Concurrent Engineering
http://cer.sagepub.com/

How Tools and Techniques in Concurrent Engineering Contribute towards Easing Cooperation, Creativity and Uncertainty

Biren Prasad

Concurrent Engineering 1998 6: 2
DOI: 10.1177/1063293X9800600101

The online version of this article can be found at:
http://cer.sagepub.com/content/6/1/2

Published by:
SAGE
http://www.sagepublications.com

CONCURRENT ENGINEERING: Research and Applications

Editorial

How Tools and Techniques in Concurrent Engineering Contribute towards Easing Cooperation, Creativity and Uncertainty

Biren Prasad

Electronic Data System (EDS), General Motors Account, CERA Institute, P.O. Box 250254
West Bloomfield, MI 48325-0254, USA

Received 12 December 1997; accepted in revised form 25 March 1998

1. Introduction

Concurrent engineering (CE) is sometimes looked upon primarily as a management and organization-based product design, development and delivery (PD^3) philosophy as described in Volume I (Prasad, 1996). However, this philosophical, methodological and conceptual aspects (Prasad, 1997) of CE, by themselves, cannot yield the needed benefits in terms of cost, quality, time to market (responsiveness), and customer satisfaction. The computer-aided or virtual environment of CE is definitely the most important approach to realizing its (PD^3) full potential. One of the virtual aspects of CE is to capture the life-cycle intent (Nielsen, Dixon, and Zinsmeister, 1991), i.e., the knowledge about the PD^3 process (Prasad, 1997) in its entirety. Knowing how a product is designed, how it functions, how it will be manufactured, and how it will be delivered are necessary so that the work-groups can leverage these knowledge of life-cycle concerns to upgrade the design as the product moves from one developmental life-cycle phase to another.

2. Types of CE Activities

There are various types of activities that take place in a product design, development and delivery (Pahl and Beitz, 1992). On one hand, there are repeated or non-creative activities that ought to be performed by someone—a work-group, a team member or an individual person.

2.1 Repetitive or Non-creative Designs

Repetitive or Non-creative Designs have more potential for automation since they contain stable design information such as product's key features and parameters, and because design processes (in fixed principle) are well defined (PDA Engineering, 1992). However, in order to achieve a better return on investments from computer-based automations, some level of life-cycle capture must start during an original (or first principle) design and must be later refined during adaptive and variant design processes (Nevins and Whitney, 1989). During this refinement process, a design description can be considered as a set of inputs, outputs, requirements, and constraints (Prasad, 1996). It is necessary to have a specific set of tools available to the CE—product development teams (PDTs)—for each type of design, and these tools should address the specific problem nature within each design type. Bowen and Bahler (1993), for example, have looked into developing a multi-domain tool using a constraint language, Galileo3, using which design classifications and their respective descriptions can be modeled. Galileo3 supports an interactive design process in which designers can add new constraints. The language allows the generation of a series of progressive design views for the CE work-groups to consider.

Many product design activities in a PD^3 process are routine types. Often PDTs are familiar with them, and they do not require much collaborative efforts. This *routine* type of activities in a PD^3 process (PDA Engineering, 1992) represents one end of the spectrum. It is possible to have, in addition, some middle-of-the-road activities that may require capturing some degree of product or process intelligence to guide decision-making. On the other end of this PD^3 spectrum, there are *creative* activities (Rosenman and Gero, 1993) that require a full set of knowledge well beyond one's own disciplines, work-groups or areas of expertise.

