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Concurrent Engineering Approaches for Sustainable Product Development in a Multi-Disciplinary Environment

Proceedings of the 19th ISPE International Conference on Concurrent Engineering

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Preface

This book of proceedings contains papers accepted and peer reviewed for the 19th ISPE International Conference on Concurrent Engineering, held at the University of Applied Sciences in Trier, Germany, from September 3 to 7, 2012. The CE Conference series is organized annually by the International Society for Productivity Enhancement (ISPE) and constitutes an important forum for international scientific exchange on concurrent and collaborative enterprise engineering. These international conferences attract a significant number of researchers, industrialists and students, as well as government representatives, who are interested in the recent advances in concurrent engineering research and applications.

Discovered in the late 80's the CE approach is based on the idea that different phases of a product life cycle should be accomplished concurrently and initiated as early as possible within the product creation process (PCP). The main goal of CE is to increase the efficiency of the PCP and to reduce errors in the late phases of the PCP. In the past decades CE has become the substantive basic methodology in many industries (automotive, aerospace, machinery, shipbuilding, consumer goods) and also adopted in the development of new services.

Meanwhile, the initial, basic CE concepts have grown up and have become the foundations of many new ideas, initiatives, approaches and tools. Generally, the present CE concentrates on enterprise collaboration and its many different elements, from integrating people and processes to very specific complete multi/inter-disciplinary solutions. Current research on CE is driven again by many factors like increased customer demands, globalization, (international) collaboration and environmental strategies. The successful application of CE in the past opens also the perspective for applications like overcoming of natural catastrophes und new mobility concepts with electrical vehicles.

The organization committee identified 24 thematic areas within CE and launched the call for papers accordingly. The submissions come from all continents around the world. The conference is entitled: "Concurrent Engineering Approaches for Sustainable Product Development in a Multi-Disciplinary Environment". This title demonstrates the variety of processes and methods which influences the modern product creation. Finally the submissions as well as invited talks were collected in 12 session led by outstanding researchers and practitioners.

The proceeding contains 100 papers by authors from 26 countries. There are papers which are theoretic, conceptual and strong pragmatic containing industrial best practices. The involvement of more than 20 companies from many indus-tries in the presented papers gives a special importance for this conference.

This book on Concurrent Engineering Approaches for Sustainable Product Development in a Multi-Disciplinary Environment is directed at three constituencies: researchers, design practitioners, and educators. Researchers will find latest research results in product creation processes and related methodologies. Engineering professionals and practitioners will find the current state of concurrent engineering practice, new approaches, methods and their applications. It is also important for educators to include the latest advances and methodologies for engineering curricula.

Part 1 of the proceedings entitled “System Innovation” gives an overview on the new research and development directories on concurrent engineering like disaster recovery and networking. In part 2 a variety of the requirements engineering best practices from industry is highlighted.

Part 3 contains the most papers and outlines the importance of knowledge-based engineering within the concurrent engineering, what kinds of methods to develop, and what is the general approach in the product creation process for capturing and using this knowledge.

Part 4 deals with the broad variety of value engineering in various industries and applications. Part 5 focuses on decision making context in engineering design.

In part 6 the authors discuss and describe specific methodologies dealing with the product and service engineering. Part 7 gives the recent insights into product lifecycle management (PLM). Part 8 deals with various aspects of concurrent engineering within the digital factory.

Part 9 highlights special aspects of consumer-oriented product design and development with applications in transportation, medicine, consumer products and public organizations. Part 10 deals with the broad variety of systems concurrent engineering of complex products especially for aerospace and space applications.

The proceeding are closed with parts 11 and 12 which comprises the recent research on cloud computing in concurrent engineering and web in concurrent engineering, respectively. While not directly related to product development and design, we consider this research important for future applications in the overall product creation process.

We acknowledge the contributions of all authors to this book, and the work of the members of the international program committee who assisted with the review of the original papers submitted and presented at the conference.

You are sincerely invited to consider all of the contributions made by this year’s participants through the presentation of CE2012 papers collated into this book of proceedings, in the hope that you will be further inspired in your work by giving you ideas for new approaches for sustainable product development in a multi-disciplinary environment.

