine components and services, all of which are combined to create value." Products can therefore be viewed as the outcome of intense cross-border collaboration.

Product development constitutes a strategic undertaking, as launching successful products is essential for the short- and long-term success of a firm and its stakeholders [34]. Product development is also characterized by complex iterative decision-making processes [4], [26], [30], by an increase in knowledge transfers across organizations and across borders [23], and by the exchange and iterative modifications of multiple, complex and heavy data files such as design data for 3D CAD applications or prototype test data

0-7695-2507-5/06/$20.00 (C) 2006 IEEE

[16]. In such a context, major product integrations, especially in the space and aeronautics sector and in the automotive industry, turn to "paperless" or "virtual" product development, where e-collaboration tools obviously play a major role.

2.2. E-collaboration tools

The recent use of Internet-based collaboration tools enables team members to collaborate electronically by exchanging real-time information and by allowing unparalleled levels of information openness [21]. E-collaboration is "more than a technological substitution for traditional face-to-face collaboration" [27] and, in addition to transactions, it facilitates real-time coordination of various decisions and activities [13]. However, e-collaboration tools are not yet fully geared up to optimize the management of knowledge among team members [37].

Firms invested massively in ERP and B-to-B e-commerce, and, in the context of new product development, in the integration of 3D CAD systems with CAE/CAM systems to create seamless "3D model pipelines" for their internal product development activities. 3D models can also be used by manufacturing equipment such as CNC machines to directly produce parts or to create tools and molds. In order to manage the 3D models, firms implemented product data management (PDM) systems, the aim of which is to store and maintain information on the product [1] such as technical documentation, bills of material, part classification, etc. A PDM system can manage 3D CAD models, 2D drawings or CNC (Computer Numerical Control) programs. As a consequence, each member of the product development team can access product information and be involved in the product development process [31].

Although e-collaboration in the context of product development has evolved considerably during the last decades, it is still plagued with a number of difficulties:

(i) *Limited software integration for the creation of a "3D pipeline" (i.e the integration of CAD, CAE, and PDM):* Since certain incompatibilities (operating systems, data formats, etc.) prevent the seamless integration of all applications, the current situation is still characterized by "islands of information systems."

(ii) *Limited cooperation offered by the 3D pipeline:* 3D CAD systems offer few functionalities to support cooperation [5]. The exchange of information is limited to similar specialists (e.g. product designers); there is no multidisciplinary cooperation. Moreover, 3D models capture only explicit knowledge, not tacit knowledge [21]. Further, 3D models are the end result of a design process, but we do not know what the design rationale was or which alternatives were examined. PDMs were supposed to support cooperation among the product development teams. However, they failed to do this because they "are not well suited for the support of distributed development activities, as they focus on homogenous IT system environments" [2]. In numerous firms, access to the PDM is reserved for the CAD engineers so they can work with 3D CAD models.

(iii) *The coexistence of 3D and 2D:* Product development team members "outside the 3D pipeline" still rely on 2D drawings [17], [6] to access critical product data. 2D drawings contain a lot of crucial technical product information but are available later than 3D models and are not as easy to understand. Team members from engineering, purchasing, prototyping, manufacturing and assembly planning, logistics, sales and marketing therefore have limited access to product information and have to wait until the 2D drawings are derived from the 3D CAD models.

2.3. Factors influencing the use of e-collaboration tools

End users do not find it easy to adopt e-collaboration tools [38], [32], and this process does not occur automatically without appropriate training and the involvement and commitment of team members. One of the rather down-to-earth challenges faced by the members of virtual teams is the difficulty of reaching colleagues who work in different time zones [38].

In new product development teams that are global and virtual, McDonough [22] found that the background and origin of team members influence the way they communicate and therefore the use of e-collaboration tools. In addition, cultural differences with respect to "work ethic, work hours, preferred method of communication, revering hierarchy, individualism vs. collectivism and concern for quality" may affect product development activities [9], as they influence the information flow and learning process [19]. Further, different cultural thought worlds, languages and professional backgrounds may also represent barriers preventing product development teams from communicating [10]. The extent to which e-collaboration tools may remove some cultural differences remains unclear from past research.

