

CHAPTER 11

CONCURRENT ENGINEERING REVISITED: HOW FAR HAVE WE COME?

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11.1 ORIGIN OF CE

Concurrent engineering (CE) was a phenomenon of the 1980s. It arose in the Department of Defense (DoD) when it was realized that a number of new defense products were being designed without any thought given at the time of design to whether the design was manufacturable. Lack of consideration of manufacturability led to many revisions at a late stage when shortcomings of the design were discovered by the factory.

From this came the notable study of projects in 13 companies that led to a report of the Institute of Defense Analyses,¹ in which the first definition of concurrent engineering was given:

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

Thereafter, the concept was given currency in many ways. DoD projects came to insist on adherence to CE principles; contractors had to demonstrate how they would take into account the concerns of

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manufacturability at the time of design, and in general, how activities usually undertaken late in a project would be given early consideration. One of the barriers was the need for additional expense early in the project to form a larger group of people representing downstream perspectives of the design (manufacturing, maintenance, disposal, etc.). The phasing of DoD development budgets at the time was not compatible with incurring a higher expenditure early, in the hope that it would be more than offset by lower development costs later on, because there would be fewer glitches in manufacturing, fewer engineering changes, and so on.

11.2 ADOPTION OF CE

The adoption of CE was even more spirited in civilian manufacturing companies. Automotive companies, the civilian aircraft industry, electronics, and other significant sectors of the economy espoused concurrent engineering with vigor. Product development was the focus of concurrent engineering when it appeared, and it was noteworthy that the new lessons of CE were fully incorporated into the then 10-year-old efforts to achieve higher quality in American manufacturing. CE was seen as adding the time dimension to achieving quality, showing that not only was quality enhanced (the design and the manufactured reality would be compatible), but the time taken to achieve it could be decreased by getting all the relevant perspectives to work in concert from the very beginning.

The way in which civilian industry went about CE was not the same everywhere. Some chose to set up product development under one large roof so that engineers from all disciplines could interact with each other. The Chrysler Technology Center² is a well-known embodiment of this idea. Another approach to CE emphasized the need to share documents electronically among many people in the course of a very large project, so that the time-consuming and voluminous documentation could be developed faster and placed in the hands of the right people as soon as possible.

11.3 DEFINITION OF CE

Quite early in the development of CE, the Concurrent Engineering Research Center (CERC) was set up by ARPA, the Advanced Research Projects Agency (then DARPA, with the D for Defense). When CERC began examining CE a new, more general definition³ was put forward:

CE is a systematic approach to integrated product development that emphasizes response to customer expectations and embodies team values of cooperation, trust and sharing in such a manner that decision making proceeds with large intervals of parallel working by all life-cycle perspectives early in the process, synchronized by comparatively brief exchanges to produce consensus.

According to this definition, CE applies not just to engineering or product development, but to the general problem of decision-making in any domain; for that purpose, a new process was advocated, conforming to certain principles. The goal was set as response to customer expectations, a goal that was expected to pervade the actions of all perspectives at all times, though who the customer was still needed to be defined for each perspective. Most important of all, the essential means of achieving CE were set forth: teams of people working together with a shared goal and a set of values that included openness to sharing information at all levels, especially in a horizontal manner within the team, trusting that the exploitation of early information would not be to the disadvantage of the information donor.

11.4 THE CE TEAM

The mental picture is of a team composed of all the perspectives of the product being developed. The team meets together throughout the project; in a sense, the whole process of product development can be viewed as a series of meetings to share ideas and technical data and plan work, punctuated by long intervals of individual task accomplishment by members of the team.

