Decentralized cooperation: a distributed approach to team design in a concurrent engineering organization

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Introduction

The basic intent of any manufacturing company is to employ a skilled (or trained and talented) work force, machinery, computers, capital, etc., which could help make good products. The traditional hierarchical (manufacturing) organizations were designed to help managers and supervisors easily keep track of their employees (people) and the jobs they were doing, tools, machinery and capital they were using, etc. (Shonk, 1992). The structural orientation and the organizational set-up for product development were mostly functional and vertical in nature. Few "experts" made improvements within the confines of a so-called department or a functional unit (McGrath, 1984). The result of that expertise gave those hierarchical organizations, for a short while, tremendous marketplace advantage (Schuster *et al.*, 1996). Even the use of certain job titles such as manager, director, supervisor, rather than leader, facilitator, coach had reflected that bias (Schulte, 1997).

Recently, products are becoming more and more complex than before. It is beyond the imagination of a single person, a single group, or even a single department to comprehend fully all aspects of a product design and development needs (McKenzie, 1997; Prasad, 1997). However, the nature of the parent organization, engaged in developing those products over the years, has not changed as much (Schulte, 1997). As such, it has been a challenge for the design and manufacturing engineers in those traditional organizations to work together as "members of a coherent team" to improve quality while reducing costs (capital, investment, etc. (Dika and Begley, 1991)), weight, and lead-time (time-to-market) (Huthwaite, 1994). In many such organizations, the realizations of productivity and efficiency gains through teamwork, empowerment, etc., have been slow and very painstaking. There are many reasons cited for such poor outcomes (Pipp, 1990). The most commonly cited reason was the "people" or the "human" component (Argyris, 1992). The best illustration of this comes

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from the remarks of Roy Wheeler of Hewlett Packard, when he was asked (Prasad, 1996):

What tools does an engineer need to get started in CE? His answer was: Pencil, paper, some intelligence and a willingness to work with peers in other functional areas to get the job done (Watson, 1991).

The "people component" involves many constantly changing variables (Hartshorn, 1997) that are more difficult to control than any other variables (Stryer, 1990). This is because *human behavior* and *corporate cultures* are difficult to measure and quantify (Taylor and Felton, 1993). There is a close association between the two. Changing the corporate culture (Fisher, 1997) by institutionalizing CE does not guarantee that the human behavior (Hartshorn, 1997) will be changed or that the two will work in close (and mutual) synergy and vice versa (McCusker, 1992). Difficulties in understanding such interactions between human behavior and corporate culture, in general, and the lack of synergy in particular, tend to be underestimated or even unaddressed as major organizational problems (Shonk, 1992). This paper, first, describes what is lacking in a traditional organization and what types of cooperation are needed for the work-groups to collaborate efficiently in a concurrent engineering organization. The paper then describes a distributed approach to designing a product development team (PDT) for concurrently designing and developing products. The paper outlines a multi-team design of PDT that has been found useful in implementing CE projects at Delphi accounts of General Motors. Finally, the elements that are essential to providing a decentralized cooperation in a CE environment and which has been found useful to carrying out an integrated product development at Delphi are outlined.

Cooperation in a traditional organization

Most traditional organizations are set-up in a hierarchical fashion (McGrath, 1984). Such set-ups have lacked the motivation for the groups to cooperate and to work as coherent teams (Shonk, 1992). For instance, not too long ago, engineers were valued according to their ability to fix manufacturing problems, not according to their ability to eliminate sources or causes of the manufacturing problems (Imai, 1986). Most reward systems, including incentives and sanctions, in traditional hierarchical organizations were solely based on individual creativity and contributions (Katzenbach and Smith, 1993). Still today, there are not many incentives on the part of an individual employee to develop defects-free products or services, or to entice him or her to work as a willing team player (Gittler, 1997). Other contributing factors in traditional organizations that are commonly cited are (Hamel and Prahalad, 1994; Prasad, 1996):

- *Decision making style*: in traditional organizations, the style of decision-making is mostly top-down and most design decisions follow an unidirectional path (such as a directive management style) (Fisher, 1997). By the time a design or a process engineer gets ready on a new development project, many decisions are already made (Prasad, 1996). The planner has chosen key product offerings, such as major design specifications, gross weight, length, width, etc. The finance community has determined what the product must cost and how much the company can afford to invest into it. Marketing has decided how many will be sold. The timing office has decided when the product must be introduced. Under these circumstances, the rest of the organization's job ends up merely engineering the product under the aforementioned restrictions or constraints. Inputs or feedback from technical experts and the product feasibility team could not be taken into consideration in those early decisions, neither the limitations of the manufacturing equipment at hand could be taken into account. Under such situations, often there is not much room or time left for the engineers to maneuver for good product realization. At times, it becomes difficult to satisfy many of the critical competing requirements and still be able to meet stated product quality and other demands within a stipulated delivery timing (Dika and Begley, 1991).

- *Lack of management commitment or action*: the management commitment to empower product development participants to do what is right and to work as a "coherent team" has been lacking (Carroll, 1997b). Often employees are given responsibility for a design project but the authority to introduce design changes is generally not entrusted to them. For instance, employees are given a set of modeling and analysis (for example, CAE, CAD/CAM) tools, and it is hoped that these tools will eliminate all their technical or organizational problems. Some management even considers providing tools to employees as empowerment. In management circles, often there is a lack of understanding of what cooperative team working actually means (Shonk, 1992). There is also a lack of authority on the employees' part to take bold actions (Carroll, 1997a).
- *Policies, practices, procedures (3Ps)*: participants in product realization are required to follow an extremely rigid and complex set of work procedures (Fisher, 1997) during product design. The organization dictates most of these work-flow steps. Circumstances often change, people move, and the planned steps in work-flow may not be valid any longer. Many of the IPD participants may not know what steps are valid and what are not, and confusion may prevail. IPD Employees often tackle what they think are the right things to do in such circumstances and trade the rest. Since these decisions are not team-based, they may not be in the best interest of the entire group, PDT, or the company (Fisher, 1993).
- *Lack of common understanding, commitment, or action*: making information, available to IPD team members, does not guarantee that it will be effectively used (Garvin, 1993) during product development.

Information must be timely and meaningful. Information is not meaningful when the team does not understand how to use the information or how others will benefit from it (Adler & Shenbar, 1990). Often, there is no prior common understanding or commitment between the recipients and the providers of information (Andrews & Stalick, 1997).

- *Ineffective communication*: effective communication between PDTs is the key to developing a knowledgeable and committed work force and setting a common set of consistent goals (George, 1997). Clear and supporting goals provide "constancy-of-purpose" (Deming, 1993). They allow everyone in a PDT to set aside frivolous issues and focus on what is really important to the "total product system". Communication is a two-way street. Effective communication takes place both vertically (in spite of differences in responsibility or PDT ranks) and horizontally (in spite of work-groups' functional differences). An ineffective communication environment (that is, giving partial information and holding the rest of it) discourages free exchange of ideas up, down, and across organizational lines. Due to ineffective communication, there is a danger that deficiencies discovered in the downstream activities (related to a product's life cycle) may not be rightly communicated to the upstream activities "Clark & Fujimoto, 1991". This inhibits innovation, retracts teamwork, and strangles opportunities for continuous product improvement.

The aforementioned five points are some typical reasons cited by many industrial product developers (Adler and Cole, 1993; Mckenzie, 1997; Pipp, 1990;) in many types of organizations for causing numerous project delays, inciting horror stories, initiating general chaos, or having ultimate productivity loss. The above is true even for a Concurrent Engineering organization when products are designed concurrently through Product Development Teams (PDTs) (Huthwaite, 1994).

Why do things have to come to this? It would be preferable to use the collective experience or knowledge of the entire project teams in a CE organization to develop design and manufacturing concepts so that, if circumstances change, the decisions can be altered quickly (Hirschhorn, 1991). It is also desirable to collectively come up with a reasonable set of specifications and objectives that are feasible and fully understood by all parties (PDTs) before they are finally committed and deployed by the CE management (Gatenby and Foo, 1990).