The very nature of collaboration activities may modify the level of use of e-collaboration tools. At the outset of the product development project, rules and procedures must be formulated to govern how the information will be distributed and exchanged among team members. This first set of activities, called

collaboration planning, encompasses all common work procedures and routines, or "systematic processes" according to Mohrmann et al. [23], whereas cooperation improvement activities entail activities such as assigning resources and monitoring collaboration [11]. Cooperation planning and improvement activities are essential as they establish the ground rules for the efficient use of e-collaboration tools.

Product development is geared towards finding solutions that are (i) usually not the "best" but rather the most "satisfying" [30], which is consistent with the seminal work of Simon [28], and (ii) derived from several iterations or loops. In particular, iterative experimental design [8] reduces both the information asymmetry (i.e. difference between information available and information needed) and the interpretation asymmetry (i.e. difference in the interpretation of information). E-collaboration seems particularly fitted for the many iterative activities performed by team members such as sharing and assessing product information and developing process and product alternatives.

2.4. Impacts of e-collaboration activities

Krishnan and Ulrich [16] suggest that more research efforts should attempt to better "understand the situations where advancements in information technology are likely to change the established wisdom about how to effectively manage product development." E-collaboration tools for concurrent product development for cross-border virtual teams, although not widespread, may generate a number of positive impacts often cited in professional journals: shorter product development, error reductions, reuse of existing design, better cross-functional and cross-organizational cooperation, reduction of travel costs, etc. Moreover, e-collaboration tools reduce the frequency of late changes in the product development stage, which are particularly counterproductive, by "front loading" [33], which allows better decisions at the early stage of the product development process. Since e-collaboration enhances multiple interactions between team members, it may very well improve team creativity, given that creativity mainly happens in interaction [7], [15], [18].

3. Methodology

3.1. Industrial context and research site

Our study was conducted in the automotive sector, with a specific focus on the e-collaboration tools used by a large German-based first-tier supplier for new product development. This first-tier supplier is responsible for the development of components, parts and systems that will be integrated into the next generation of cars. Some of the products that have been developed by this first tier include navigation systems, ESC (electronic stability control), ABS (antiblock braking system), advanced diesel injection or hybrid systems, all of which can be qualified as complex products allying high-precision mechanics, software, electronics, and hydraulics.

The automotive sector is characterized by powerful trends which have a strong impact on new product development activities. First, the sector is highly globalized, with development centers and manufacturing facilities around the world. Firms in the different tiers of the supply chain rely on e-collaboration tools and, in particular, tools that support virtual product development. Second, the automotive supply chain is increasingly integrated. First-tier suppliers have evolved from "part makers" to "innovative solution providers" or "full service providers." The suppliers do not only design, manufacture and deliver parts and components but also invest in R&D for the development of new products that reduce emissions and costs and improve security and services (calibration of the component for the customer), and perform activities like installation studies that were previously done by the car makers (e.g. check how an alternator can fit into the motor). In such a context, the product development process has to be extended to upstream (lower tiers of suppliers) and downstream (car makers) partners.

3.2. Data collection and respondents

The empirical evidence was gathered in three separate but complementary phases.

First, focus groups were organized with eleven key team managers in order to gain a deeper understanding of the ongoing collaboration between product development teams and to identify the e-collaboration tools which had been implemented.

Second, a panel of eight experts was asked to rate the level of complexity of the different e-collaboration tools. Their assessment allowed us to derive a weighted score (i.e a weighted sum) that takes into account both the level of use of each cooperation tool and its relative complexity.

Third, a survey was conducted. The questionnaire was pre-tested with and fully validated by project and R&D managers, who assessed the relevance of each question and made sure that respondents could understand the wording. The questionnaire was then distributed to all members of three product development teams (N = 110). A total of 61 respondents participated in the survey, which

corresponds to a 55.5% response rate. Respondents are members of new product development teams where e-collaboration tools are implemented, are geographically dispersed in different countries, and are involved in the product development activities either as upstream specialists—i.e. manufacturing, sales, marketing (24%)—downstream specialists—i.e. engineering, product design, etc.(45%)—or product managers (31%).

This paper mainly focuses on the survey results.

3.3. Research variables

In addition to factual data on the respondents such as their position, their location and their business unit, the questionnaire contained perceptual variables (see Appendix 1), all of which are measured on seven-point Likert scales. Construct reliability proved to be satisfactory (Appendix 1) since the Cronbach alpha coefficients are within the guidelines set by Van de Ven and Ferry [35] ranging from 0.62 to 0.95.