11.5 THE ESSENCE OF CE

At the heart of CE lay some very simple ideas:

- *Focusing on Customers*
 - Formulating goals that seek out the customer's input early
 - Using metrics to evaluate tasks that are customer-driven
 - Tracking changes in customer requirements
- *Teaming*
 - Devolution of decision-making on a team selected for the purpose
 - Inclusion of all perspectives in the team
 - Joint problem-solving
 - Willingness to compromise

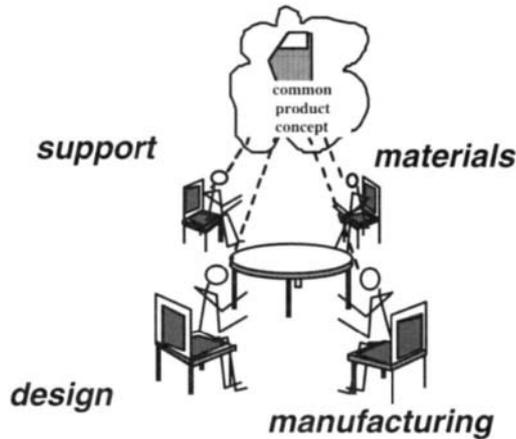


Fig. 11.1 A CE team.

- *Working Cooperatively*
 - Attaining consensus
 - Planning early
 - Managing tradeoffs
 - Communicating regularly
 - Sharing knowledge early
 - Propagating the influence of one decision on others
 - Reducing risk
- *Improving Processes*
 - Planning a concurrent style of working and task breakdown among perspectives
 - Ability to work without complete data
 - Willingness to brook periods of inconsistency
- *Systems Engineering*
 - Integrating and automating

No single idea of CE was new in the late 1980s, when the rush began, but putting it all together resulted in new insights and inspiration for a new approach. The uniqueness of CE lay not so much in the fundamental insights as in some practical consequences of those insights:

- It defines the right composition of a team by an operational test
- It tries to resolve the conflict between:
 - Parallel working and consistency
 - Individual empowerment and teamwork
 - Early propagation of influence and rigorous system engineering
- It puts emphasis on the process rather than the organization structure
- It posits that all three conflicting goals can be achieved simultaneously:
 - Cost reduction
 - Quality improvement
 - Time speed-up

11.6 BARRIERS TO CE

The contradictions in CE are very real and some of the barriers to adopting it arise from the inability to reconcile them in a practical way for the routine working of the team. A new set of values has to be understood and observed by team members. Organizations previously given to a command style of work performance have to realize first the greater fruits of empowering individuals to exercise their own initiative, with goals set only at the most general levels possible. From there they have to learn the additional imperatives implicit in the accountability of individuals to teams.

Engineers brought up in the classical mold have difficulty in reconciling the demands of parallel work and rigorous analysis. The former assumes that engineers will work with tentative and incomplete data and proceed to develop results that may be overthrown upon critique at the next meeting when the results are shared. On the other hand, rigorous analysis works sequentially, step by step, with full information. It is discomfiting to have the usual sequential mode of working set aside in the interest of faster discovery of conflicts among perspectives. It will even be necessary to develop new tools and methods to cope with incomplete inputs to perform analyses.

11.7 APPLICABILITY OF CE

CE has a point of confluence with the newer reengineering tenets: it emphasizes the Process rather than the Organization structure. Indeed, in the simplest case, CE presents the organization structure as a team leader with a host of players from different perspectives — a single flat entity. In more complex cases (such as defense products), there is at best a two-level structure of a team leader supervising several sub-teams, each responsible for a certain part of the product. CE, in any event, is a particular way of working; it is not a call to reorganize the company or change the reporting structure. Therefore, it should be equally applicable to organizations that have the classic structure of departments, each representing a function, and to organizations (consulting companies are typical) who frequently have no functional structure at all, but put together teams to service a client drawn from several specialized individuals.

Though CE was invented in the context of ensuring that the design of a product is manufacturable, it applies as much to service companies as it does to companies that design and manufacture products. In services, too, a full range of perspectives should be brought to bear so that every aspect that can affect the service is allowed to contribute to the solution being developed, for the client. The software industry is a case in point. Clearly, the users, the system maintenance people, the designers, the programmers, the test staff, the technical documentation staff, and sometimes even hardware designers have to work together, in parallel.

