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DISTRIBUTED TEAM INNOVATION – A FRAMEWORK FOR DISTRIBUTED PRODUCT DEVELOPMENT

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Abstract

In response to the need for increased effectivity in global product development, the Polhem Laboratory at Luleå University of Technology, Sweden, and the Center for Design Research at Stanford University, USA, have created the concept of Distributed Team Innovation (DTI). The overall aim of the DTI framework is to decrease the negative impact of geographic distance on product development efforts and to further enhance current advantages of worldwide, multidisciplinary collaboration. The DTI framework uses a three-layered approach to the advancement of global collaboration; with product development, education, and research in dynamic and synergetic interaction. From our preliminary findings, we believe that the approach we have taken in the DTI initiative will make significant contributions to meet current challenges of distributed product development.

Keywords: Collaborative design tools, globalization, learning environments, distributed product development, work environment

1. Introduction: distributed product development

In order to cut cost and time, while still meeting demands on quality, many manufacturing companies need to raise their level of competition by making use of resources (production facilities, consultants, educators etc.) from all over the world. Global presence and activity is often considered a competitive advantage, and the diversity of cultures and competencies in such organizations are regarded as a big strength. In light of increasing globalization, a crucial challenge for distributed organizations is to make distance less of a concern. The challenge is even more crucial in the case of distributed product development because of the wide range of media and channels of communication such as sketches, notes, hardware, 3D CAD models, gestures, and voice that engineers use in order to bring ideas into concrete realization. These media have been employed in activities such as brainstorming, simulation, computer aided design and hardware prototyping which traditionally took place in collocated settings and will now have to be distributed across time and space.

Information technology and globalization will force far-reaching reforms in traditional production systems, in order to enable companies to cope with rapid changes while taking advantage of greater mobility and access to information. Companies' expertise must be improved to help them deal with transitions to new products and new production technology, including sharply increased elements of IT, software and services. The emerging needs of the globalizing industry have been summarized by Bengt-Olof Elfström, Research Director at Volvo Aero Corporation, in the following question: *"How will companies be more effective in* *globally distributed development?"* Further, Elfström presents five key areas, which give the requirements of global companies to increase the effectiveness in distributed collaboration;

- Generating new concept solutions
- Generating new knowledge
- Implementing new methods and technologies in industry
- Gaining access to educated persons with knowledge and experience of new methods and technologies
- Recruiting of new engineers with knowledge and experience of new methods and technologies

In this paper, we present the Distributed Team Innovation (DTI) framework, a joint initiative by Luleå University of Technology, Sweden, and Stanford University, USA, to investigate the future of global collaborative product development.

1.1 Challenges of geographically distributed teams

The geographical distribution of product development teams introduce a great variety of challenges, which fundamentally means that the goal of bridging distance has a lot more to it than "just" reducing physical distance. Challenges of geographically distributed teams include:

- *Time differences*: Since team members may be located in different time zones, coordination of work is often difficult. Time differences can make it hard to schedule meetings or initiate contact, and the "window of opportunity" [1] for collaborative work can be very small due to a limited overlap in work hours. Thus, for many of the globally distributed teams, "time is distance" [2 pp.167-186].
- *Cultural differences*: Team members may come from different countries and cultures, and thus have different ways of talking, being and acting – they have different "cultural conditioning" [3] that influences how they perceive other cultures. Successful collaboration depends largely on team members' ability to build trust, rapport, and respect to bridge the differences. The potential for conflict is great, especially if it is true that "trust needs touch" [4], and managing conflicts becomes a key factor for success [2 pp.213-233].
- *Proximity*: Even such a seemingly small physical distance as 30 meters greatly reduces daily contact and informal communication between collocated team members [2 pp.57-80, 137-162]. Furthermore, as physical distance increases, the "information richness" [5] inherent in face-to-face communication decreases. Non-verbal information – such as facial signals, direction of eye-gaze, gestures, and posture – is more difficult to interpret accurately [6].
- *Awareness*: Collocated team members often communicate very informally, which enables them to rapidly and continually exchange information, monitor progress, and learn about what others are doing [7]. They get a general sense of who is around (awareness about people) and what they are doing (awareness about process). Maintaining awareness across distance is crucial for successful collaboration.
- *Communication latency*: A common problem of cross-site communication is the delay in the resolution of work issues [8]. Issues that would be resolved in minutes or hours in a collocated setting can take days or weeks in a distributed situation due to