2.2 Creative Designs

Creative design involves *generation of entirely new con-*

1063-293X/98/01 0002–05 $10.00/0

figuration subtypes (often bearing little or no relationships exist with the old subtypes). Creative design incorporates innovative design but involves creation of products that have little obvious relationships to an existing line of products. Creative design is a creation of a new structure in response to a set of functional requirements (Rosenman and Gero, 1993) that may be difficult to be completely stated at one time. Creativity is concerned with exploration in a design space that is only partially defined or known. In the beginning, product specification information is often sketchy, an existing product design information is commonly very sparse, and the design process is generally not very well understood. The processes are obscure (for example, presence of intuitive or creative talents) and the domain knowledge is available generally in implicit or incomplete forms. In those creative situations, the concurrent teams (PDTs) focus first on issues and concerns, which are of general nature or of domain type—such as identifying which information is necessary and how to develop relevant procedures to produce this information. Once such information is produced, the work-group members then look into ways of assessing original product life-cycle assumptions to see if they still apply. The PDTs at times iterate on these assumptions, if necessary. In addition, the PDTs negotiate with other work-group members a number of times to ensure that the information and procedures that the design team has developed so far are consistent with other work-groups and with the rest of the product life-cycle functions.

3. Classification of CE Techniques by Degree of Creativity and Cooperation

Depending upon the types of activities and needs for cooperation, the degree of intelligence required by a PDT in CE varies. This is shown in Figure 1 where six levels of techniques or methods (required for a class of activities) are identified against the "degree of creativity" and "needs for cooperation" axes (Prasad, 1997). The first of such techniques is "network-based techniques," which can be performed by a product development team (PDT) or its team-member and where the activities are routine types. This is identified in Figure 1 as level 0. The next level of techniques is level 1. Over time, PDT members may have discovered heuristics in performing such routine tasks—what has worked the best (best practices) so far and—what process to follow in what situations (common systems). Such activities are still routine types, although, to reduce the lead-time, some level of intelligence, such as spreadsheet logic and documentation-based techniques could be useful. Needs for cooperation increase as one moves away from simple problems to a family of parts involving a number of similar geometry creations (level 2 activities). The use of variable-driven techniques (Kurland, 1994) [such as parametric (Kulkarni, Prasad and Emerson, 1981), variational (Pabon, Young and Keirouz, 1992) or feature-based techniques (Dixon, 1988)] are useful for level 2 to alleviate the