Only thus is time saved and quality improved simultaneously. Quality can, of course, be improved by spending more time, and therefore more money, but how to accomplish it in less time and at less expense is what CE is all about. In that respect, it takes further and gives new meaning to Deming's statement "Quality costs less." He was alluding to the consequences of poor quality for the customer who has to put up with the problem and for the supplier who has to fix it. But CE says that you can achieve better quality in less time if you start by involving all the perspectives and share information among them continually so that they can react immediately when any decision seems to have poor consequences for later stages.

11.8 CE AND THE INDIVIDUAL

How desirable is CE? In spite of the emphasis on the team, one can agree that the quality of the company's work is determined to a great extent by the qualities of the individual, such as:

- Diligence in work
- Dedication to quality
- Level of skill
- Repertoire of tools
- Inventiveness

The team is the proper enabler for this individual competence to be raised to a collective level for tasks that require multiple people. The majority of modern artifacts, no matter how seemingly simple, involve multiple design and manufacturing technologies and several areas of competence to deliver. We should look upon the team as the way to deliver a consistent product when the required competence exceeds what any one or two individuals may possess.

11.9 TEAMWORK CAN LEAD TO CHAOS

Teams, though, result in chaos more often than not. There are many reasons:

- Teams are often a sham, never destined by their originators to coalesce.
- Teams rarely invest enough in achieving a common vision before setting out on the detailed work.
- Customer focus is more easily stated than subscribed to in practice.
- Teams do not keep practicing and working on team processes.
- Coordination is not given sufficient importance.
- Motivating factors are geared to recognize individual work, rather than team achievement.
- The leader of the team is not up to the job.

It is not easy or mechanical to work in teams and achieve a team identity. Achieving it overnight by decree is impossible, but without it the CE vision will remain a mirage.

11.10 CE AND INNOVATION

There is a mistaken idea that inventiveness is not encouraged in a team. It is thought that all invention or discovery results from quiet meditation by an individual who thinks long and hard about a subject and plays around with many ideas until a happy thought strikes him or her. This view is promoted by the long history of science and technology, where such, has been the mode of operation. Hence, people will be tempted to assume that the new mode of teamwork might result in product harmony and speed, but it will not break new ground or result in anything like a recognizable new invention, a patent, or a revolutionary product. This view has been overtaken by the sheer complexity of modern products and the pervasiveness of multiple technologies in the life cycle of single products. It has become commonplace even in science to have large teams of people working on experiments, whether it be in genetics, space science, or particle physics.

Wherein lies the source of discovery in such cases? One may recognize that the clash of ideas can spark new insights when people of like interests but different viewpoints congregate to discuss and explore a new field. This happens every day at scientific conferences; researchers return from the best of these gatherings to work at their research with quite new motivations and insights, garnered from discussions at a conference.

The same thing happens in a team at work continually. Complementary strengths occur in the persons forming the group, providing the foil needed to make new ideas emerge. The group milieu also provides the critique that “new” ideas must endure to survive and become “good” ideas. The cut and thrust of group debate allows ideas to be sifted more quickly.

11.11 CE LESSONS

CE is becoming more widespread. The principles are recognized and companies value it. But they have discovered:

- CE does not work without a mandate from above.
- CE does not work without a strong team leader.
- CE works best with physical collocation of the entire team.
- Technology-based CE is best achieved by integrating the tools employed by several perspectives.

For the computer scientist, the most interesting aspect of CE is that a number of new and old information technologies can be exploited to improve the efficiency of the CE process. As may be expected, these are the technologies to support collaboration within a group.