difficulties to find the right person, initiate contact, and discuss possible solutions. The communication latency also makes the flow of ideas less fluid.

- *Mobility and heterogeneity*: As people tend to become less bound to particular offices or desktop computers [9], there are difficulties not only to initiate contact with people, but also to communicate via a wide range of technical platforms (e.g. laptops, PDAs, mobile phones) and different operating systems and applications.

1.2 Opportunities of geographically distributed teams

Although making global collaboration work involves immense challenges, there are also significant opportunities that come with geographical distribution, some of which are:

- *Time differences*: The use of a global work force allows for 24-hour design [10] and offers potential to accelerate development cycles by combining teams from different time zones, with different degrees of overlapping work hours.
- *Cultural differences*: Differences in, for example, culture, education, organization, and work methods allow for multiple perspectives on ideas and offer potential for new ideas leading to innovation. When considering social processes as crucial for successful design, diversity in all forms will add to the creative power of the global team [2 pp.407-430, 11, 12].
- *Market closeness*: When product development is not restricted to one physical location, companies will be able to harness local markets while still making use of the required resources and expertise available world-wide. This allows for closer and stronger relationships with, for example, customers, distributors and retailers.
- *Proximity*: As physical distance increases, tacit knowledge (e.g. intuition, individual perception, rules of thumb) is not as easily spread through informal communication channels, and must therefore be made more explicit in order to be used throughout the company. The extra effort of ”globalizing local knowledge” [13] could very well prove to be a competitive advantage for distributed companies. Further, geographical distribution could lead to a better mix of individual and collaborative work, since collocated work is often characterized by a lot of meetings and disruptions [2 pp.83-110].
- *Mobility and heterogeneity*: Collaboration is no longer dependent on the availability of a single physical space, the co-presence of team members, or a specific technical platform. Product development not only becomes increasingly global, but also increasingly mobile.

The potential for distributed product development is great, but to realize that potential we need to intensify our research efforts in order to turn challenges into opportunities, and to further advance the possibilities for successful global collaboration.

2. Distributed Team Innovation

In response to the need for increased effectivity in global product development, the Polhem Laboratory at Luleå University of Technology, Sweden, and the Center for Design Research at Stanford University, USA, have created the concept of Distributed Team Innovation (DTI). The overall aim of the DTI framework is to decrease the negative impact of geographic distance on product development efforts and to further enhance current advantages of worldwide, multidisciplinary collaboration. There are many different ways of dealing with these issues. One way is to focus on the development of distance-spanning technologies that better fits the needs of geographically distributed teams. Another way is to focus on the development of design methods that are more appropriate for global settings. Undoubtedly, both these approaches are highly relevant when it comes to improving the possibilities for successful global collaboration. In order to forcefully deal with any issue of globalization in product development, we first have to increase our understanding of what global product development really is about - global product development calls for global paradigm in research and education. If we, as design researchers, want to learn more about global product development, we need to closely study global development projects. If we, as educators, want our students to gain experience of global design collaboration, we must give them the possibility to work extensively in such projects. Furthermore, to ensure the validity and usefulness of our research and education efforts, we need to make sure that these global projects are highly relevant from an industry perspective [14]. At the intersection of academia and industry, there is a seemingly endless debate about whether academic research has any industrial relevance, and whether there exists a fundamental mismatch between engineering education (as "taught" in academia) and engineering practice (as "performed" in industry) [15].