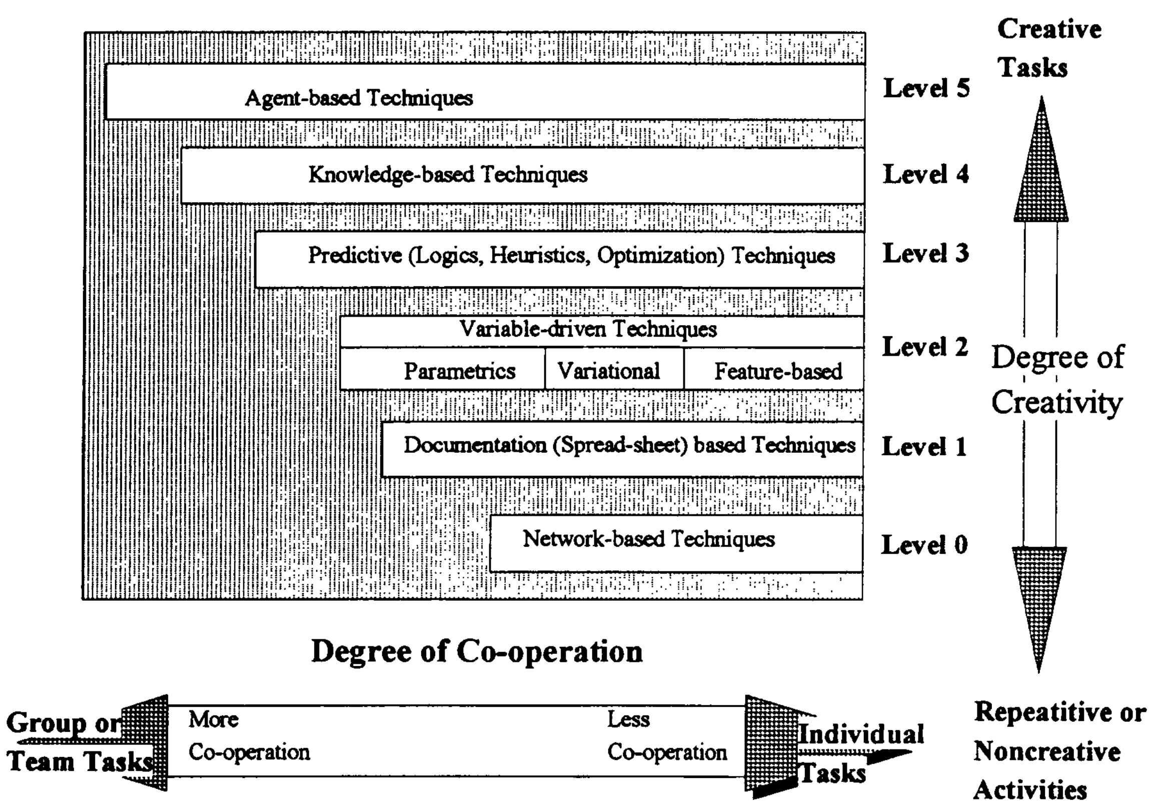

Figure 1. Levels of techniques driving cooperation in a CE office.

boredom tasks of recreating the design-details repeatedly based on their slightly differing geometrical compatibility.

There are product design problems, which extend *beyond geometry*—whose solutions require non-geometrical knowledge, such as materials substitution, configuration designs, layout designs, knowledge of interacting elements of the problem, design rationale, customer preferences, cost-benefit analysis, etc. These are classified as level 3 or predictive techniques. Knowledge-based techniques are more suitable to capture a level of intelligence using heuristics, optimization, neural networks, fuzzy logic, etc. (Rosenfeld, 1989). As such knowledge-based techniques (Wilson, 1995) are often well positioned to deal with "knowledge-rich" class of problems (level 4). At the end of this spectrum are the agent-based or "multiple knowledge-based" activities (level 5), which require product development teams (PDTs) with intelligence, ingenuity, and creativity. An individual work-group of a PDT with its own knowledge may not be able to comprehend the interdisciplinary complexity of the decisions that are needed. Most complex decisions are made during PDTs design review sessions, quality network circles, or in similar collaborative settings (Sriram, Stephanopoulos, Gossard, Groleau, Serrano and Navinchandra, 1989). The levels of techniques addressing all these types of activities are contained in Figure 1. There are six levels of techniques identified—one for each type of activities from level 0 to level 5. Level 5 activities are not easily amenable to automation techniques since frequently the creativity possibilities are unlimited.

4. Classification of CE Tools by Degree of Creativity and Uncertainty

In Figure 2, an attempt is made to classify the applicable range of tools by the *degree of creativity* and *degree of uncertainty* present. The computerized tools required for creative tasks (levels 4 and 5) are of a very different nature than those required for solving routine type of activities (level 0).

The range of such tools having potential for use in product design development and delivery (PD^3) process can be classified into the following six difficulty levels:

Level 0: Networking Tools: The types of activities that may fall in this category are document computerization and access facilities for text, graphics, schematics and distributed data base facilities. Networking tools also include communication tools such as electronic mails, GroupWare and multimedia between and across the members of CE teams.