11.12 CONCURRENT ENGINEERING TECHNOLOGIES

11.12.1 Communication

The simplest of these are the technologies of communication, which have undergone a revolution. E-mail, in use for a quarter of a century, has now become the accustomed medium of communication among people at technical companies, even between those only a door or two from their working colleagues. This has been supplemented over the last few years by the appearance of multimedia mail, allowing complex documents to be exchanged. Simple team communication, ranging from notices and instructions to requests for information and action items, can be communicated very effectively by multimedia mail, especially if (as in Lotus Notes,⁴) the e-mail is given the structure of a database with templates to display the characteristic formats of different types of communication within the company.

Multimedia desktop conferencing software⁵ has further augmented the possibilities for groups that need to meet from time to time. Team meetings can now be held over the network, with live graphics, video if need be, and interaction capabilities for everyone, quite akin to what they would have if everyone were in the same room. The blackboard at which technical people like to discuss has been replaced by a virtual “whiteboard” on which anyone can place a drawing and have it made visible to persons half a continent away on their own screens, who can immediately respond—by voice with speech packets conveyed by the data network, by modifying the drawing and annotating it for others to see, by playing a video for the sake of the audience, and so on. The possibilities are limitless, and even if body warmth is not communicated on wires, all the important details formerly missing in fax, phone, and so on are now richly present.

The lesson is, however, that if some of this is not captured systematically and made part of a meeting record, it will be lost for future decision-making. A structured way (decisions, action items, etc.) of capturing the record will enable building indexes for future reference. Storing the record and indexing it not only saves the corporate memory of salient events, but also provides a mine of

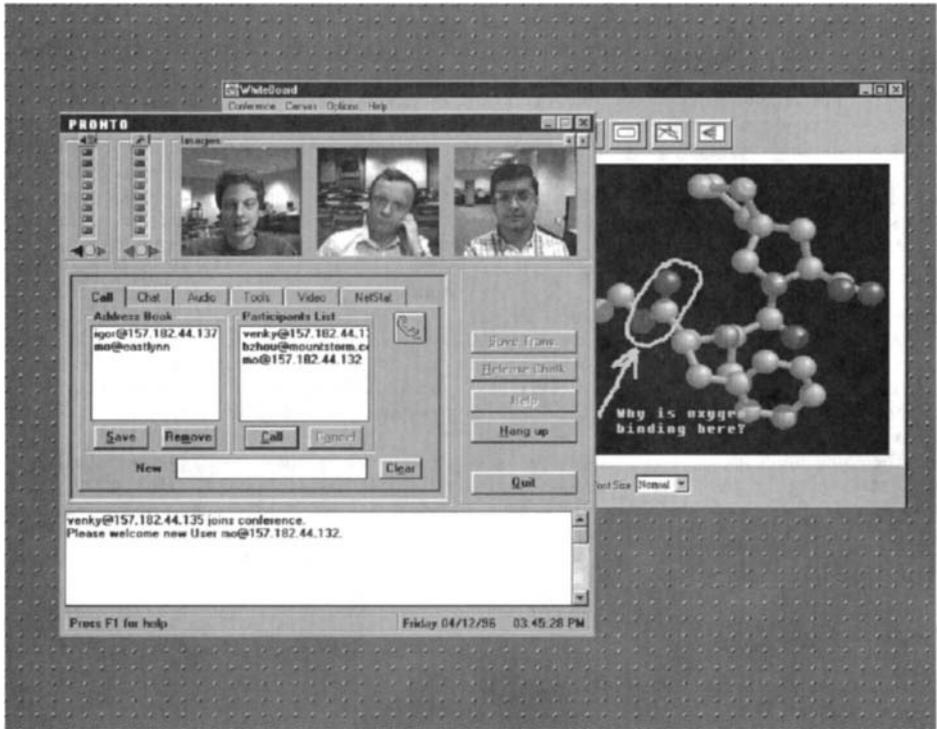


Fig. 11.2 A screen from the MONET desktop conferencing software.

information for turning past project history into a set of episodes that can be used as lessons for designers.