It is well known that the success of any organization involved in rapid product realization depends on its teams' ability to handle changes (Hammer, 1990). Changes occur at all levels in an organization: during people management (Stryer, 1990; Carroll, 1997a), product management (Gatenby and Foo, 1990), process management (Schuster *et al.*, 1996), or enterprise management (Garvin, 1993). Organizational learning (Argyris, 1992), building a learning organization (Senge, 1990; Garvin, 1993), and establishing "knowledge for managing change" (Andrews and Stalick, 1997) are becoming strategic tools for winning product competitiveness (Hamel and Prahalad, 1994; Huthwaite, 1994). Concurrent Engineering teams must manage change carefully, whether it occurs upstream (for instance, during a strategic planning process of a product design), or downstream (for instance, during a phased deployment process, such as manufacturing) levels (Prasad, 1996). One of the greatest challenges in managing change is to figure out how to get people to work with each other and as a part of a concurrent team (Hartshorn, 1997) for product development. Unfortunately, human beings in such teams, by nature, tend to be territorial and look for their own (personal) interests (Fishbein and Azjen, 1975)

Self-interest versus company-interest

Part of the change – in moving from a traditional organization to a concurrent engineering organization – involves recognizing that everyone – not just individuals, work-groups and departments – all operate out of their own self-interest (Fisher, 1993). Some groups even fight to protect their own turf instead of working toward a common set of consistent goals (George, 1997). This generates a number of controversies. Early indicators or signs of controversies are avoidance, non-accommodation, conflicts, personal goals, egos, etc. A number of these controversies are listed in Prasad (1996). The defensiveness, foot dragging, and "so what" attitudes are all potential hindrances to implementing this change in product development. For example, personal belief, attitude, intention and behavior are more important than the computer productivity tools for effective communication (Fishbein and Azjen, 1975). When controversies occur and something goes wrong, finger pointing begins along some familiar refrains: "if they only built the part the way we designed it, we would not have these problems!" … "if they had listened to what I said regarding …!", "I told you so … what is in it for me", etc. Such counterproductive arguments are merely a reflection of our heritage, environment under which we have been brought up, our cultural history, and there is not much one can do to change that significantly (Fisher, 1997). It might be easier for the CE management to exploit the individuals' own sense of "self-interest" or pride and apply that toward the teams' or the groups' interests (Deming, 1993). It would be excellent if management could create an environment where the teams feel that it would be in their best "self-interest" or "self-esteem" to cooperate with one another rather than compete. Would that be an unusual change? Cooperation has been and usually is a part of ones' daily work environment (Hartshorn, 1997). In Japan, for instance, cooperation has been a way of life for many years (Imai, 1986). All parties were able to share information right from the conceptual design of the product to continuous improvements. There was no hidden agenda or designers' secret in the work.

For many years (as late as early 90s), teamwork was not encouraged in the American academic institutions (Carter and Baker, 1992). The culture and the curriculum of the past have discouraged people from cooperating. In the past, when students worked together, it was blatantly referred to as “cheating”. But in recent years this has changed (Fisher, 1997). Many schools have remodeled their curriculum to emphasize computer-supported cooperative work, coordination, teamwork, open-ended problem solving, project-based design lessons, and communication skills (ASME/NSF, 1996).

The change the world is witnessing today in the academic and professional circles are not very unusual either. Professionals all over the world have freely communicated with each other for many years (Deming, 1993). They have openly shared their views in journal articles on new ideas, new theories, and new applications. Team’s skills are very much encouraged and rewarded in most industries (Pipp, 1990). Competition, on the contrary, leads to loss. People pulling in opposite directions on a rope, for instance, only exhaust themselves – they go nowhere (Deming 1993). A cooperation with supporting focus (for example, constancy-of-purpose (Deming, 1993) or shared vision (George, 1997) is the key linchpin of achieving teamwork (Katzenbach and Smith, 1993) and of winning future competitiveness war (Hamel and Prahalad, 1994). There are seven elements (called 7Cs) to this team cooperation philosophy (Prasad, 1996).

- *Collaboration*: this describes a process of value creation that a traditional structure of communication and teamwork cannot achieve. Instead of focusing on methods of communication (such as teams with definite roles and set of operating procedures), collaboration seeks out the unplanned and unpredictable events in product development.
- *Commitment*: empowered teams define the tasks and prioritize areas to make breakthrough opportunities. Goals and objectives, duration, utility, complexity, expected results, and key success factors are outlined as much as possible. Management is fully committed to meeting the goals.
- *Communications*: effective communication is the precursor to meaningful collaboration. Communication is a free and open exchange of information among the teams, whereas the collaboration is a commitment to create a shared understanding and work together (Sullivan, 1988).
- *Compromise*: there is compromise and input from every discipline so that simultaneous development of the product, process, and associated tooling can be achieved.
- *Consensus*: project team and management members may disagree on some issues, but teams’ support on the requirements and a commitment to project objectives from the very outset is essential. These common objectives are reinforced throughout the life of the project (Prasad, 1996).
- *Continuous improvement*: product or process design teams work toward the total elimination of waste. The concept focuses on enhancing productivity and profitability through continuous improvements of product quality and reduction in product development cycle-time (Imai, 1986).

- *Coordination*: the most cited definition of coordination is by MIT Sloan School of Management – "coordination is the act of managing interdependencies between activities" (Malone, 1991). Coordination involves actors performing interdependent activities that achieve goals, and its analysis includes goal decomposition, resource allocation, synchronization, group decision making, communication and the preparation of common objectives. Partnerships are formed among all disciplines involved in the project and communication links are formally established and utilized. Suppliers are involved in the early stages of the project (Margolias and O'Connell, 1990).

The above gives a set of 7Cs characteristics for achieving cooperation (Prasad, 1996). CE teams must examine the extent to which the organizational culture or "self interest" supports or detracts from achieving a unified product concept (or deviates from a common set of company goals (George, 1997)).

Individual versus team contributions

This section tries to mathematically model a team's productivity in a CE organization based on the individual contributions of its members and the productivity gains that mainly come from the interactions among its members. From this model, the paper then tries to demonstrate that if a concurrent team is designed in such a way that its members' interactions are positive (meaning team members are cooperating with each other), it can be shown that the whole (net contributions of the entire project team) is much larger than the sum of its parts (meaning sum of the individual contributions).

Let us assume that the symbols a, b, c, d, … designate the contributions of the teams A, B, C, D … in a company. There are three types of contributions a product development team generally makes to a company's overall throughput or its productivity (Prasad, 1996):

- Individual contributions
- Team contributions
- Group synergy contributions

The impact of the individual contributions on the organization will be equivalent to an algebraic sum of a, b, c, d :

$$\text{Individual contributions} = a + b + c + d + e + \ldots\ldots \quad (1)$$

Team contributions in a CE organization generally come from group interactions – groups working in pairs, trios, etc. (Bolman & Deal, 1992). If we denote interaction between a group of IPD members by an angle-parentheses < > then the contributions coming from a company's group interactions can be expressed as follows (Prasad, 1996):

$$\text{Team Contributions} = \langle ab \rangle + \quad \langle ac \rangle + \quad \langle ad \rangle + \quad \langle\ \rangle + \ldots$$
$$\langle bc \rangle + \quad \langle bd \rangle + \quad \langle\ \rangle + \ldots$$
$$\langle cd \rangle + \quad \langle\ \rangle + \ldots \tag{2}$$

$$\langle abc \rangle + \quad \langle abd \rangle + \quad \langle abe \rangle + \quad \langle\ \rangle + \ldots$$
$$\langle acd \rangle + \quad \langle ace \rangle + \quad \langle\ \rangle + \ldots$$
$$\langle ade \rangle + \quad \langle\ \rangle + \ldots$$
$$\langle bcd \rangle + \quad \langle bce \rangle + \quad \langle\ \rangle + \ldots$$
$$\langle abcd \rangle + \langle abce \rangle + \langle abcf \rangle + \langle\ \rangle + \ldots$$
$$\langle\ \rangle + \tag{3}$$

Depending upon the number of terms included, the angle-parentheses < > in Equation (3) denote an interaction among groups of two, three or more. Such sets of group interactions in the past have been shown schematically through a Venn diagram. A group interaction may reinforce or nullify efforts of the interacting IPD groups (Adler and Cole, 1993). If a magnitude of an interaction between a pair of teams is positive, it is called group cooperation. If it is negative, it could be due to controversies or unconstructive competitions between the groups involved. As such, the net productivity of a Concurrent Engineering company depends on the following three factors:

A CE company's productivity gain = individual contributions
+ productivity gains due to team Interactions
+ productivity gains due to group synergism (4)

The last term represents the gains in productivity due to group synergism. Commonly, it is very hard to model "synergism". The impact of group synergism results in an order of magnitude difference, since their results could be "multiplicative". A "tiger team" is a good example of a group synergism (Schulte, 1997). A "tiger team" generally consists of pulling in the best and the brightest talent from the different product development areas or disciplines that were essential for a team project. NEC followed this approach for developing a new laptop computer. They set a ninety-day limit to prevent apparent loss of market share to their competitors. They instituted a "tiger team" consisting of experienced management and personnel from various computer development projects. They gave this tiger team full authority over all aspects of product development. A "backward scheduling" technique was used to assure that the product development team would meet the ninety-day target. The success of the NEC tiger team was a significant example of what a highly motivated group with a strong product experience-base from related disciplines, a highly cooperative team with decision making authorities, and a high urgency and strict enforcement of target, can do to a project in a short while. It was certainly a challenge for the tiger team, since this type of cooperative "behavior pattern" was not in place at NEC anytime before. Unconstructive competition in any organization tends to pull the groups apart. If an individual team is self-motivated (Wellins, 1992), its contribution will be positive.