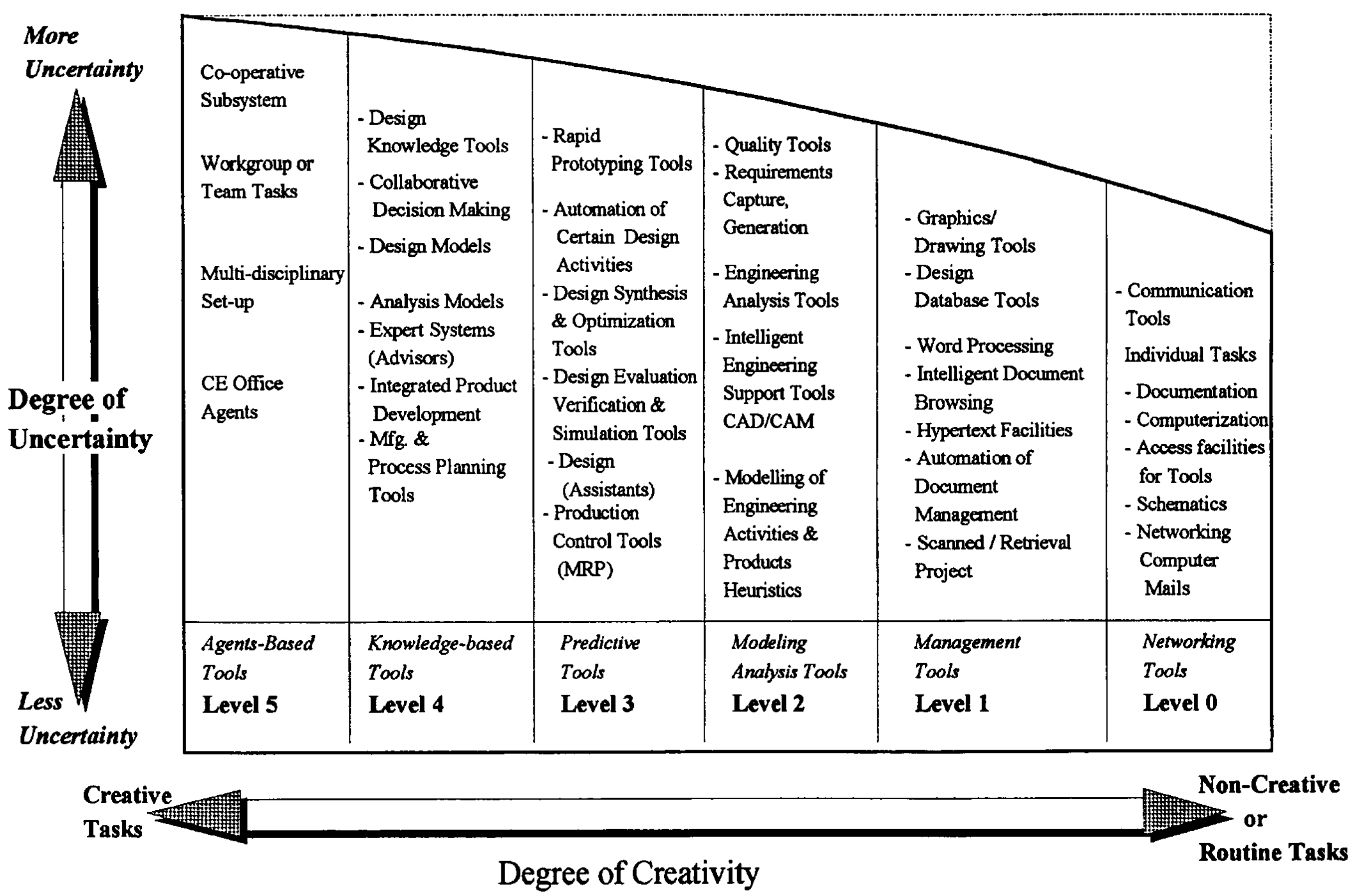

Figure 2. Automation levels of computerized tools in a CE office.

Level 1: Work-flow Management Tools: These control the priority of tasks in a work-group, a unit, a department, or in an enterprise setting. Database tools, such as proven systems database, proven components and part database can be used for this purpose. Other types of tools in this category are: word-processing, spreadsheet, schedules, work-flow charting and time management, browsing, graphics/drawing tools, hypertext facilities, intelligent document management, retrieval and version control, quality tools, etc. The quality tools include an array of conceptual tools, such as cause and effect diagrams, check sheets, histograms, pareto diagrams, control charts, scatter diagrams, matrix charts, SPC, etc.