11.12.2 Task Coordination

When multiple persons work on a project, there is an essential need for coordinating their work over the long haul, so that their mutual interdependence is recognized:

1. Their dependence on each other for completion of prior assigned tasks, and
2. Their dependence on each other for the input required by assigned tasks and the output resulting from task performance.

When the tasks are performed in a sequence by different people in a wholly predictable manner, the technology of *workflow* is applicable.⁶ Workflow packages allow a company to design a sequence of tasks to create a process that can be repetitively used. The workflow takes care of many things: notifying a person when a prior task is completed and he or she needs to perform the next task in sequence, making the package of data required to perform the tasks flow automatically to the desktop of the person performing it, so that all supporting paper documents may be eliminated, and storing the results of the tasks under stringent database security so that the final outputs and the intermediate stages of processing are all readily accessible from a database long after the process is over. Notification, routing, and database storage are important to coordination, and modern workflow packages have extensive and flexible support for all phases. However, workflow is not very good for non-repeatable processes, such as the classic CE case of product development.

For a one-off project, such as product development, there are no repeatable processes, except on a microscale. The task network for the whole project will be unique. In such cases, workflow has little to offer for collaboration support and one must appeal to standard project management—with a collaboration twist:

- The task network should be visible to all.
- Progress should be reportable by each individual from his or her workplace via computer.
- The data sharing should be via network databases.
- The flow of instructions, drawings, and work authorization should take place without paper.

- Questions should be handled electronically.
- The whole project history should be stored.

Such project-management packages are scarce today, but undoubtedly it is the wave of the future to conduct group work over computer networks. The difficulty is that you have to combine classic PERT techniques with interactive, distributed, task, and data management. We already see the glimmerings of a such new generation of desktop project-coordination tools with a significant collaboration flavor.⁷ Such packages go beyond the standard metrics of time and cost to provide unique project assessment tools. All the metrics can be evaluated for single tasks, for sub-projects containing several tasks, or for the entire project. The display of these metrics as colors in Gantt charts provides a very useful qualitative view for managers. For instance, if they wish to assess the understandability metric of the project tasks, it can be shown on a Gantt chart in which the perfectly understandable tasks (all outstanding questions satisfactorily answered) are shown as green, those with over half the questions answered are shown as yellow, and those with less are shown as red.

11.12.3 Negotiation/Tradeoff

All design is compromise. During the collaboration, when alternatives are considered to solve a problem or different concepts are being evaluated to realize a product, it is necessary to have quantitative analyses of the cost/benefit. Simple spreadsheets are a way of capturing design goals, criteria, and design variables that influence the product performance from a customer standpoint.

It is impossible, however, to develop general support for this because the computation of product performance criteria is often a tedious numerical process that needs many custom-designed computer programs. Human judgment will intervene, too. Thus tools to support tradeoff among alternatives must perform be custom and proprietary in nature.

However, when the weighing of ideas and concepts can be done in a less technical way and the collective judgment of the team can be made to bear on a decision, some computer support can be afforded for the process. Tools can be designed to support brainstorming and the evaluation of ideas among a team of distributed individuals over the network. One such is the software called Group Systems V from Ventana Corp;⁸ another is the Group Decision System (GDS) of CyberMarché,⁹ itself modeled on CM/1 from Corporate Memory Systems.¹⁰ The latter software allows the team to start a discussion focused on a problem under a leader. Members of the team can supply solutions, supported by arguments. The whole decision grows as a tree from the discussion node to the solution nodes, and thence to the argument nodes. The leader can put in motion a decision-pruning process at the end that involves voting, first on the arguments and then on the solutions, having in mind the customer criteria stated in advance.