4. Results

4.1. Description and current deployment of e-collaboration tools

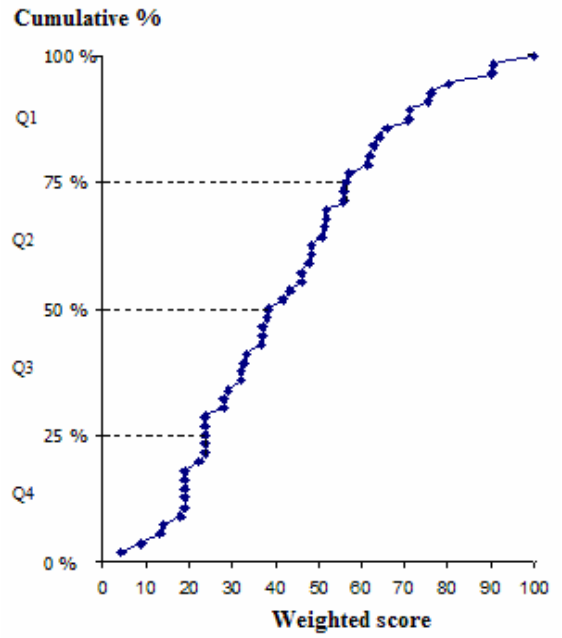
The large first-tier supplier has been the key sponsor for the diffusion of e-collaboration tools among the geographically distributed teams members responsible for new product development. The focus groups revealed the existence of four tools which are briefly described in appendix 2.

All four tools rely on the e-vis product either for saving data files, exchanging data, controlling data exchanges, exporting data files and viewing 3D models. The four e-collaboration tools are currently used but are not fully deployed within all the business units of the first-tier supplier and among key business partners (suppliers and manufacturers). Full deployment of these tools is expected in the next year.

4.2. Distribution of respondents by their level of use of e-collaboration tools

Figure 1 presents the cumulative percentage of respondents with respect to the level of use of e-collaboration tools. The distribution is divided into four quartiles. The first quartile (Q1) represents the top users or leaders in e-collaboration whereas the last quartile (Q4) contains team members that could be called low users or laggards. The goodness of fit test reveals no bias between the two groups in terms of their respective involvement in product development activities as upstream specialists, downstream specialists or project managers (p=0.279). As the firms in the first quartile (Q1) seem to outclass and outdistance the rest of the respondents (Q2+Q3+Q4), we will carry out comparative analyses of these two groups.

Figure 1: Level of use of E-collaboration Tools



4.3. Determinants of the use of e-collaboration tools

Table 1 presents the means for the research variables that were identified as potential determinants of the use of e-collaboration tools, namely variables pertaining to the team context, cultural differences and collaboration activities.

Some interesting observations can be made from table 1:

(i) Training is significantly higher for the top users of e-collaboration tools (5.54) than for their counterparts in the other group (4.00). However, level of involvement in the team and accessibility of team members do not differ significantly between the two groups.

(ii) In terms of cultural differences, language and professional background differences are significantly higher for the top users but no significant difference is

found between the two groups with respect to behavioral differences.

(iii) The type of collaboration activities seems to play a marginal role overall. However, the top users display higher means for all five collaboration activities.

Table 1: A Comparative Analysis of Users of E-Collaboration Tools

Research variables	Q_1[1] Means	$Q_2+Q_3+Q_4$[2] Means	p[3]
Team context:[4]			
-Level of involvement in team	5.12	5.25	NS
-Accessibility of team members	4.96	4.46	NS
-Training	5.54	4.00	**
Cultural factors:[4]			
-Language differences	5.92	3.67	**
-Professional background differences	4.46	3.63	*
-Behavioral differences	3.76	3.60	NS
Collaboration activities:[4]			
-Cooperation planning activities	4.56	4.40	NS
-Cooperation improvement activities	3.34	2.82	NS
-Sharing of product information	4.56	4.57	NS
-Elaboration of product and process alternatives	5.14	4.87	NS
-Product information assessment	4.46	4.25	NS

1. First quartile of e-collaboration users
2. Second, third and fourth quartiles of e-collaboration users
3. Level of significance (unilateral t-tests): NS non-significant, * p < .05, ** p < .01, *** p < .001, ****<.0001
4. Based on 7-point Likert scales

4.4. Impacts of use of e-collaboration tools

The top users (Q1) perceive that e-collaboration tools have a significant impact on all dimensions presented except for the cost dimension (Table 2). Team communication improvement receives the highest score for each group of users whereas cost reductions have the lowest scores.