Level 2: Modeling & Analysis Tools: Tools of this level should enable the generation, refinement, quantification and prioritization of requirements, such as QFD, Objective tree, etc. Such tools are the result of modeling engineering activities, for example, geometric modeling tools, such as solid modeling, surface modeling, etc. Tools may also be of product modeling types, such as STEP/Express, using feature-based (Dixon, 1988) or similar techniques. It also includes engineering analysis and support tools, such as FEA, mechanism analysis, mathematical calculations, intelligent CAD/CAM, wherein rules of thumbs, heuristics, and parametric rules for model creation are captured.

Level 3: Predictive Tools: These tools are a result of design evaluation, verification and simulation, design synthesis and optimization, and automation of design activities based on parametric, simulations, design assistants, advisors or expert type of systems. Tools that are useful for design evaluation and verifications are design for X-ability (reliability, serviceability, assembly, disassembly, manufacturability, testability, safety, etc.), failure mode and effect analysis (FMEA), fault tree analysis, etc. Tools that are useful for design synthesis are: boundary searching, functional analysis, concept selection, feature-based design (Dixon, 1988), design retrieval, materials selections, value engineering, production control tools, etc.

Level 4: Knowledge-Based Tools: These tools help teams to apply manufacturing and engineering intelligence to sort out bad alternative design concepts from good ones. KB tools include design knowledge tools, collaborative decision making tools for coordination, and analysis/design models (Rosenfeld, 1989). This also includes design automation based on optimization techniques, expert systems (advisors), integrated product development, manufacturing and process planning, etc. The latter includes tools, such as process capability, manufacturing process selection, materials selection, Manufacturing Resource Planning (MRP), Computer-aided Manufacturing (CAM) tools, Numerical Control (NC) and CNC verification tools, etc.

Level 5: Agent-based Tools: Such tools are used when constraints are present, when multiple knowledge sources (product and process knowledge) are present as agents, and when conflicts occur requiring trade-off (Sriram, Stephanopoulos, Logcher, Gossard, Groleau, Serrano and Navinchandra, 1989). Agent-based tools belong to distributed AI and cooperative knowledge-base fields such as cooperative expert system, CE office agents, etc. GroupWare technology replaces the conference room with the "electronic" whiteboard.

The range of such tools can be represented in a set form as:

$$\text{Range of Tools} \equiv \cup[\{\textit{Networking Tools}\}, \{\textit{Work-flow Management Tools}\}, \{\textit{Modeling \& Analysis Tools}\}, \{\textit{Predictive Tools}\}, \{\ldots\}, \{\textit{Knowledge-based Tools}\}, \{\textit{Agent-based Tools}\}]$$

Where $\cup$ indicates a *Union-of.* The level of intelligence and degree of cooperation are very much related to each other. Cooperation provides the degree of confidence in the use of the captured knowledge or intelligence. *Agent-based tools* contain the largest amount of cooperative knowledge or product intelligence. The usefulness of tools depends upon the collective creativity of the individual teams participating in applying the seven Ts (e.g., tools and techniques) to problem solving (Prasad, 1995). The PDTs' dependence on cooperative problem solving decreases as we move to lower level tools (level 3, or level 2, or level 1) requiring less team cooperation and more individual effort. Level 0 tools, for example, do not require any team cooperation. The applicability of a set of tools at a particular automation level depends upon many factors. The important ones are *degree of certainty, accuracy and completeness* of information, and its integrity in current work environment and procedures. It is not difficult to capture the domain knowledge in most routine tasks with a high degree of confidence. Mining of rules in routine tasks is most common in levels 0 through level 2. Level 2 tools allow teams to build a modeling environment and to capture the domain knowledge before any eventual automation of the design activities can take place. The rest of the levels are more suited for specific applications such as family of parts' category involving multiple group interactions or multiple disciplines. Higher level (levels 4 and 5) tools are useful when a product or a part is frequently redesigned for a variety of specifications. Typical examples include different bore size and stroke length cylinders for 4-cycle, 6-cycle and 8-cycles engines, etc.