Group Systems V is a capable package that is being used in many organizations to aid the group decision-making process while preserving anonymity. It has a very flexible set of voting protocols

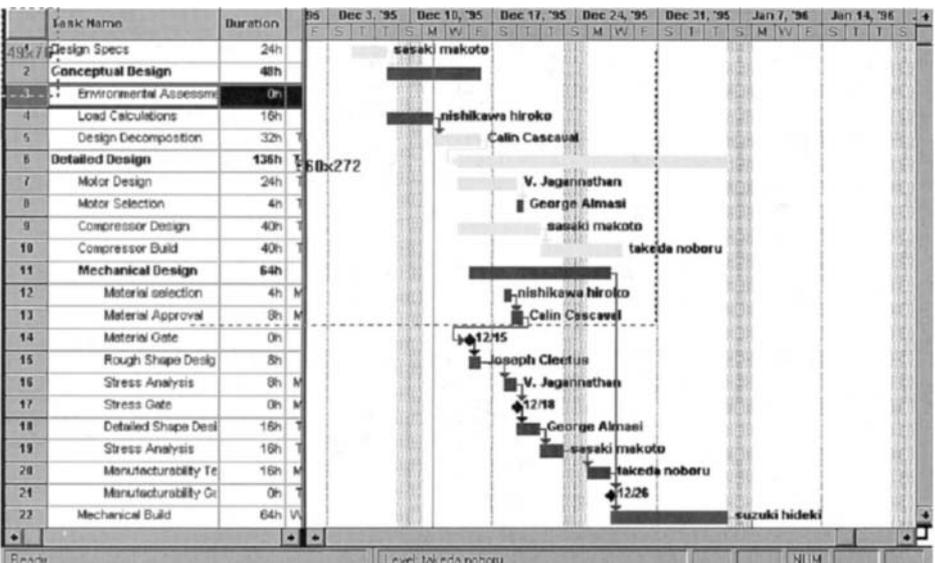


Fig. 11.3 A distributed project assessment chart.

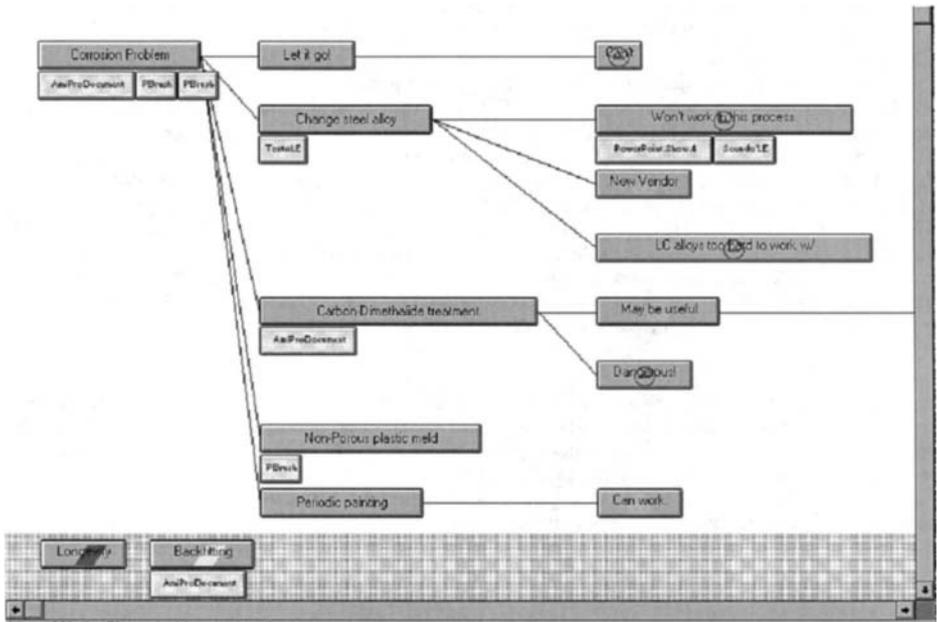


Fig. 11.4 The main screen of a well-developed discussion in GDS.

and automatically produces the minutes of group sessions held under its aegis. A good team facilitator is a must, and the process is usually carried out in a decision room equipped with networked personal computers, though there is nothing in the software itself to prevent its use by remotely connected team members. It is the team leader function that chiefly demands face-to-face interaction to drive the meeting from one stage to the next. In this it falls short of the kind of remote communication that is preferred, in general, for collaboration tools.