Thus, the net contribution of all the working teams will depend upon the signs of the groups' interactionsÑwhether the effort is in cooperation or in controversy. Clearly when the group interactions are all positive, or at least some are zero (meaning non-participative), the team contributions will all be additive aggregating, perhaps, in a positive net result. Negative contributions tend to cancel the positive contributions and the net results are smaller. In an organization such as CE, the efforts of all work-groups generally will be mixed – some additive and some subtractive.

How to entice positive interactions (i.e., cooperation) from the groups (Stryer, 1990) is what the CE management needs to explore. One of the elements that are essential to cooperation is the identification and nurturing of an effective CE organization (Shonk, 1992). This means one must develop methods to work toward the "self-interests" of the teammates in such a way that the group outcome is in the best interest of the individuals, the work-groups and the company "Hirschhorn, 1991". Methods that promote self-esteem are when teams find joy, dignity, enthusiasm and curiosity in whatever they do (Gittler, 1997). One method called performance by design (Taylor and Felton, 1993) entails realizing organizational functions with "intrinsic or extrinsic motivations" – that is through items of self-interest (Hartshorn, 1997). Such motivational forces promote teaming and discourage turf wars (Deming, 1993). Another useful technique is to involve members in mapping the major steps (for instance, decomposing the tasks, task frequency) of the CE project work-group (Hirschhorn, 1991); identifying the time, starting task performance (Hughes *et al.*, 1996), concurrency and resource requirements for each step (Pasmore, 1988).

Some people are born with a natural inclination to learn. They possess a set of beliefs, attitudes and often exhibit certain behaviors (Fishbein andAzjen, 1975). Researchers have found that a team goes through four major stages of tasking from the time it organizes and finally gets under way. Tuckman in his 1965 article identified these as forming, storming, norming and performing (Tuckman, 1965). Professor Kim Clark of the Harvard Business School had said that highly productive organizations are characterized by the existence of "early group conflict" (Clark and Fujimoto, 1991). The concept development phase, for example, should raise the major issues of potential conflicts between organizational areas relating to each of the design alternatives studied. Each team member should not only express his or her concerns, but should have the opportunity to influence the final design outcome, when it is still early. Teams should be reasonably confident (on each other) that the supporting goals of the project can be met with synchronized thinking (Schulte, 1997).

It is not unnatural, therefore, for some self-directed teams to enjoy work; find joy in learning, problem-solving, and meeting new challenges, and discovering some of his or hers innate abilities (Fisher, 1993). One role a management can play is to facilitate the interactions (Stryer, 1990) between the CE work-groups. There are a variety of conceptual tools (Carey, 1992) that can ease this group planning process (Kimbler and Ferrell, 1997). Examples include Project Evaluation and Review Technique (PERT), project management with Critical

Path Method (CPM), Precedence Diagramming, Gantt charts, etc. Quality Function Deployment (QFD) is a helpful technique to sort out the various types of product and customer inputs (Clausing, 1994). There are also motivational techniques (e.g., group-dynamics), and extrinsic sources (e.g., team rewards, bonus, etc.) and intrinsic sources of motivation (Bolman and Deal, 1992) that can assist teams in implementing this change. Several books (e.g., Cole, 1989; Garvin, 1993; Senge, 1990) including Fisher's Leading Self-directed Work-teams (Fisher, 1993), provide practical and useful suggestions for diminishing a group's natural resistance to change and for implanting self-esteem. Lucent Technologies focused on team efforts and team goals by establishing synchronized team thinking and team incentives (Schulte, 1997).

Deming (1993) says that good management knows how to nurture and preserve these cooperative behaviors and how to build self-esteem attributes in cooperating teams (Stryer, 1990). Thus, synergism is the outcome of many factors. Notables among those are the factors that define the environments that promote cooperation (Gittler, 1997) and the factors that are the core elements of that environment (Fishbein and Azjen, 1975). A good design of the teams provides the elements of an environment that promotes cooperation. Examples of the environmental elements include: size of the groups, the functions of the groups, the groups' priorities, and a multitude of other things that affect group interactions (Hughes *et al.*, 1996). For a CE organization, the work force is comprised of four major teaming components, namely, a logical component, a virtual component, a technological component and a personnel (work-group or humane) component. Personnel component is the one that is traditionally made out of several work-groups and/or sub-teams each specializing in one or more life-cycle aspects for product design and development. This design of cooperative teams for a CE organization is discussed in section 5, and a decentralized design of these cooperative teams is discussed in section 6. The individual compositions of each of the four work-groups that participate in a CE organization are discussed in Section 6.

Cooperative teams in concurrent engineering

Cooperation is a structured process for an honest three-way cooperation between employees, organization (such as management), and the customers. The three-way cooperation involves exchange of information up, down, and across the CE organization (Galbraith, 1974). This creates a deep common understanding of personal, organizational, and customer goals. The process combines work-group's personal values (rewards, pay, job satisfaction) (Wellins, 1992) with organizational values (profitability, cost, quality, return-on-investment, time-to-market, customer satisfaction, policies, etc.) (Luther, 1997)to build a balanced commitment toward achieving mutual success (Pipp, 1990). As once said by Dr. Deming, personal values are of two types: extrinsic (jobs, salary, bonus, incentives, reward, personal security, and related) and intrinsic (values and attitudes, interest and motivation, self-esteem, dignity and pride in quality work, pride in innovation, etc.) (Hughes *et al.*, 1996). A team cooperation is generally accomplished through a four-step structured process (Prasad, 1996).

- The first step is the gathering of data, materials and behavior information related to the product design and development. During this step a three-way cooperation takes place between employee, management (or organization) and the customers (Galbraith, 1974).
- In the second step, three-way cooperation leads to a deep understanding of CE goals.
- In the third step, weighting factors are added to personal, organization and customer values and CE goals to obtain priority for team commitment.
- The last step is the team actions. In this case, individual teams are empowered (Carroll, 1997a) through supportive actions, personal roles and responsibility, and empowerment – freedom to make decisions or act on them.

An integrated product development (IPD) can be viewed as a cooperative work-group environment – called product development team (PDT) – spanned by four multi-dimensional concurrent teams (Prasad, 1997) (see Figure 1). The teaming concept has grown out of the recognition that CE is a multi-perspective, multi-team phenomenon involving a complex interplay among 7Ts (talents, tasks, team, time, technique, technology and tools) (Prasad, 1996). More than one work-group is necessary for product realization, and within each work-group, a number of concurrent teams are required to support the various perspectives. For example, a Personnel team only provides the required talents for a work-group – examples being customers, designers, engineers, processors, assemblers, managers and others. They are generally shown as a part of a cooperation team to achieve a unified product concept. The Personnel team must be supported by other PDT processes (could be computer-supported). They are named here as Logical teams, Virtual teams, and Technology teams (Adler and Shenbar, 1990).