5. Concluding Remarks

The choice of tools and techniques for a PD^3 process depends upon the *degree of complexity, degree of creativity* and the *degree of uncertainty* at hand. Knowing the tools and techniques, and their classifications can be quite helpful in identifying the places in the product life-cycle domain when their use would be more appropriate and relevant (Prasad, 1995). In routine tasks it is more appropriate to apply tools that are of lower level-class, such as networking (level 0), workflow management (level 1), and modeling and analysis tools (level 2). As PDT deals with more complex tasks in terms of creativity, level 3 and level 4 type tools are more appropriate. If the product development teams (PDTs) are mainly dealing with creative tasks, it might be useful to apply tools and techniques that exploit the cooperative nature of product solution, such as agent-based techniques.

References

Bowen J., D. Bahler, 1993, "Constraint-based Software for Concurrent Engineering," *IEEE Computer*, Special Issue on Computer Support for Concurrent Engineering, Vol. 26, (January), pp. 66–68.

Dixon, J.R., 1988, "Designing with Features: Building Manufacturing Knowledge into More Intelligent CAD Systems," *Proceedings of the ASME Manufacturing International '88*, April 17–20, 1988, ASME Press.

Kulkarni, H.T., B. Prasad, and J.F. Emerson, 1981, "Generic Modeling Procedure for Complex Component Design," *SAE Paper 811320, Proceedings of the Fourth International Conference on Vehicle Structural Mechanics*, Detroit, Warrendale, PA: SAE International.

Kurland, R.H., 1994, "Understanding Variable-driven Modeling," *Computer-Aided Engineering* (January 1994), pp. 38–43.

Nevins, J.L. and D.E. Whitney, eds., 1989, *Concurrent Design of Products and Processes*, New York: McGraw-Hill Publishing, Inc.

Nielsen, E.H., J.R. Dixon, and G.E. Zinsmeister, 1991, "Capturing and Using Designer Intent in a Design-With-Features System," Proceedings, 1991 ASME Design Technical Conferences, *2nd International Conference on Design Theory and Methodology*, Miami, FL.

Pabon, J., R. Young, and W. Keirouz, 1992, "Integrating Parametric Geometry, Features, and Variational Modeling for Conceptual Design," *International Journal of Systems Automation: Research and Applications (SARA)*, Volume 2, No. 1, pp. 17–36.

Pahl, G., and W. Beitz, 1992, *Engineering Design: A Systematic Approach*, New York: Springer-Verlag (Edited by Ken Wallace).

PDA Engineering, 1992, "What's Needed for Competitive Manufacturing—Concurrent Thinking: Simplifying the Process," *Concurrent Engineering Supplement to Computer Aided Engineering* (October 1992), pp. S1–S15.

Prasad, B., 1995, "On Influencing Agents of CE," *Concurrent Engineering: Research and Applications—An International Journal*, Volume 3, No. 2, June 1995, pp. 78–80.

Prasad, B., 1996, *Concurrent Engineering Fundamentals: Volume I*—Integrated Product and Process Organization, One Saddle River, New Jersey: Prentice Hall PTR.

Prasad, B., 1997, *Concurrent Engineering Fundamentals: Volume II*—Integrated Product Development, One Saddle River, New Jersey: Prentice Hall PTR.

Rosenfeld, L.W., 1989, "Using Knowledge-based Engineering," *Production*, Nov., pp. 74–76.

Rosenman, M.A., and J.S. Gero, 1993, "Creativity in Design Using a Design Prototype Approach," Chapter 6 of *Modeling Creativity and Knowledge-based Creative Design*, Edited by Gero and Maher, Hillsdale: New Jersey: Lawrence Erlbaum Associates, Publishers., pp. 111–138.

Sriram, D., G. Stephanopoulos, R. Logcher, D. Gossard, N. Groleau, D. Serrano, and D. Navinchandra, 1989, "Knowledge-based System Applications in Engineering Design: Research at MIT," AI Magazine (Fall 1989), Vol. 10, No. 3, pp. 79–96, AAAI Press.

Wilson, J., 1995, "Knowledge-based Engineering—A New Tool in Car Design," *Automotive Interiors International*.