The issues of global product development were investigated using the context of a real-world product development project with Volvo Car Corporation and Volvo Aero Corporation as sponsors. As objects for the research were two teams of students; one team of four students from the ME310 course at Stanford, and one team of four students from the Sirius course at Luleå. Using the latest technology and methods for communication over large distances, participating teams experienced global design collaboration, supported by professional coaches, corporate liaisons and faculty advisors. Thus, the perspective of the DTI framework is multifaceted; with product development, education, and research as equal and mutually beneficial parts of a creative process. It is not only a case of students learning as they go about developing a product – it is also a case of developing methods and work practices for global collaboration, creating virtual and physical environments that support this way of working, and last but not least, building an educational framework that prepares the students for innovative teamwork on a global arena.

2.1 Objectives and methods

The Distributed Team Innovation framework uses a three-layered approach to the advancement of global collaboration; with product development, education, and research in dynamic and synergetic interaction. The following sections describe the objectives of each "layer", and the methods used to pursue our goals.

2.1.1 Product development

The funding provided by Volvo Car Corporation and Volvo Aero Corporation is based on a partnership model between academia and industry that involves return on investment through innovative concept solutions, knowledge transfer, new methods and technologies for distributed product development. Also, the partnership gives them access to potential employees with unique competence of their organization, process and products as well as experience of global product development.

- *Volvo Car Corporation*: Hans Folkesson, Senior Vice President of R&D, claims that their commitment to the Sirius/ME310 course is "*an outstanding example of co-operation between university and industry. We work with enthusiastic students who* *solve problems from new angles whilst we contribute with our industrial expertise and experience. In this co-operative project, the students get to work in a real development process, work towards a given goal and develop an idea for a product, whilst at the same time being constrained by time, resource and cost limits. This is a valuable experience that the students take with them to industry."*

- *Volvo Aero Corporation*: Professor Bengt-Olof Elfström, Research Director, states that the Sirius/ME310 project *"is an important part of Volvo Aero Corporation's technology and competence development as well as our recruitment strategy. In the future we expect to see even greater emphasis placed on early product development, creativity, and the use of virtual and distributed product development tools."*

2.1.2 Education

Global product development requires engineers to collaborate in geographically distributed teams. Thus, higher education needs to prepare engineering students for work in such world-wide projects by letting them experience global design collaboration, in the context of real industry problems.

- ME310 is a three-quarter graduate sequence where student design teams work with corporate partners on design innovation projects. Teams gain hands-on experience working on industry sponsored projects, with significant budgets, to develop prototype products. The design environment of the course is purposefully modeled after situations faced by many engineers and designers in industry. The students learn to work in global, multi-disciplinary, and collaborative design teams. Past sponsors of ME310 projects have included major automotive companies, such as Ford, Volvo and Toyota, consumer product companies, such as Schick and Siemens, small entrepreneurial startups, such as Immersion and Virtual Technologies Inc, and large non-commercial entities such as NASA. The approach to design in the course can be characterized as rapid prototyping with multiple iterations. It is based on the understanding that students come to the course with sufficient world experience to challenge the stated client requirements, build solutions to meet revised objectives using easy-to-prototype materials, and learn important and strategic lessons from the success or failure of these early attempts. Even though the final project report is not due for another seven months, the students are expected to write a preliminary final report after the first month. This report is expected to contain at an appropriate level of detail, information about the requirements, the design, the testing and the manufacturing. An updated version of this report is also expected after four months of work. Our research suggests that this rapid interplay of physical and abstract work is critical for creative work and for deeper understanding of the subject matter [16, 17].

- The Sirius course at Luleå University of Technology is the final-year course in product development for engineering undergraduates studying towards a MSc. in Mechanical Engineering. Sirius involves teams of students carrying out a product development project in close co-operation with an industry partner. The modular nature of engineering degrees at Luleå University of Technology also makes it possible for students studying other, complementary disciplines to participate in Sirius. The varying background of the students provides a wide knowledge base in the project groups and an opportunity to gain understanding of the complementary relationship between different engineering disciplines. The product development process in Sirius is based on the systematic approach to engineering design [18, 19] and CAD-tools and simulations are an important part of the verification process.