Figure 2 shows these four cooperating teams as a set of four triangles, which when put together form a single PDT square. Conversion from four (team) triangles (with 12 sides and 9 nodes) into a PDT square (with four sides and 4 nodes) is indicative of fusion, which takes place when four contributing teams coalesces into one PDT team (Prasad, 1996). The letters: L, P, T, V on the triangles represent the first letter of the four concurrent teams of a PDT. The dependency is mutual; for example, other PDT processes must support the Personnel team as well. The Virtual team employs right information tools and computer techniques to speed up each of the PDT tasks and connects them together (make them available to the rest of the PDT). The Technology team defines what are the rights tasks to do in each category. The Logical team defines the product, process and work tasks, identifies task frequency (such as first time task, infrequent task and change to task) (Hughes *et al.*, 1996), and the

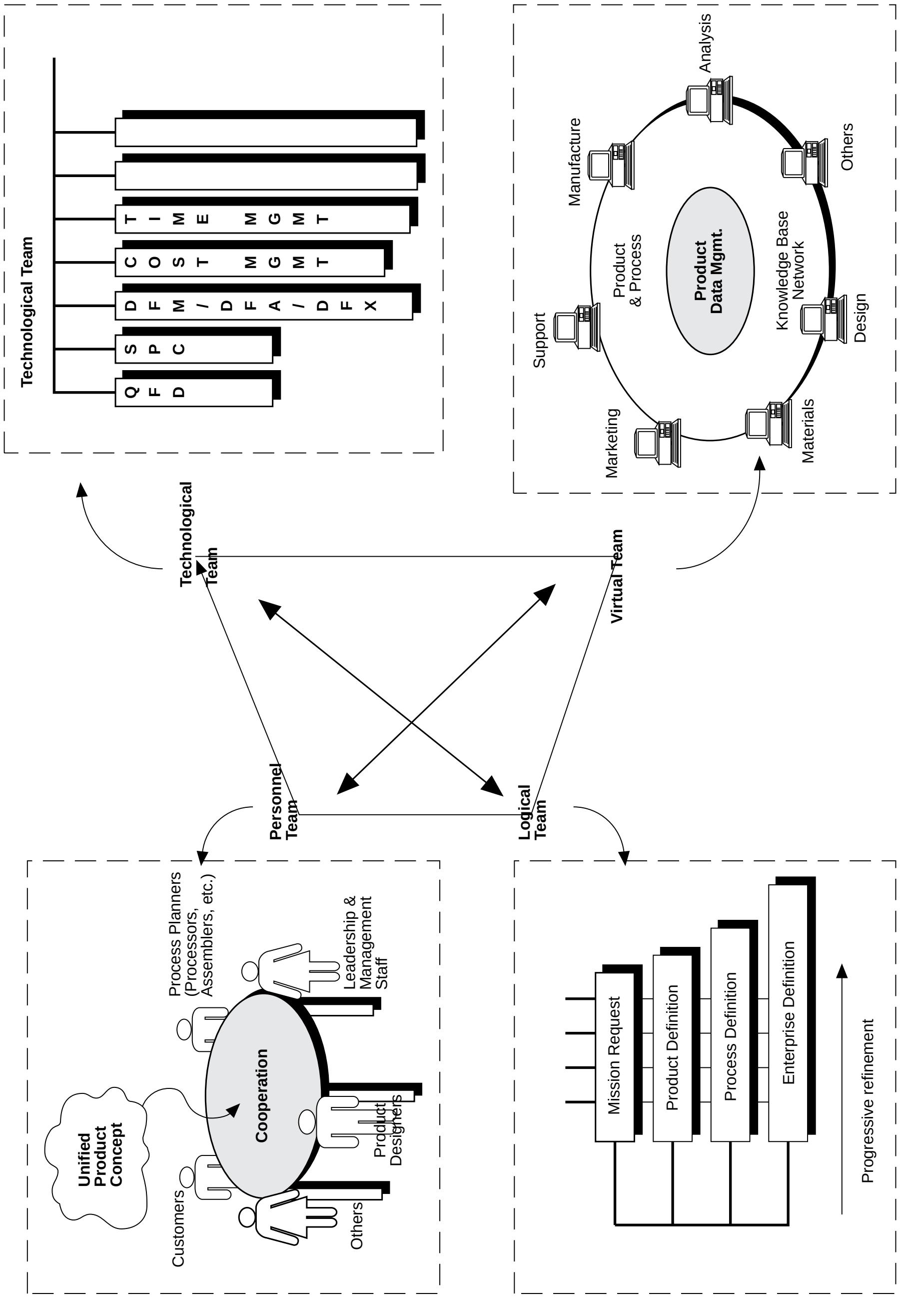

Figure 1.
Concurrent teams in product development

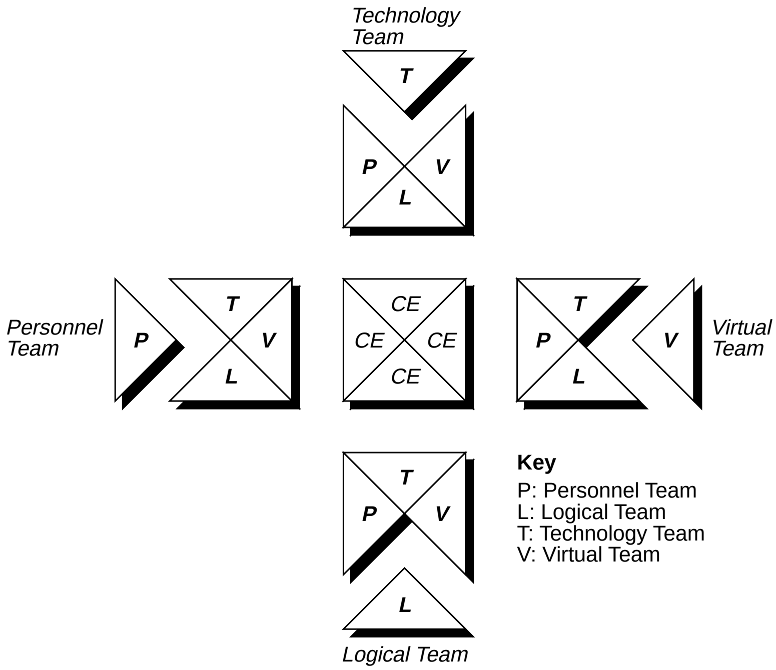

Figure 2.
Cooperative CE teams

order (tasks' timing) in which these tasks would be executed. The Personnel team defines the work-group authority, modes of work-group communication, work-group roles and responsibility, points of assertiveness or conflict resolution (Hughes *et al.*, 1996). The Personnel team may call upon the Technology team (Adler and Shenbar, 1990) to provide them with right process tools and techniques to use. Personnel team does this concurrently by calling upon the Logical team to arrange the scheduled tasks in parallel. Personnel team defines the work-group tasks briefing and walkdown (Hughes *et al.*, 1996) and executes those tasks efficiently. It does this by calling upon the Virtual team (information systems and control systems) to speed up the process (information access, control and tasks' execution), and provide work-group training (task training, hardware system training, leadership and team skills training). A new technology would not be successful without considering its implications on Personnel teams (such as humane work-group (Hartshorn, 1997), core-competencies or expertise (Prahalad and Hamel, 1990), a good team culture (Fisher, 1997)), a good organizational (Galbraith, 1974) culture, and their integration (computer-based) (McKenzie, 1997) and automation (knowledge-based) aspects (Prasad, 1997). In developing a product concurrently, the aim, therefore, is to infuse cooperation between the four contributing PDT teams. They are discussed in the following sub-sections.

Logical team design

Logical teams break up the product development process into logical units (such as activities or tasks) so that they can be dealt with adequately. Logical teams not only partition requirements between sub-units and define their interfaces, but must also follow up to ensure that the interface boundaries are not crossed (meaning, tasks are not coupled). Logical team checks whether or not customer expectations are properly analyzed and factored in so that they (logics) transform into appropriate product features and functions, and that product functional specifications are partitioned out to the right work-groups for them to work on concurrently. Figure 1 shows a simple example of breaking up a product development process into four logical sets of process steps: mission definitions, product definitions, process definitions and enterprise definitions. The Logical teams must ensure that the interface change-requests in the break-up process are properly evaluated and mediated between the affected PDT parties (internal or external). This assignment is customarily given to system engineering teams with responsibility for such things as mission analysis, system definition, functional specifications, requirements partitioning, and hierarchical breakdown of the product tree structure. The product tree structure (PtBS) may be logically partitioned into functional sub-units (such as sub-systems, components, parts, and materials, features, etc.) (Prasad, 1996). The total product definition is further broken down into sub-units, a portion of which may be designed internally while the rest may be subcontracted out.