Table 2: Impacts of E-Collaboration Tools

Research variables	Q_1[1] Means	$Q_2+Q_3+Q_4$[2] Means	p[3]
Impacts of e-collaboration tools[4]			
-Product development time improvements	4.69	3.39	****
-Creativity enhancement	5.00	4.07	*
-Manufacturing performance improvements	4.28	2.67	**
-Product performance improvement	4.20	2.94	**
-Cost reductions	3.60	3.00	NS
-Team communication improvement	5.31	4.30	**

1. First quartile of e-collaboration users
2. Second, third and fourth quartiles of e-collaboration users
3. Level of significance (unilateral t-tests): NS non-significant, * p < .05, ** p <.01, *** p<.001, **** p < .0001
4. Based on 7-point Likert scales

4.5. The best discriminating variables between the two groups of users (Q1 vs. Q2+Q3+Q4)

Going one step further, we identified the variables which best discriminate between the two groups of users. Assumptions for performing the two discriminant analyses are met: the examination of the correlation matrix shows no high interdependencies among independent variables, while the sample size, although rather small, is large enough (n > 30) to assume multivariate normality and the test known as Box's M allows us to accept the null hypothesis that covariance matrices are equal. However, results for the discriminant analyses are only shown when we introduce the stepwise procedure since the sample size (n=61) precludes multivariate analyses with a large number of variables. For both discriminant analyses, a corrector factor for unequal sample sizes in the two groups (Q1 vs. Q2+Q3+Q4) was introduced.

The first discriminant analysis conducted on the two groups of users identifies two discriminating variables: language differences and training. The resulting discriminant function which is highly significant (p<0.000) allows us to correctly classify 80.0% of users in their respective groups (Table 3).

Table 3: The Best Predictors of the Level of Use of E-Collaboration Tools: Main Results of the Discriminant Analysis

Variables entered by the stepwise procedure:		
	Standardized coefficients[1]	**p**
Language differences	0.826	0.007
Training	0.723	0.002
Classification results obtained by the two variables retained by the stepwise procedure:		
	Predicted group membership	
	Q_1	$Q_2+Q_3+Q_4$
Actual group membership		
Q_1	90.9%	9.1%
$Q_2+Q_3+Q_4$	23.5%	76.5%
Percentage of users correctly classified:		**80.0%**

1. Standardized canonical discriminant function coefficients

The second discriminant analysis concerns the impacts of e-collaboration tools. Only one variable—namely team communication improvement—discriminates significantly between the two groups of users; it yields an overall classification rate of 70.0% which is satisfactory (Table 4).

Table 4: The Most Discriminating Impacts of the Level of Use of E-Collaboration Tools: Main Results of the Discriminant Analysis

Variables entered by the stepwise procedure:		
	Standardized coefficients[1]	**p**
Team communication improvement	0.695	0.014
Classification results obtained by the two variables retained by the stepwise procedure:		
	Predicted group membership	
	Q_1	$Q_2+Q_3+Q_4$
Actual group membership		
Q_1	76.9%	23.1%
$Q_2+Q_3+Q_4$	33.3%	66.7%
Percentage of users correctly classified:		**70.0%**

1. Standardized canonical discriminant function coefficients

5. Discussion of the results and implications

The findings of this pilot study point to two powerful determinants of the level of use of e-collaboration tools, namely language differences and training, the two most significant variables in the bivariate and multivariate analyses (Tables 1 and 3, respectively). *Language differences* are often omnipresent in cross-border communications. In fact, although all team members have some minimal basic understanding of the english language, language barriers prevent the effective communications needed when discussing technical specifications or foreseeing the impacts of proposed design changes. In these circumstances, it becomes much easier to refer to visual representations such as those offered by the e-collaboration tools. In the context of product development activities, engineers have a strong "visual culture" anyway, as pointed out by Henderson [12], and express their ideas through visual representations such as 3D models or prototypes. Even team members from other function such as sales or marketing are used to relying on physical prototypes and 2D models. E-collaboration tools allow team members with multiple native languages to integrate their different inputs more effectively. *Training* is essential to the adoption, use and full deployment of e-collaboration tools. In a competitive sector like the automotive industry, resources must be severely rationalized: resources are scarce and very little slack exists. However, less slack not only means less ability to innovate in the context of product development [25] but also implies less spare time for training. In the field study, some training was offered to team members with the support of certain proactive managers. However, more extensive training would result in a better appropriation of e-collaboration tools, which in turn would generate more positive impacts.