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2011: Boston, USA
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2007: São José dos Campos, Brazil
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2001: Anaheim, USA
2000: Lyon, France
1999: Bath, UK
1998: Tokyo, Japan
1997: Rochester, USA
1996: Toronto, Canada
1995: McLean, USA
1994: Pittsburgh, USA

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Part VIII CE within the Digital Factory

Part IX Consumer-oriented Product Design & Development

Part I
System Innovation

Current Concurrency in Practice

Nel Wognum[1], Richard Curran[2]

Abstract Concurrent Engineering has been a major theme in the 80s and 90s of the previous century in research and practice. Many advantages have been achieved in terms of cost and time reduction and quality improvement. While starting with a design-manufacturing alignment, gradually the CE way of thinking has been extended to incorporate more lifecycle functions together with a stronger focus on and involvement of both customer and supplier. In this paper a history of CE is sketched as well as its major achievements and challenges. Challenges are briefly described that exist in two application areas, aeronautics and agro-food.

Keywords

Concurrent Engineering, Collaborative Engineering, Early Supplier Involvement, Collaborative/Open Innovation, Value Engineering, Supply Chain Networks

1 Introduction

In the '80s of the past century, the term Concurrent Engineering was coined to indicate a way of working in product development and design to meet consumer demands in shorter time, with fewer errors, and lower costs. Concurrent Engineering was meant to improve industry's competitiveness especially in the West to catch up with the advantage gained by Japanese companies like Toyota.

The essence of Concurrent Engineering (CE) has been the concurrent execution of design processes with the design of downstream processes, in particular manu-

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facturing. Teams of multiple functions and disciplines were formed to discuss design proposals from different, multidisciplinary, point of views. In these teams, design disciplines, manufacturing and assembly, marketing and purchasing were often represented.

Several new terms were used to indicate more specific approaches of Concurrent Engineering, like Design for Manufacturing and Design for Assembly. Since many design and development processes also required the involvement of external technology providers the term Collaborative Engineering has also been used to indicate the concurrent way of working.

Later, more downstream processes became involved in Concurrent Engineering, like service and disposal. The necessity to incorporate the customer early in the design process was also recognized in the approach called Open Innovation, in which consumers, customers, suppliers, and OEMs collaborate to identify potentially successful product ideas. In this way waste in terms of time and cost is reduced considerably by the upfront matching of insights of important stakeholders.

All these approaches basically center on boundary-spanning processes. Although the term CE is hardly used anymore, process thinking and boundary-spanning processes have gained more and more attention. Current business requires collaboration between companies, like networks and supply chains, to maintain or improve their market position. Information technology plays a large role in supporting information sharing and aligning people and companies.

In this paper, current approaches to CE are discussed as they currently have been adopted in different industry areas. In particular, challenges that still exist are addressed as well as insights already gained. In section 2, the history of CE is briefly discussed. In section 3, achievements of CE implementation are presented as recorded in the literature. In section 4, developments in aeronautics are presented. In section 5, challenges that exist in the agro-food supply chains are discussed. The paper ends with a summary and future challenges.

2 History of CE

In this chapter, a brief history is sketched of the main developments in CE in the past decades. First, Concurrent Engineering is briefly described, including Early Supplier Involvement. Second, Collaborative Engineering is described, followed by Collaborative Innovation.

2.1 Concurrent Engineering

In the 80s, organisations were forced to change the product development process from the traditional 'over the wall' approach' to more integrated ways of working to beat growing competition, react to reduced product life cycles, and meet changing market and customer demands (Trygg, 1993). They needed to be able to develop new products, which were cheaper, delivered faster and provided a greater functionality (Clark and Fujimoto, 1991). Concurrent Engineering (CE) was considered to offer a solution to the problems encountered.

Concurrent Engineering (CE) has had tremendous attention in the literature since Winner et al. (1988) in the DoD Institute of Defense Analysis coined the term. The concept has resulted from a DARPA initiative to improve the product development process. The first definition of CE was (Winner et al. 1988):

> *"Concurrent Engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacturing and support. This approach is intended to cause the developers from the outset to consider all elements of the product life cycle from conception to disposal, including quality cost, schedule, and user requirements"*

This definition stresses the parallel, concurrent, execution of product and process design activities by integrating multiple design disciplines and upstream and downstream functions involved in the lifecycle of a product. Many studies have been devoted since then on further defining this concept. CE is known under various different names, like Simultaneous Engineering, Concurrent Product Development, and Integrated Product Development with definitions slightly different from the one above (see e.g., Bergstrom 1990, Cleetus 1992).

CE has three basic elements: early involvement of participants, the team approach, and the simultaneous work on different phases of product development (Koufteros et al., 2001). CE teams typically consist of the functions marketing, product engineering, process engineering, manufacturing planning, and sourcing activities. The principle focus was the integration of and alignment between design and manufacturing functions, while taking into account consumer demands and supplier capabilities.