11.12.4 Data-Sharing

The most important among technologies to support the collaboration required by concurrent engineering are those that enable the storing and subsequent sharing of information. The technical barriers to this are enormous in the general situation when the users are on different types of computer platforms, on different networks, using applications that produce proprietary data types, and so on. The challenge is to make data-sharing possible even when there is heterogeneity of one kind or another among those who need to share data. The consensus is that such heterogeneity is the rule, rather than the exception, even within one company or one department—and today's collaboration must be worldwide and cross the boundaries of companies and networks.

A variety of techniques and software to share information are now available. The diagram below shows a representative set of such techniques.

Acrobat: Software to render the output of any software package into a neutral form, devised by the Adobe Corp., so that it can be viewed without the native software that created the output.

Notes: Forms-based e-mail and database software useful to create shared databases over a wide area network and create workflow applications.⁴

EDI: Electronic data interchange, a host of formats standardized by various interest groups under ANSI to exchange commercial information of different types among companies who wish to do business with each other electronically.¹¹

Web: The Internet de facto standard, consisting of a transport protocol called HTTP, a document format description standard called HTML, and a variety of graphic and video standards, so that users can access linked multimedia documents placed on Web servers from anywhere in the world. Currently, there are many application packages, such as databases and spreadsheets, that are readily accessible using the Web interface, without extra work.¹²

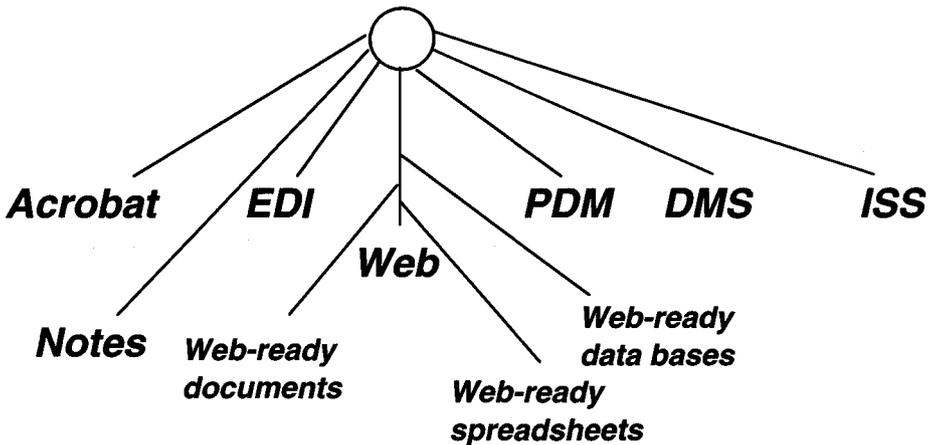


Fig. 11.5 Data-sharing technologies.

PDM: Product Data Management Systems that store information about products, their decomposition structure, and revision history, in order to support a company's manufacturing, inventory control, maintenance, and other technical activities.¹³

DMS: Document-management systems that perform much the same as PDMs, for the more general class of documents occurring in a company. Also enables fast retrieval by indexes, keywords, document types, and even text search.¹⁴

ISS: An information-sharing system that constructs a model of the disparate information lying in different databases, builds gateways to each of them, and provides a single system image to external users who wish to access data from any of the constituent databases. A virtual unification of databases.¹⁵

11.12.5 Electronic Design Notebooks

The support for design rationale capture is quite poor in engineering organizations. The best that is done in a systematic fashion is to annotate drawings when they are revised to state on the drawing the nature of the revision and its cause. However, this has many weaknesses in a complex project.