Professional background differences turn out to be significantly higher for the top users of e-collaboration tools (Table 1). The visual representation enhanced by the e-collaboration tools may act as a bridge between the engineers (design, manufacturing) and the non-engineers (sales, finance, marketing). In addition, the field research strongly suggests that there are differences between the different engineering specialists since current product developments in the automotive sector rely on electronics, software and mechanics that must converge in "mechatronics" [3]. E-collaboration tools seem to remove some professional "rigidities" between engineers and non-engineers.

The nature of the *collaboration activities* carried out by team members does not seem to play a significant role as a determinant of the level of use of e-collaboration (Table 1), although top users seem to be more actively involved in cooperation improvement.

In terms of the impacts of e-collaboration tools, the most significant variable discriminating between the top users and the other users (Q1 vs. Q2+Q3+Q4) is *team communication* (Table 4). In fact, e-collaboration tools allow for synchronous and more effective communication, which reduces the information asymmetry between team members and increases the quality of their decisions. Other impacts are also positive and significant (Table 2), namely product development time improvements, manufacturing and product performance, and creativity enhancement. For cost reductions, the difference between the two groups of users is marginal and non-significant. In fact, the e-collaboration tools fail to generate significant short-term bottom-line impacts (means for cost reductions are low for both groups of users: 3.60 and 3.00, respectively) but seem to deliver either intangible benefits such as creativity enhancement and team communication or benefits such as product development time reduction, improved products, and more effective manufacturing processes that would improve bottom-line figures in the longer run. This time-lag effect may be the result of the rather recent introduction of e-collaboration tools.

6. Conclusion

Product development is increasingly being conducted by cross-border teams, using e-collaboration tools. The pilot study examined some potential determinants of the level of use of e-collaboration tools and the alleged impacts of these tools. The results must be interpreted with some caution as the sample size is rather small (n = 61), the context is industry-specific and the use of e-collaboration tools in interorganizational environments is still not widespread. More research is required to examine patterns of e-collaboration among geographically distributed product development teams in different industries. Our preliminary results suggest that the determinants of the level of use of e-collaboration tools by cross-border product development teams are strongly biased towards human-related factors (language differences, training, professional background differences) and that the overall impact of these tools is positive but not strongly related to cost reductions.

In very globalized industries such as the automotive industry, product development is highly dependent on e-collaboration tools that hold the potential to build on specialized knowledge across nations, organizations and professions to develop customized products for different market needs and varying regulatory environments.

7. Acknowledgements

The authors gratefully acknowledge grants from FQRSC, NSERC and SSHRC. We appreciate the useful comments and suggestions from the two reviewers.

8. References

[1] Abramovici, M., Gerhard, D., and Langenberg, L., "Application of PDM Technology for Product Life Cycle Management". *4th CIRP International Seminar on Life Cycle Networks* (edited by F.-L. Krause and G. Seliger). Berlin: Chapman & Hall, 1997, 195 – 208.

[2] Abramovici, M., Gerhard, D., and Langenberg, L., "Application of Product Data Management Technology for Enterprise-wide Distributed Product Development". *10th International IFIP WG 5.2/5.3 Conference PROLAMAT 98* (edited by G. Jacucci, G.J. Olling, K. Preiss and M.J. Wozny). Trento: Kluwer Academic Publishers, 1998.

[3] Adamsson, N., "Model-Based Development of Mechatronics Systems – Reducing the Gaps Between Companies. Tools and Methods of Competitive Engineering". *TMCE 2004. Rotterdam*: Millpress, 2004, 405-413.

[4] Ahmed, S., Wallace, K.M. and Blessing L.T.M.. "Understanding the Difference how Novice and Experienced Designers Approach Design Tasks". *Research in Engineering* Design,2003, 14:1-11.

[5] Bochenek, G.M., and Ragusa, J.M., Virtual (3D) collaborative environments: an improved environment for integrated product team interaction? *Proceedings of the 36th Hawaii International Conference on System Sciences*, IEEE Computer Society Press, Los Alamitos, 2003, 249-258.