Conflicts easily arise within cross-functional CE teams because of different interpretations leading to confusion and lack of understanding. Each team member focuses on different aspects, like marketing on usability, engineering on functionality, production on manufacturability, and purchasing on affordability (O'Neal, 1993). In such situations, communication needs to be predominantly personal and involve face-to-face contact.

The early involvement of relevant stakeholders in the design and development process enables exchange of preliminary information. Such information exchange may reduce the number of engineering change orders, which are often the reason for delay in product development projects (see e.g., Milson et al., 1992). Strategies for the exchange of preliminary information exchange may differ with the level of downstream uncertainty and costs of process idleness (Terwiesch et al., 2002).

To support collaboration in teams and facilitate information exchange and use, many attempts have been made to develop engineering knowledge and collaboration tools (see e.g., Chen and Liang, 2010). They are, however, still poorly developed (Lu et al., 2007). As reported by Lu et al. (2007) based on a VIVACE document (VIVACE, 2005) 26% of project meetings in Airbus involve international partners, more than 400 one-day trips were taken by Airbus engineers to collaborate with other project members on a daily basis, while they also spent an average of 49% of their daily ativities in meetings and discussions with stakeholders. It can be said that engineering collaboration has become a highly collaborative activity in today's industry.

2.2 Collaborative Engineering

Gradually, the number of stakeholders that needed to be involved in the design process increased. In particular, downstream functions, like service and asset recovery have been involved early in the design process. Because products are used and need to be disposed eventually, environmental concerns have also added to product design and development complexity (see e.g., Lenox et al., 2000).

The desire for incorporating multiple lifecycle considerations requires tight integration of multi-disciplinary knowledge and collaboration between engineers across various cultural, disciplinary, geographic and temporal boundaries (Lu et al., 2007). Todd (1992) has defined collaboration as the process of multiple people working together to achieve a greater goal than is possible for any individual to accomplish alone.

Putting the emphasis on collaboration has led to the term Collaborative Engineering (CE*) with the following definition (Willaert et al. 1998):

> *Collaborative Engineering is a systematic approach to control lifecycle cost, product quality, and time to market during product development by concurrently developing products and their related processes with response to customer expectations, where decision making ensures input and evaluation by all lifecycle functions and disciplines, including suppliers, and information technology is applied to support information exchange where necessary.*

Because fundamental knowledge about human collaboration and its underlying sciences is lacking, a CIRP community has attempted to start a new human-centered engineering discipline by developing a first step of a socio-technical theory of collaborative engineering (Lu et al., 2007). This theory builds on various theories from collaboration science, like organizational behavior, social psychology, social choice and decision science.

In addition to involving the purchasing function early in the design process the supplier itself has become a team member. Together with the buyer the parts and materials supply as well as the required logistics are taken into account as early as possible (O'Neil, 1993). In addition, the supplier could take responsibility for (parts of) the development process or be involved in different phases, like concept design, engineering, or process engineering (see e.g., McIvor and Humphreys, 2004).

Early supplier involvement (ESI) as part of CE and CE* has received much attention from researchers and practitioners at the end of the 90s and early 2000s. A literature review by McIvor and Humphreys (2004) revealed that despite the potential benefits of ESI negative impact of various factors might exist, like technology uncertainty, low levels of trust between the buyer and supplier, poor communication and co-ordination mechanisms. These factors are similar to those mentioned often also in the context of CE and CE*. Development and monitoring of collaborative relationships are critical for preventing problems with supplier performance (Zsidisin and Smith, 2005).

2.3 Collaborative Innovation

Research and Development in large companies used to be internal in the past decades. Many R&D project, however, have led to results that appeared not to be useful for the respective companies leading to waste in terms of time, money and missed market opportunities. However, some of those results turned into valuable companies (Chesbrough, 2004). To limit waste and increase the success rate of technology projects, a new business model gradually emerged from Closed Innovation (with extensive control) into Open Innovation.

Open Innovation requires collaboration between a firm and external sources of knowledge, like technology providers, start-ups, small enterprises, consumer organizations, etc. External knowledge increases the potential number of innovations, while also external parties can exploit internal knowledge. Procter & Gamble (P&G), for example, changed the concept of R&D into C&D (Connect and Develop (Dodson et al., 2006) to indicate the necessity to open up its knowledge and admit external knowledge to keep up and improve its competitiveness. Its experience with CE and CE* models allowed P&G to transit to the new model in reasonable time.

Gradually, the concept is also adopted in more traditional and mature industries like the food industry (Sarkar and Costa, 2008). As argued by Sarkar and Costa, since the number of actors is large and no one actor alone can meet all, often contradictory, requirements of customers, consumers and legislation bodies, open innovation should be common practice. However, empirical evidence is still anecdotal to date, although the necessity and need for open innovation is gradually recognized.