When it is first made, the drawing does not contain a justification for each of its constituent parts, and that situation will persist through all its revisions. Much of the design rationale and original design intent will never be captured. Further, when a change is made to one part of the product, consequential changes may need to be made to other parts. Unless the link between the parts is maintained and examined whenever changes are made, it is possible that a revision will be made that is inconsistent, unsafe, or inefficient. When variant products are designed, what can be changed and should be changed to suit the new requirements, and what may not be changed without severe disadvantage and redesign, is not clear. Indeed, a design process involves alternatives that were considered and rejected, and the memory of the unselected alternatives is lost in conventional records, since it may not even have been recorded.

The idea was mooted long ago that these things could be cured if only the designers captured their daily work electronically. Many so-called electronic design notebooks (EDN) were prototyped¹⁶ so that the steps of the design work done by individual engineers could be captured in documents with CAD images, analytic results, annotations, design criteria, and so on recorded, along with indexes by which they can be retrieved in future. Since a great deal of product-development work is done on the computer, it might be possible to add the additional support to capture the important results and annotate them without too much added effort for the working engineers, whose aversion to documentation is itself a difficult barrier.

EDNs have not come into vogue, probably because they are still clumsy to use and demand a lot of work for little payoff—a payoff, moreover, that accrues not to the documentor, but to some future engineers on another project. It remains one of the aspects of collaboration that has the least satisfactory support, perhaps because the goal is to encourage collaboration between people over unknown expanses of space and time and with unspecified projects lying in the future.

11.12.6 Process Libraries

Though processes in product development are not strictly repeatable on a macro-level, when you zoom in and look at the individual tasks performed by development engineers, there are many stan-

standard tasks they will perform again and again with some little intelligent variation appropriate to the new situation. Therefore, concurrent engineers have sought ways of speeding up standard mini-processes that occur in product development (for example, stress analysis). Usually, a sequence of programs is executed with the piping of data from one step to the next, with some conversion and filtering in the general case.

Support for this was developed early in the DICE project in a software package called the Communications Manager.¹⁷ The CM allows the executing programs to be run on different workstations in a network, and includes the ability to perform steps in parallel automatically if the data dependence among the programs will permit that. Similar work has been done by a group at General Electric, in work that they call, somewhat misleadingly, the electronic "workbook."¹⁶

In earlier work at MIT, T. Malone¹⁸ suggested that the best practices of an organization can receive efficient computer support if they are organized as a process library. Whenever something needs to be done involving a complex sequence of steps, an adviser program attached to the process library would select the best appropriate process for the case at hand and then execute it with more or less automatic support, like a workflow. The initial attempt is to develop such a library for commercial processes, such as purchasing. No analogous attempt has been made to develop a process library of product development processes, or technical processes, in general.

11.13 APPLICATION OF CE PRINCIPLES

The principles of concurrent engineering are applicable to every field of human endeavor. There is no problem of any dimension that does not require far more knowledge and competence than a single human can possibly possess today. It seems a commonplace observation that a problem can have a satisfactory solution only if all aspects of it are considered and every potential perspective satisfied. But for one reason or another—sometimes from a desire to exercise autocratic power, sometimes from unreasoned haste, often from a lack of mental rigor to see the problem whole, and perhaps from a lack of appreciation of what concurrent engineering entails—problem-solving is oversimplified.

Ironically, achieving a satisfactory solution takes more time when shortcuts are taken that violate CE principles. This is the enduring lesson, often learned and forgotten. Though some of the technology that can support CE has been described, this compendium must not give the impression that the technology is primary. It is not. What is of primary importance is to act according to CE principles, by seeing the problem as a whole, involving all pertinent perspectives from the start, instilling a common vision, and having the will to exchange openly and pursue a path of collaboration.

Of course, much of the supporting information technology is just as universal as the CE principles. Therefore, the underlying collaboration technology, no less than the CE principles that it attempts to realize, can be applied equally, for example, to planning and executing an economic development project and to a technical engineering project.

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