Personnel team design

The Personnel team identifies both the roles and responsibilities of the Product Development Team (PDT) work-groups and its contributing members, experts, and advisers. Personnel team executes the product development process and provides expertise for the Logical team in process breakups (process breakdown structures). A Personnel team is largely influenced by the individual characteristics of its work-groups and its contributing members, such as:

- work-group members' interest and motivation;
- work-group skills, capabilities and limitations ;
- work-group values and attitudes, and
- members interpersonal behaviors.

Besides interpersonal behaviors, the group behaviors of the Personnel team also influences (work-group's) productivity and outcomes – such as safety team behaviors and operational team behaviors. The Personnel team is given authority for decision-making, assertiveness or conflict resolution and follows a standard mode of communication that is common to all work-group members. Included here are the means of organizing, rewards and policies, hiring, training (task technical training, hardware system training, leadership and work-group skills training), motivating, measuring, and interfacing to ensure teamwork (Hughes *et al.*, 1996).

Virtual team design

The Virtual team aids the Personnel team (work-groups) in understanding the interactions and tradeoffs among the different, and even conflicting, mission requirements such as cost, quality, and performance. Examples in Figure 1 show a set of seven computer icons as Virtual teams linked to a computer network. Seven has no significance except seven was initially picked up for this illustration. Teams are called Virtual, since they can be present in the form of computer programs or modules and can reside anywhere (each is interconnected with one another via a computer network). The Virtual teams are generally made out of both information systems (computer modules) and control systems (such as technical, schedule controls, supervisory control, and process change controls).

Technology team design

Technology teams generate strategies and concepts (Cole, 1989) on design perspectives (e.g., strategies relating to its manufacturability, ease of assembly, serviceability, reliability, etc. (Gatenby and Foo, 1990)) for a work-group to use during IPD. The Technology team is responsible for ensuring the integration and consistency of the total design definition of the product. Early focus is often on assuring analytically the highest product quality at the lowest inherent cost. Technology team is responsible for performing (or overseeing) the high-level analyses (e.g., Total Quality Management, QFD, Statistical Process Control (SPC), X-ability, Time Management (responsiveness), Cost Management, Infrastructure Management, etc. (Clausing, 1994)) associated with the overall product (Adler and Shenbar, 1990). A partial but important mix of CE PDTs' potential capabilities is shown in Figure 1.

$$\text{CE PDTs} \equiv \cup\,[\textit{Logical Team, Personnel Team, Technology Team, Virtual Team}] \quad (5)$$

Where, ∪ indicates "Union-of" the terms in the square bracket. The next section provides an insight into a decentralized cooperation idea, which could lead to maximum team productivity.

Decentralized cooperation for maximum teamwork productivity

The key to the success of a CE process is a decentralized team design – selecting, training, motivating, and forming a product development team (PDT) membership and a structure, which may be distributed globally, but still able to achieve a maximum level of teamwork productivity from this cooperation. A work-group, at a minimum, is expected to be as effective as the participating members that are working in it (Shonk, 1992). The performance or an effectiveness of a PDT composition could be much greater than all the individual work-groups combined, if such a PDT is well designed. Individually, each work-group's action reflects a specific contribution toward a technical or business goal related to practice, process, or technique. Each goal, in turn, can improve a company's bottom line or levels of its customers' satisfaction. However, because of strong interactions (relationships among its work-groups and PD teams' actions), the total PDT contribution could be much larger. When this can occur is discussed next.

Let us also assume that "team i" is working with "team j" in pairs. The n^{th} way interactions (when n >2) amongst the teams are not considered in the following calculations.

Define a_i as the individual actions (or contributions) of team i with no outside interactions. The following are examples of a set of actions (a_i) an individual or a team may take:

Team 1 action: *involve supplier,*
Team 2 action: *establish project's time table,*
Team 3 action: *establish customer requirements,*
Team 4 action: *establish verification plan,*
Team 5 action: *conduct competitive analysis,*
Team 6 action: *establish functional requirements,*
Team 7 action: *define buy/integrate/develop strategy,*
Team 8 action: *establish concept selection matrix,*
Team 9 action: *select baseline system,*
Team 10 action: *approve purchase request, etc.*

Define α_{ij} as the normalized factor of improvement in team i's output as a result of team j interaction with team i (see Figure 3),

- If $\alpha_{ij} \neq 0$, the team j does produce an appreciable effect on team i.
- If $0 < \alpha_{ij} < -1$, team j has a disruptive effect on team i; the team's contribution from its mutual interaction is reduced, but the net from all teams' interacting could still be substantial.
- If $\alpha_{ij} < -1$; it means team j causes team i to be counterproductive; or it may imply that team j is working against the current understanding.

α_{ii} – represents the effect of team i onto itself (self-learning or self-improvement).

- If $\alpha_{ii} = 1$; it means team i is present and is fully active. Team i is contributing to its full extent.
- If $\alpha_{ii} = 0$; means that team i is either absent or team i is not contributing to its full potential.

With the above definitions of α_{ij}, the total effect of mutual interactions (two-way and in pairs) on the team outputs can be expressed as:

$$\sum_{i=1}^{n}[a_i + \sum_{j=1}^{n}\{\alpha_{ij} a_i\}] \quad (6)$$

which can be simplified as:

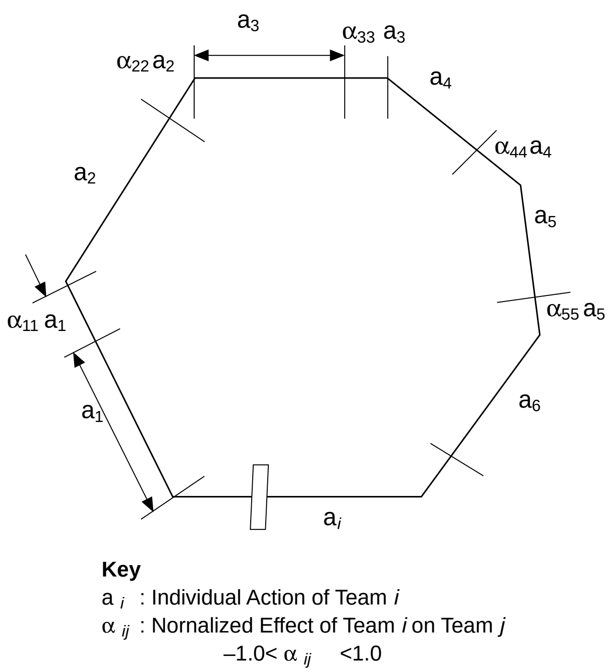

Figure 3.
The whole is far greater than the sum of its parts

$$[\sum_{i=1}^{n}(a_i)+ \quad \sum_{i=1}^{n}\sum_{j=1}^{n}\{\alpha_{ij}a_i\}] \tag{7}$$

In order for the whole to be far greater than the sum of its individual parts, the following must be true:

$$[\sum_{i=1}^{n}(a_i)+ \quad \sum_{i=1}^{n}\sum_{j=1}^{n}\{\alpha_{ij}a_i\}] >> \sum_{i=1}^{n}(a_i) \tag{8}$$

$$\text{or} \quad \sum_{i=1}^{n}a_i \sum_{j=1}^{n}\{a_{ij}\} >> 0. \tag{9}$$

Comparing this to the sum of parts shows that the "whole will be far greater than the sum of its individual parts" as long as most of the coefficients (interactive effects) are positive. This can be stated in a mathematical form as follows:

$$\text{or} \quad [\sum_{j=1}^{n}\{\alpha_{ij}\}] >> 0. \tag{10}$$

The above is not a necessary condition but sufficient for the "whole to be far greater than the sum of its parts" condition to be true. Where, α_{ii} is the improvement made by an i^{th} team to oneself (self-learning), and α_{ij} is the improvement in ith team due to an action initiated by the j^{th} team.

An attempt is made to represent this graphically in Figure 3. The initial actions, a_i, are represented by the sides of a polygon. To show the effect of interactions due to itself, sides of the polygon are shown to be extended in the same direction by an amount equal to a product of α_{ii} and a_i – an individual action of an ith team before this learning. Both α_{ii} and a_{ij} are called interaction coefficients. Interaction may reinforce efforts, or it may nullify efforts. Representing the synergistic outcome as described above simplifies the group interaction process to a deterministic level. By doing so, the model may ignore, however, many of the things that occur when humans interact, such as personal relationship, love and affection.