[6] Boujut, J.F., and Laureillard, P., "A Co-operation Framework for Product-process Integration in Engineering Design". *Design Studies*, 2002, 23:497-513.

[7] Csikszentmihalyi, P., *Creativity: Flow and the Psychology of Discovery and Invention.* New York: HarperCollins, 1996.

[8] Debackere, K., "Technologies to Develop Technologies: the Impact of New Technologies on the Organisation of Innovations Projects". *Nijmegen Lectures on Innovation Management, Antwerpen*, 1999, Maklu-Uitgevers (Belgium).

[9] Edwards, H.K., and Sridhar, V., "Analysis of the Effectiveness of Global Virtual Teams in Software

Engineering Projects". *Proceedings of the 36th Hawaii International Conference on System Sciences*, IEEE Computer Society Press, Los Alamitos, 2003, 19-27.

[10] Griffin, A., and Hauser, J.R., "Integrating R&D and Marketing: A Review and Analysis of the Literature". *Journal of Product Innovation Management*, 1996, 13:191-215.

[11] Holland and Plischke, Handbuch Kooperationsmodelle Datenlogistik. Darmstadt: VDA AG Kooperationsmodelle – Datenlogistik, 2001.

[12] Henderson, K., *On Line and On Paper: Visual Representations, Visual Culture, and Computer Graphics in Design Engineering*. Cambridge: MIT Press, 1999.

[13] Johnson, E., and Whang, S., "E-business and supply chain management: An overview and framework", *Production and Operations Management*, 2002, 11;4, 413-423.

[14] Jokinen, K., Borgman, J., and Sulonen, R. , "Common Data Model for Design Document Exchange in Business- to- Business Networks",*Proceedings of the 38th Hawaii International Conference on System Sciences*, IEEE Computer Society Press, Los Alamitos CA, 2005.

[15] Kappel, T.A and Rubenstein, A.H. (1999). "Creativity in Design: The Contribution of Information Technology". IEEE Transactions on Engineering Management. 46:132-143.

[16] Krishnan, V., and Ulrich, K.T.,"Product Development Decisions: A Review of the Literature", *Management Science*, 2001, 47:1-21.

[17] Lang, S.Y.T., Dickinson, J., and Buchal, R.O., "Cognitive Factors in Distributed Design". *Computers in Industry*, 2002, 48:89-98.

[18] Leenders, R.Th.A.J, Van Engelen, J.M.L., and Kratzer, J., "Virtuality, Communication, and New Product Team Creativity: A Social Network Perspective". *Journal of Engineering and Technology Management*, 2003, 20:69-92.

[19] Lyles, M.A., and Salk, J.E., "Knowledge Acquisition from Foreign Parents in International Joint Ventures: An Empirical Examination in the Hungarian Context". *Journal of International Business Studies*, 1996, 27:877-903.

[20] Markus, M.Y., and Christiannse, E., "Adoption and Impact of Collaboration Electronic Marketplace", *Information Systems and e-Business Management*, 2003, 1:2, 139-155.

[21] Mascitelli, R., "From experience: harnessing tacit knowledge to achieve breakthrough innovation". *Journal of Product Innovation Management*, 2000, 17:179-193.

[22] Mcdonough, E.F., Kahn, K.B., and Griffin, A., "Managing Communication in Global Product Development Teams". *IEEE Transactions on Engineering Management*, 1999, 46:375-386.

[23] Mohrman, S.A., Finegold, D. and Mohrman, A.M., "An Empirical Model of the Organization Knowledge System in New Product Development Firms". *Journal of Engineering and Technology Management*, 2003, 20:7-38.

[24] Reich, R.B., The Work of Nations: Preparing Ourselves for 21st century Capitalism, New York: *Alfred A. Knopf*., 1991

[25] Richtnér, A., and Åhlström, P., "Forms of Organizational Slack in Product Development". *9th International Product Development Management Conference*, 2002, 2:727-742.

[26] Robertson, D. and Allen, T.J., "CAD System Use and Engineering Performance". *IEEE Transactions on Engineering Management*, 1993, 40:274-282.

[27] Rutkowski, A.F., Vogel, D.R., Van Genuchten, M., Bemelmans, T.M.A., and Favier, M., "E-collaboration: The reality of virtuality", *IEEE. Transactions on Professional Communication*, 2002, 45:4, 219-242.