Vanhaverbeke (2006) argues that the open innovation business model should be based on integration of theoretical frameworks, like value chain analysis, transaction-costs theory, rational view of the firm, and the resource-based view (RBV). In addition, governance of innovation networks, on internal, firm and external level, needs to be studied. Networks or supply chains that will eventually produce the product need to be designed also with appropriate governance (see also section 5).

3 CE Achievements

CE, CE*, ESI, and CI are approaches requiring collaboration within and across organizational borders. These approaches present complex problems that require a socio-technical approach in which both the technical and social systems and their interaction are taken into account. Koufteros et al. (2001) have found that firms that have adopted CE practices report better performance in product innovation and quality, while they are also able to charge premium prices. A firm's internal context is important for facilitating cross-functional integration. Once achieved, external integration is sought for with customers and suppliers to coordinate activities across the value chain. Information technology is an enabler for this way of working. Many success stories can be told with reductions in product development time of 50-70% (see e.g., Trygg, 1993), but also many failures.

In the early 90s, a survey of Swedish manufacturing firms showed that Swedish firms had a broad awareness of the importance of product development (Trygg, 1993). Various names have been given to the CE way of working, with integrated product development as the one most widely used. Reducing lead-time was considered the most important goal for CE, followed by customization of products. The dominant element of CE for achieving lead-time reduction is the use of multi-functional project teams, sometimes including customers as well as suppliers, especially in companies successful in reducing lead time (about 50%). However, such teams are not sufficient for success, because also companies not successful in reducing lead-time (about 23%) appeared to be using them. Additional methods are needed, like QFD and FMEA, which were used by the most successful companies as well and typically in aerospace. In addition, CAD/CAM integration also was more widespread in such companies.

In another study in British industry Ainscough and Yasdani (2000) have found that CE was not uniformly spread among British industry sectors. Of the large companies, 100% claimed to practice CE, with only 63% of medium-size companies with (101-500 people) and 50% of the smaller companies. Medium and large companies heavily relied upon formal product development processes, multifunctional teams, tools and techniques, information technologies, and project management activities for executing CE. The functional structure is not suited for executing complex projects like CE projects making various integration mechanisms necessary, although small companies do not seem to need extensive integration mechanisms, because people are closer together.

Implementation of organizational structures needed for executing CE, CE*, ESI, and CI projects, including complex information technologies needed to handle and share the large amounts of information involved in such projects, requires extensive organizational change. As with all major changes, observable also with implementation of ERP systems and other integration systems, various factors play a role in making such changes a success or failure. McIvor and Humphreys (2004) have listed factors that play a role in adopting ESI, which are not much different from the factors mentioned for other major organizational changes.

In the next two sections some achievements and challenges are discussed in two application areas: Aeronautics in section 4, innovation in the agro-food sector with consequences for governance decisions in section 5.

4 Aeronautics

At the start of the 20th century, the Wright Brothers worked already in a highly concurrent environment with a seamless flow of communication from one discipline to the other, with constant updates and explanation of terms and information. This is significant as it highlights the ability of small teams to work in a highly concurrent manner. Later, the aerospace industry moved away from this situation (VIVACE, 2005), requiring the reintroduction of concurrent practices.
Today, development time for an aircraft can be 10 years[3] for a new 'concept' at a cost of 10 billion dollars, while even derivatives (altered forms) of an existing aircraft can take an average of over a year. However, from the start, the aerospace industry became more and more complex, in terms of the product and its levels of detail, the organisations, and the associated socio-technical information systems (VIVACE, 2005). The serialisation of life cycle process also introduced the integration challenge, where information and analysis relevant to the concept stage (from subsequent downstream stages) should be available during the conceptual design process.

There are a number of reasons why aerospace and aircraft design became more complex, even though the product form has not changed that drastically. These include the pressure to produce aircraft at higher rates – leading to the breakdown of the product structure and production workflows to enable repetitive work packages that then require a lot of integration effort in delivering the end product. There is also the advancement of computer and software systems that has increased the amount of potential analyses and the potential for managing ever-greater amounts of information and accompanying levels of detail. However, at an organisational level, consolidation has taken place with one company buying up many others such as Boeing in the US, leading to ever-growing companies, including culture differences and much inefficiency of scale. In general, the industry is now dominated by multi-national organisations, like Airbus and Bombardier, while all companies now look to leverage as much value as possible through exploitation of the

[3] In comparison, during World War II, the P51 Mustang was first rolled out only 102 days after the first contract was signed, and flown a month later on the 26th Oct. 1940