The left-hand side of equation (8) can be written as

Team Id	Action list a_i	Examples of interaction coefficients – $a_i\alpha_{ij}$
Team 1	$a_1 \equiv$ Involve supplier in a PDT	$a_1\ \alpha_{11}$: Supplier involvement is an effective was to enhance product design. $a_1\ \alpha_{12}$: The members in this PDT should be familiar with the problem domain. $a_1\ \alpha_{13}$: We need a person with a mechanical engineering degree. $a_1\ \alpha_{14}$: A person, who has an automobile brake design experience. $a_1\ \alpha_{1j}$: Also, who knows or have done finite element analysis.
Team 2	$a_2 \equiv$ Establish project's time table	
Team 3	$a_3 \equiv$ Establish customer requirements (CRs)	$a_3\ \alpha_{31}$: What are the sources of data to develop a better CRs $a_3\ \alpha_{32}$: First source is the voice of the customers (VOCs) $a_3\ \alpha_{33}$: Better customer requirements yield better products $a_3\ \alpha_{34}$: Warranty or field data is another source for CRs. $a_3\ \alpha_{35}$: VOCs can come from three main sources: Internal customers, External customers and Past & future customers. $a_3\ \alpha_{3j}$: Market analysis is another source.
Team 4	$a_4 \equiv$ Establish verification plan	
Team i	ai ≡	$a_i\ \alpha_{ij}$:

Table I.
Examples of team actions 'a_i' and interaction coefficients

$$\text{or} \quad \sum_{i=1}^{n}(a_i)+\sum_{\substack{j=1 \\ i=j}}^{n}\{a_i\alpha_{ij}\} + \sum_{\substack{j=1 \\ i\neq 1}}^{n}\{a_i\alpha_{ij}\} \tag{11}$$

The first part of the above equation is the individual contributions. The second part represents the contribution due to self-learning, and the third part is due to a pair of team interactions. The following Table I gives examples of "a_i" and "{a_i α_{ij}}".

In Figure 3, the first two terms are plotted. All self-interactions are assumed self-assertive, i.e., positive. Negative interaction will, of course, reduce the length of the corresponding side by an equivalent amount. The net effect of the third term, even though it may be positive for a cooperative team, is assumed negligible and thus ignored. For an action ai, if an interaction coefficient (say α_{ij}) is positive, it is often due to cooperation between the i^{th} and the j^{th} team.

If an interaction coefficient (say α_{ij}) is negative, it is due to the interacting teams having competitive, controversial or adversarial relationships. Examples of such controversial overtones were discussed earlier.

An effective team is like a peak-performing symphony orchestra: a diverse group of specialists creating an inspirational performance through mutual harnessing and cooperating process. Like an orchestra, a work-group is a collection of specialists brought together to achieve a common set of consistent goals. Teamwork cross-pollinates teams' ideas and gives members of a work-group a better understanding of their approach and methods of common problem solving on the whole project. In each work-group, there are four groups (L, P, T, V) of teams cooperating (Prasad, 1996):

(a) Logical team (e.g., distribution of functions),

(b) Personnel team (e.g., people),

(c) Technology team (e.g., QFD), and

(d) Virtual team (e.g., computer-supported functions).

This is schematically shown in Figure 1. The Personnel team consists of experts in subject areas relevant to a work-group such as product designers, process planners, customers, suppliers, and leadership staff. In an organizational setting, they are surrounded by a multitude of support personnel who take care of other logistics, such as financial control, organizational management, education and training, marketing, work practices and industrial relations. Management of the CE organization must commit to and support the necessary changes in responsibilities and execution, and empower the Personnel teams with major decision making responsibility (Carroll, 1997b). The management must begin to balance the teams' autonomy and their self-interest with a reward-system based on teamwork – so that as a whole it builds a more effective organization. Each work-group (team of teams) in such an organization enthusiastically accepts the new responsibility and enjoys the changed environment as if it was their own creation.

Technology teams (advances in tools and technology (Carey, 1992)) and Virtual teams (advances in computer-aids and methods) mostly help during decision making for integrated product development (IPD). IPD is a fulcrum of a scissors type mechanism. Mechanical advantage of the scissors type mechanism is not complete without the "pull" from the Personnel team or the Virtual team. This does not mean that any two (say, the Technology and the Virtual team) will not do the job, but the two by themselves may not be able to meet the required challenge. Another analogy of the cooperative tool is a stool. The four CE teams are like a four-legged stool (see Figure 4). Just as without any one of the legs, the stool would not be stable. Likewise, if any of the CE elements is missing, the CE organization would not be effective. As shown in Figure 4, the Product Development Team (PDT) manager is at the center of the stool. If one leg lacks in capabilities (for instance, the teams do not share a common vision (George, 1997) or not able to share the expected team loads), the stool can still stand but it would limp (will not be as effective). So if there is any instability in the PDT environment, it is due to the controversy from one of the teams. The Logical and Personnel teams provide the environment (process and methods), while the Technology and Virtual teams provide the automation tools and technology (Carey, 1992). Once the right environment is in place, automation (Technology or Virtual teams) can help speed the practice, but it cannot compensate for the wrong environment. Therefore, the Personnel team must work together closely and, with the help of the Logical team, produce the highest quality definition possible. The Logical team receives the highest attention of all topics addressed in CE implementation. As shown in Figure 4, typical Logical team topics include decomposition, systematization, interface development, unification, common systems and standards. A typical Personnel team configuration includes: teams of engineers, analysts, and planners from the various disciplines and departments: marketing, engineering, design, manufacturing, etc. Examples of Virtual team include a variety of networks (inference, service, etc.), agents (receiving, requesting, affecting, etc.), concepts (agent-based) and tools (computer-based) (Carey, 1992).

Elements of decentralized cooperation

The best-laid constancy-of-purpose-oriented plans and the most prodigious efforts, however, will not prove effective without four key elements: convergence and collaborative thinking, empowerment, team recognition, and deep common understanding. As shown by Prasad (1996), these are critical elements that are considered part and parcel of a successful constancy-of-purpose-oriented CE work force.

Convergence and collaborative thinking

This is an important feature of a constancy-of-purpose-oriented PDT work-group. Figure 5 describes the stages of teams' progress through which