[28] Simon, H.A., *Administrative Behavior. A study of Decision-Making Processes in Administrative Organization*. New York: The Free Press, 1945.

[29] Sosa, M.E., Eppinger, S.D., Pich, M., McKendrick, D.G., and Stout, S.K., "Factors That Influence Technical Communication in Distributed Product Development: An Empirical Study in the Telecommunication Industry". *IEEE Transactions on Engineering Management*, 2002, 49:45-58.

[30] Stempfle, J., and Badke-Schaub, P., "Thinking in Design Teams – An Analysis of Team Communication". *Design Studies*, 2002, 23:473-496.

[31] Spur, G. and Krause, F.L., Das Virtuelle Produkt: Management der CAD-Technik., 1997, Munich: Carl Hanser Verlag.

[32] Susman, G.I., Gray, B.L., Perry, J., and Blair, C.E., "Recognition and Reconciliation of Differences in Interpretation of Misalignments when Collaborative Technologies are Introduced into New Product Development Teams". *Journal of Engineering and Technology Management*, 2003, 20:141-159.

[33] Thomke, S., and Fujimoto, T., "The Effect of "Front-Loading" Problem-Solving on Product Development Performance". *Journal of Product Innovation Management*, 2000, 17:128-142.

[34] Ulrich, K.T., and Eppinger, S.D., *Product Design and Development*, 2nd edition. New York: McGraw-Hill Higher Education, 2000.

[35] Van de Ven, A., and Ferry, D., *Measuring and Assessing Organizations*, Wiley Interscience, New York, 1980.

[36] Valnion, B.D., "Das Ansehen des Ingenieurs im Wandel: Vom Kostenfaktor zum Innovationsträger - Eine Analyse und Ergebnisse einer Befragung". *Marcus Evans Konferenz "Digitale Fahrzeugentwicklung"*, 2002, Munich: Marcus Evans.

[37] Warkentin, M.E., Sayeed, L., and Hightower, R., "Virtual Teams versus Face-to-face Teams: An Exploratory Study of a Web-based Conference System". *Decision Sciences*, 1997, 28:975-996.

[38] Wierba, E.E., Finholt, T.A., and Steves, M.P., "Challenges to Collaborative Tool Adoption in a Manufacturing Engineering Setting: A Case Study". *Proceedings of the 36th Hawaii International Conference on System Sciences*, IEEE Computer Society Press, Los Alamitos, 2002, 3594-3603

Appendix 1: Constructs and their measures

Team Context:

Level of involvement in team: **(α=0.62)**

You were involved at the very early stages of the project;

You spend a large part of your working time on this project.

Accessibility of team members: **(α=0.81)**

The people in the development team are geographically dispersed;

The people in the development team are difficult to reach.

Training: **(α=0.71)**

The training you received showed the basic features of the cooperation tools;

The training you received showed what job-related tasks the cooperation tools were good for solving.

Cultural Factors:

Language differences: **(N/A)**

Differences exist among team members concerning mother tongue.

Professional background differences: **(α=0.69)**

Differences exist among team members concerning technical terms used (jargon);

Differences exist among team members concerning professional background (e.g. engineering vs. marketing).

Behavioral differences: **(α=0.69)**

Differences exist among team members concerning time orientation (e.g. short-term vs. long-term);

Differences exist among team members concerning tolerance of ambiguity and uncertainty;

Differences exist among team members concerning how decisions are made.

Collaboration Activities:

During the development project, do you perform the following activities?

Cooperation planning activities: **(α=0.78)**

When working with your colleagues in the development team (internal, customers or suppliers):

You define the information to be shared in terms of frequency and response time;

You define the information to be shared in terms of format and content;

You define the accuracy, maturity and quality of data (e.g. binding);

You define methods and media to exchange information (e.g. common data repository, send announcement);

You define and practice systemic procedures or approaches to working with your colleagues (e.g. problem solving, team meeting).

Cooperation improvement activities: **(α=0.78)**

You attend a seminar on cooperation and tools;

You document your experience in the current project;

You assign resources for the improvement of cooperation;

You evaluate and benchmark the success of cooperation.

Sharing of product information: **(α=0.64)**

You prepare and publish information for suppliers or customers (e.g. requirements or changes);

You prepare and publish information for internal purposes (e.g. presentation);

You prepare and publish "preliminary" product information* (not released).