2.1.3 Research

The research part of the DTI project was performed as a case study of collaborative design in both collocated and distributed settings. The understandings derived from the fieldwork were used as a basis for an iterative design of supporting virtual and physical environments.

- *Case study*: The goal of the case study was to investigate communication as it was played out in a real-world product development activity. Drawing from the concept of ethnomethodology [20], we felt it important to try to understand things in the context in which they occur, without making assumptions about what modes of communication could be useful for successful collaboration. The study was performed using ethnographic methods such as observations, field notes and videotaping [21 pp.123-154]. Several modes of communication were observed during the study, such as collocated teamwork, telephone conferences, and videoconferences using tools of different quality. Both synchronous and asynchronous distributed collaboration was observed continually throughout the study. The qualitative approach was combined with quantitative data derived from system log files.
- *Participatory Design*: Since the distributed team consisted of relatively few members, there was a great opportunity to further adapt the general research concepts derived from the case study in close collaboration with the users. Rather than seeing users as passive sources of information, techniques for Participatory Design [21] were used to actively involve the users in the system design. The virtual and physical environments designed and re-designed within the DTI project is further described in section 2.3.

2.2 Distributed development of ”virtual pedals”

A team of four students from the ME310 course at Stanford and a team of four students from the Sirius course at Luleå joined as a distributed team with the goal to design “virtual pedals”, taking into account that the need for mechanical connections between pedals and actuators has disappeared with the introduction of drive-by-wire technology in the automotive industry. A drive-by-wire system can eliminate the foot injuries that mechanical pedals cause in the majority of frontal collisions, but such a system can also allow for position and feel adjustability, cost reduction, and safer driver positioning. The design space for the project was very wide and the only limitations were that the accelerator and brake should be foot controlled, taking into account the power of habits. The project started in October 2001 and ended in June 2002, after seven months of global product development, education, and research.

2.3 Technology support

During the course of the project, the nature of collaboration changed depending on what tasks the distributed team needed to perform within the different project phases (benchmarking, concept design, detail design etcetera). Thus, the team needed to use different communication channels that were well suited for the task at hand. Many of the communication tools were web-based in order to support mobility without the need to install different applications at each place (home/project space/workshop).

2.3.1 Formal communication

For formal communication the team mainly used e-mail, telephone conferencing, and videoconferencing with different quality levels. For high-quality videoconferencing they used the Confero [22] system, which is IP-based and designed for broadband use. In the early concept phase - when much information gathering was done regarding existing systems, patents, and research about foot injuries - DocuShare [23] from Xerox was used to store and categorize information. In the detail design stage, more of the information exchange concerned CAE models, animations, and video clips of hardware prototype testing.

2.3.2 Informal communication

A web-based collaboration tool called the Contact Portal [1] was developed in order to support informal communication and information sharing. The Contact Portal combines several information channels; awareness cameras, instant messaging, Short Message Service (SMS), and asynchronous tools such as diaries, e-mail archives and document servers in one place.

2.3.3 Physical environments

To enable collaborative work not only the tools and methods is needed, also the physical environments in which the users collaborate must be adapted to the users and their needs. The Stanford team members used the ME310 Loft as their primary project space. The design of the Loft allows for close interaction between different design teams, and is also equipped with workstations, printers, awareness cameras, as well as conferencing facilities. For prototyping and fabrication, the Product Realization Laboratory (PRL) was used. The Luleå team members used the Distributed Team Room (DTR) as their main project space, which evolved during the course of the project. The DTR is equipped with a high quality audio system and a plasma display for conferencing. All team members can move around freely with the use of wireless microphones – enabling them to go to the whiteboard and sketch during a videoconference, without degrading the audio quality. The wireless microphones also decrease the risk of getting audio feedback from the loudspeakers. The Sirius workshop was used for prototyping and manufacturing.