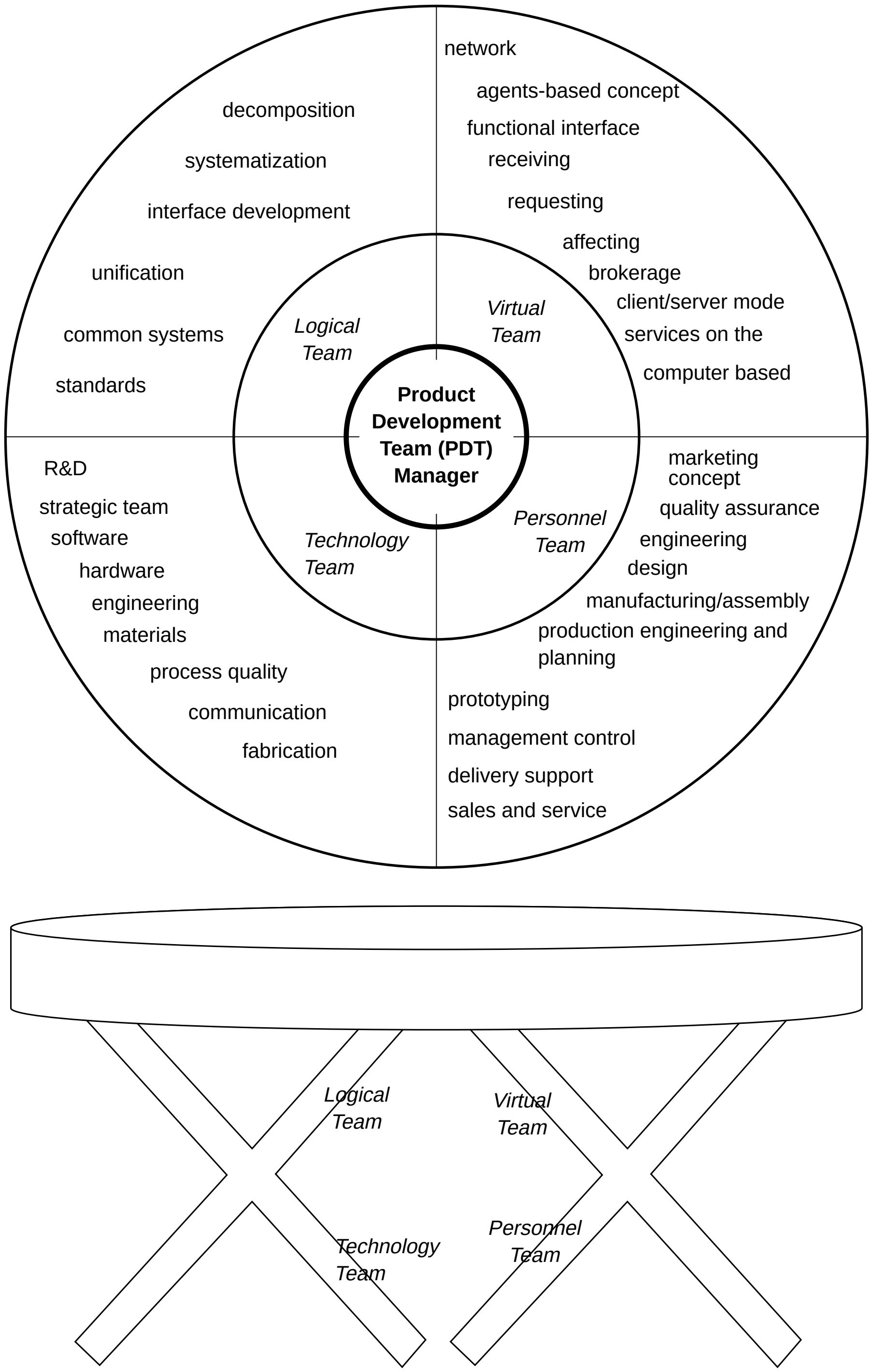

Figure 4.
Typical composition of each team

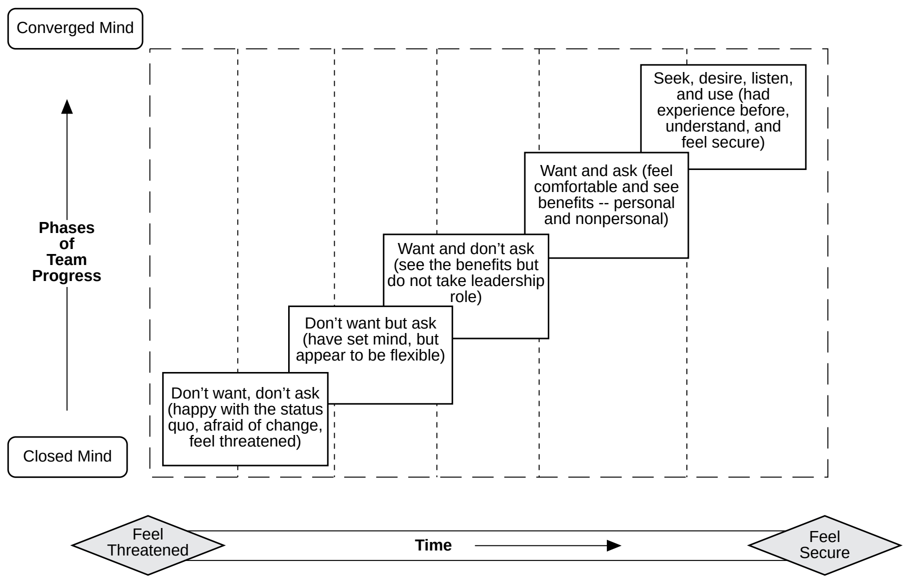

Figure 5. Phases of team progress leading to convergence in thinking

convergence of collaborative thinking takes root. Five stages are chosen to describe progress from a closed mind to a converged mind set. These are merely pointers or intermediate steps and does not necessary represent distinct phases.

- In the beginning stage, most product development teams possess a closed mind, “don’t want, don’t ask” attitude, afraid of unknowns and often feel threatened. With time, members of each team develop an understanding of each other’s point of view. They begin to appreciate importance of their disciplinary contributions at various points along the way and their impact to the product goals’ realization. The attitude sails through a series of changes:
- Second, it moves to “don’t want but ask” attitude from “don’t want, don’t ask” attitude initially.
- Third, it goes from “don’t want but ask”, to “want and don’t ask” attitude.
- Fourth, it goes from “want and don’t ask” to “want and ask” attitude. Collaborative thinking extends teamwork concepts and communication capabilities and applies them to formulate how a work will actually be done. Considering this, the product development teams form an expanded group knowledge of the whole thing in such a way that it allows each team member to completely understand the needs and goals of his fellow members. This collective mind-set allows members to grasp each other’s differing point of views, which results in confidence building and increased level of cooperation.

- Fifth, it moves to "seek, desire and listen" (see Figure 5). At this stage, their minds get converged – product development teams feel more secure than ever before. With convergence and collaborative thinking, the impact of cross-functional teaming on the product realization is maximized.
- Design reviews: design reviews (made out of select cross-functional review teams) are an efficient method to:
  - (a) monitor the progress of a CE project,
  - (b) facilitate reporting and appraisal of results to CE management, and
  - (c) keep the product development teams' interest in line with the common set of consistent CE project goals.

Design reviews promote a team oriented review strategy, which optimizes the PDT's collective talents in problem solving. A carefully timed and organized design review is not an engineering inspection, but rather a value-added process of team building and a first step toward convergence and collaborative thinking. During design review, it is important to stick with a standard review format and timing.

Empowerment and Involvement

Empowerment is often referred to as power of involvement. No matter whether an involvement is planned or is inadvertent, the result has always been positive – truly involved people can do anything. Empowerment does not mean that the line or functional (PDT) managers have to "give up" control. Rather, it refers to sharing of responsibility in matters of process definitions, such as policy making, and overall CE strategy formulation. It also means transfer of needed authority and assigned responsibilities to the PDTs so that they could make good decisions being closer to the problems. If the PDT management has rightly empowered the work-groups by establishing a self-governing "check and balance" process (in terms of assigned responsibilities, established purpose, capabilities, targets, benchmarks, and review process), the goal directed process can move smoothly. The work-groups will understand the boundaries and parameters within which to operate, and the available resources to draw upon. The CE project will get the benefit of collective inputs in formulating decisionsÑtechnical or non-technical – with less management barrier. In the beginning, this may appear restrictive for experienced PDT employees, since they may have to:

(a) Learn to work side-by-side with people they may not have traditionally gotten along with,

(b) Learn to speak a technical language they never spoke before,

(c) Work closely and cooperatively with people, who at one time might have worked for them. Now, for a good part of their own success, they must rely on their teammates' performance (and share team reward), and

(d) Acquire more interpersonal and group dynamic skills.

Team recognition

Recognition and reward are mechanisms used frequently by CE management in one form or the other. However, these awards and recognition are often given to an individual, even though he or she may be part of a team (McGrath, 1984). In CE, team's recognitions and awards carry more weight so as to entice the entire product development team to work together (Prasad, 1996). Product development teams are required to freely collaborate in setting the concurrent project's goals with the "constancy-of-purpose" in mind, and in meeting these goals on time and within budget (Malone, 1991). The rewards for achieving these objectives on the part of the CE teams are quite promising to the company as well. Constancy-of-purpose-oriented management style is expected to provide an optimum productivity gain and costs/benefits advantages (Prasad, 1996).

Deep common understanding

Empowerment and rewards are useful for team motivation. Deep common understanding is useful for creating highly charged employees and PDTs. Such a group of PDT members has a high level of confidence in each other and is able to quickly create an informal atmosphere of human networking. They communicate with each other and would be able to come up with a highly reliable plan in a short time. They form a pyramid of cooperating teams – the so called "Learning Organization" (Garvin, 1993; Senge, 1990) for Concurrent Engineering. It has three sides to it. This is shown in Figure 6. The first side contains a common set of consistent goals – from its corporate vision to the project goals (Andrews and Stalick, 1997), following the Strategic Business Unit's (SBU's) "constancy-of-purpose" (George, 1997) management plan. On the remaining two sides, the PDTs' skill sets (Wellins, 1992) corresponding to life-cycle management and work-group management are listed (see Figure 6).