Development of product and process alternatives: **(α=0.84)**

You collect requirements, suggestions and wishes;

You explain, discuss and reach agreement on product or process issues;

You prepare different product or process alternatives, which are discussed during meetings or submitted for comments;

You define changes to be made.

Product information assessment: **(α=0.88)**

You assess the product information* according to criteria like manufacturability, quality, costs, and environmental impact;

You assess the impact of changes on the product, the process and costs.

Impacts of E-Collaboration Tools:

Time improvements: **(α=0.82)**

Less travel was required;

The number of changes was reduced;

The time required to perform your task(s) was reduced;

You were able to begin your task(s) earlier and resolve issues earlier (e.g. manufacturability).

Creativity enhancement: **(α=0.84)**

You were able to explore more issues;

You were able to generate more alternatives;

The alternatives were more creative.

Manufacturing performance improvements**: (α=0.95)**

The production time was reduced;

The manufacturability was improved.

Product performance improvement: **(α=0.81)**

The technical performance of the part / component was better (e.g. functional performance)

The life-cycle performance of the part / component was better (e.g. maintainability)

Cost reductions**: (α=0.78)**

The investments in manufacturing and assembly equipment were reduced;

The product and production costs were lower.

Team communication improvement: **(α=0.76)**

The quality of the decisions and technical discussions with your colleagues were better (e.g. more transparency);

The information asymmetry (deficit of information) in the team was reduced.

Appendix 2: E-Collaboration Tools

Visualization of 3D models:

- The team members can view the 3D models in the DMU format using a dedicated viewer.with functions such as product structure, rotation and zoom, measurement (exact geometry), mark-up or redlining (to write comments), cross-section, product explosion, etc.
- The 3D models in the DMU (Digital Mock-up) format are saved on e-Vis. The viewer allows team members to gain a better understanding of the product (how the parts fit together, the main dimensions, the weight, how the geometry looks, holes, width, etc.).

Publication of 3D CAD models

- The native 3D CAD models had to be converted into the DMU (Digital Mock up) format and an "export menu" was used by the CAD design engineers wishing to export data from their CAD/ADM into e-Vis.
- The interface behind the "export menu" was programmed by the first-tier supplier and allows the 3D CAD data to be extracted from the EDM (Electronic Data Management) system, converted into the DMU format and saved in a specific location in e-Vis (as specified by the engineer who exported the data).

E-Vis: E-Vis is a product from UGS PLM (www.ugsplm.com) that sells software tools related to "PLM" (Product Life-Cycle Management): CAD systems like Unigraphics, PDM, simulation software, 3D viewers (like Teamcenter Visualization) and cooperation software (like Teamcenter Community).

Conferencing with 3D models:

- Team members in different countries are "sharing" the viewer (see description above) and discuss technical issues using 3D models in the DMU format while sitting in front of their PC or laptop. If one team member makes a measurement or rotates the models, their colleagues see these actions instantly. In addition, secondary users can also take the lead in the conference and explain their own point of view.
- 3D conferencing uses a command-sharing principle where only the commands are exchanged between the applications. This means that the content of a screen does not have to be transmitted from one PC to the other PCs. This mode of conferencing is therefore appropriate for "graphic-intensive" application like the visualization of 3D models. Indeed, once the 3D models are downloaded on the different PCs, only commands like rotation, zoom, etc., are exchanged (the control being managed by e-Vis). Consequently, the required bandwidth is high at the beginning of the conference (to download the 3D models) but low during the conference as only commands are exchanged. It enables quasi-real-time interactions between the participants of the 3D conference.

Application sharing:

- Application sharing is a variant of "3D conferencing." 3D conferencing works only between two viewer applications (for instance VisView professional)
- Application sharing is more generic than 3D conferencing since it allows one to share different applications (e.g. Microsoft Word) or the entire desktop between different PCs. During application sharing, the conference participants can view and control one participant's application. From a technological point of view, the "content of a screen" is sent from one PC to the other PCs, which requires high bandwidth (preventing the use of "graphic-intensive applications"). Therefore, application sharing is suitable for applications like Microsoft Word or Excel. Otherwise, the performance is due to a high latency. The best-known application-sharing programs are NetMeeting from Microsoft, WebEx, Interwise and Centra.
- In other words, application sharing is not suitable for sharing a viewer application (3D conferencing is better).