3. Results

The primary results of the DTI approach points to considerable contributions in all three focus areas; product development, education, and research. Innovative concept solutions are generated by tomorrow's engineers, who gain invaluable experience and knowledge of global collaboration in the context of real-world product development projects. Also, the understanding of global teamwork is improved, and thus the possibilities for designing appropriate technology support. The following sections briefly describe the results in each area:

3.1 Product development

The final prototype, called the MonoPedal II, fully integrates a position adjustability system, a foot interface, sensing electronics, and software. Testing of the pedal in a simulator at Stanford revealed that the MonoPedal II is better than traditional pedals in certain areas such as reaction time and on par with traditional pedals in other areas such as comfort and control. The team completed the project by providing Volvo with two prototypes; one where the foot interface system was installed in a Volvo S80 car, allowing for actual test driving, another MonoPedal II system, complete with adjustability, was installed in a test rig for future exploration. Patent is currently pending.

3.2 Education

The student project received the top grades at both Stanford and Luleå, in competition with several fully collocated projects. The project also received the "Best of Program Award" in a national design competition arranged by the James F. Lincoln Arc Welding Foundation.

3.3 Research

The DTI framework has enabled us to approach many of the challenges of distributed teams, such as awareness, communication latency, and mobility, while taking advantage of the benefits of team diversity and distribution in time and space. The research findings derived from the ethnographic case study described in section 2.1.3 are discussed in detail in [1] and [24], where the main findings indicate that the informal information flow between remote team members was very low compared to the informal interactions between local team members. To address these issues, some tools were developed, such as the Contact Portal [1], acting as a natural starting point for initiating and maintaining contact with remote team members. The features of the Contact Portal also promoted awareness and shared understanding since team members were allowed to monitor progress at the remote site, while having the possibility to resolve issues in a rapid, opportunistic way. The high-quality videoconferencing capability enhanced the ability to understand body language and other non-verbal information, making physical proximity less of a concern compared to telephone conferencing and low-quality videoconferencing. In the study, we also noticed that one-on-one conversations, held in parallel to a main discussion, were common in collocated teamwork, and that they served as a natural part of creative teamwork [24]. Current systems for distributed collaboration can not provide sufficient support for these subtle interactions, which has important implications for supporting and improving the performance of global teams by suggesting that the one-to-many channel of today's videoconferencing is severely limiting, despite the current advantages of high-quality audio and video.

4. Discussion and future work

Given that the product development projects in ME310/Sirius typically last 9 months, research ideas can rapidly be tried out and integrated into the DTI framework. These fast implementations and iterations are often difficult to do within industry due to, for example, company policies and regulations. The current wisdom is that teams need to meet with each other physically. Can this be avoided? One of our goals is to work on distributed social activities that can replace this need for travel. If we can do this, distributed product development can scale up significantly. Further, our findings suggest that we can also learn more about local collaboration by "breaking up" collocated teams. By assigning teams with distributed coaches, we will be able to investigate the role of coaches in distributed collaboration. Another important aspect is that of hardware; we can easily share the geometry of a pedal concept, but how do we share the "feeling" and "experience" of driving with these pedals without having physical prototypes at each site? A possible approach to investigate within the DTI framework is a distributed driving simulator with hardware-in-the-loop.

5. Conclusions

The real user experience is undoubtedly the best way of learning distributed collaboration. To reach out to the industry with the research, a good way is to get the research tools and methods into the engineering design education and the DTI project has been a good example of such knowledge transfer. The collaboration tools of today; broadband conferencing, shared applications and whiteboards can support formal meetings to a certain extent. Supporting informal meetings and distributed social activities is still an issue of great challenge. From our preliminary findings, we believe that the approach we have taken in the DTI initiative will make significant contributions to meet this challenge. From an industry standpoint, Professor Bengt-Olof Elfström from Volvo Aero Corporation concluded that the initial DTI project very well met with the five requirements stated in the introduction of this paper.

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