From the Delphi's experience of implementing CE projects, it has been observed that in order to achieve an effective collaboration, the various PDT members of the distributed pyramid should:

- Create a state of mind (mind-set or a deep common understanding). This must account for the company's interests as opposed to its members own interests while PDTs participate in their company efforts to improve or design new products.
- Follow an occupational culture so that PDTs can develop shared views of problems that need to be resolved collectively utilizing the knowledge of their members "native-views".
- Harness the education and background strengths of each contributing member in shaping the product development from all different angles so that all useful views are represented.

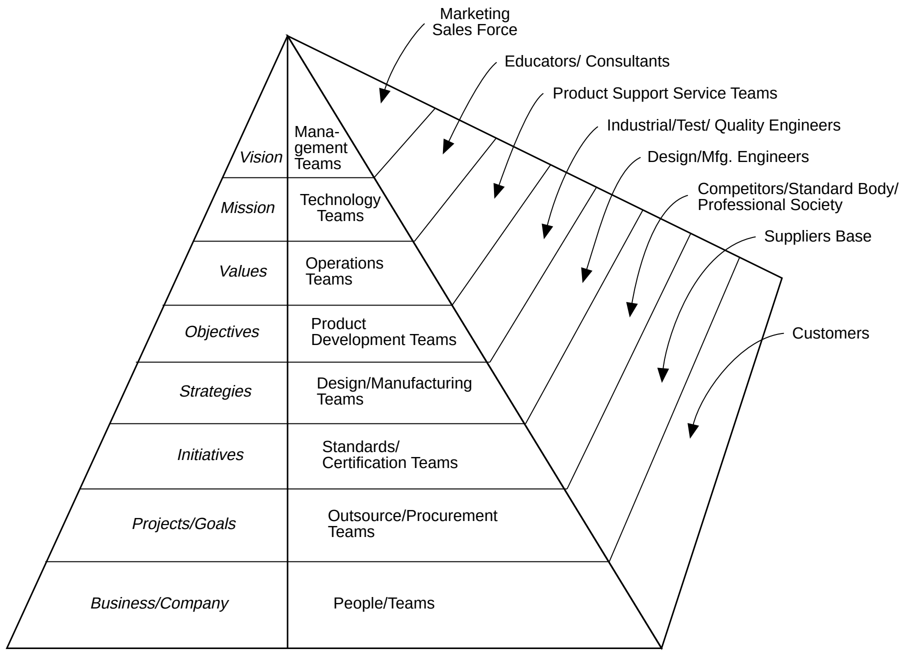

Figure 6.
Pyramid of cooperating teams

- Follow a value system that ties the PDTs together, such as sensitivity to other members' capabilities, respecting member "native-view" opinions, setting priorities that cross functional boundaries, and institutionalizing means to resolve personal or technical conflicts.

Concluding remarks

The key to the success of a CE-based organization is "team design" – selecting, training, motivating, and forming product development team (PDT) membership and its composition. A Concurrent Engineering (CE) work-group is expected to be, at least, as effective as its participating group-members in terms of the CE outputs it deliver. The effectiveness of a CE product development team (PDT) could be much larger than all the individual outputs of the work-groups combined, if its composition and designs of such PDTs are well planned and thought out. Individually, each work-group's action reflects a specific contribution toward an organizational technical or business goal. However, because of strong group interactions (relationships among the work-group's actions and synergy), the total PDT contribution is expected to be much larger. The paper shows that in addition to Personnel teams (work-groups), three other teams – Logical teams, Virtual teams and Technology teams – are needed as a part of a PDT configuration to design and develop artifacts concurrently.

A multi-component design of a "PDT" is described here for a concurrent engineering organization. The paper first describes how to configure a multi-team "PDT" organization that provides a decentralized cooperation during an integrated product development (IPD) process. The paper then shows how, with strategic design of a "concurrent product development teams", an organization can achieve optimum teamwork productivity during an IPD. Right skill mix of the needed Personnel team compositions (disciplines, boundary crossing, background, number of people, and talents) of a work-group and right designs of other PDT teams help entice cooperation. The description is based on EDS's implementation of a "concurrent product development team" environment at Delphi Divisions of General Motors. Subsequent implementation of this theory (IPD design and composition) at General Motors has shown that this concept is an effective way of concurrently designing and developing automobiles (and their parts) in less time and cost. It has been observed working through a number of automotive projects and clients that the teamwork productivity of a CE organization is largely controlled by the design of such "concurrent product development teams". The paper, later, describes four key elements of this decentralized cooperation, namely, convergence and collaborative thinking, empowerment, team recognition, and deep common understanding. It is hoped that the theory and conceptualization presented in this paper will provide a basis for future researchers to extend the ideas to other fields of interest and for comparing the effectiveness of the critical "teaming" elements identified.

References

ASME/NSF (1996), "Integrating the product realization process (PRP) into the undergraduate curriculum", New York, ASME Council of Education, NSF Grant # 9354772, New York.

Andrews, D.C. and Stalick, S., (1997), "Avoiding morning-after syndrome: transforming your organization without regrets", *National Productivity Review*, Vol. 16 No. 4, Autumn, pp. 5-14.

Adler, P.S. and Shenbar, A. (1990), "Adopting your technological base: the organizational challenge", *Sloan Management Review*, Vol. 32, pp. 25-37.

Adler, P.S. and Cole, R.E (1993), "Design for learning: a tale of two auto plants", *Sloan Management Review*, Vol. 34, Spring, pp. 85-94.

Argyris, C. (1992), *On Organizational Learning*, Oxford, Basil Blackwell.

Bolman. L.G. and Deal, T.E, (1992), "What makes a team work?", *Organizational Dynamics*, Autumn, pp. 34-44.

Carey, W.R. (1992), *Tools for Today's Engineer – Strategy for Achieving Engineering Excellence*, Section 1: Quality Function Deployment, SP-913, Proceedings of the SAE International Congress and Exposition, February 24-28, Detroit, Michigan, SAE Paper # 920040.

Carroll, B., (1997a), "Speaking the language of empowerment: a tale of two teams", *National Productivity Review,* Vol. 16 No. 4, Autumn, pp. 63-6.

Carroll, B. (1997b), "The role of management intervention in the development of empowered work teams", *National Productivity Review*, Vol. 16 No. 2, Spring, pp. 25-30.

Carter, D.E. and Baker, B.S. (1992), *Concurrent Engineering: The Product Development Environment for the 1990s*, Addison-Wesley Publishing Company, Reading, MA.

Clark, K.B. and Fujimoto, T. (1991), *Product Development Performance: Strategy, Organization, and Management in the World Auto Industry*, Harvard Business School Press, Boston, MA.

Clausing, D.P. (1994), *Total Quality Development: A Step-by-step Guide to World-Class Concurrent Engineering*, ASME Press, New York.

Cole, R.E. (1989), *Strategies for Learning: Small Group Activity in American, Japanese, and Swedish Industry*, University of California Press, Berkeley and Los Angeles.

Dika, R.J. and Begley, R.L. (1991), "Concept development through teamwork – working for quality, cost, weight and investment", SAE Paper # 910212, International Congress and Exposition, SAE, Detroit, MI, February 25 – March 1, pp. 1-12.

Deming, W.E. (1993), *The New Economics*, Cambridge, MA, published by MIT Center for Advanced Engineering Study.

Fishbein, M. and Azjen, I. (1975), *Belief, Attitude, Intention and Behavior*, Addison Wesley Publishing Company, Reading, MA.

Fisher, J.R. Jr (1997), "The three dominant cultures of the work-place", *National Productivity Review,* Vol. 16 No. 2, Spring, pp. 37-48.

Fisher, K.K. (1993), *Leading Self-directed Work Teams: A Guide to Developing New Team Leadership,* McGraw-Hill Company, New York, N.Y.

Galbraith, J. R. (1974), "Organizational design: an information processing view", Interfaces.

Garvin, D.A. (1993), "Building a learning organization", *Harvard Business Review*, July-August, pp. 78-91.

Gatenby, D.A. and Foo, G. (1990), "Design for X (DFX): key to competitive, profitable products", *AT&T Technical Journal*, Vol. 69 No. 3, (May-June), pp. 2-13.

George, S., (1997), "Focus through shared vision", *National Productivity Review*, Vol 16, No. 3, Summer, pp. 65-74.

Gittler, A. (1997), "Teams need more than enthusiasm to succeed", *National Productivity Review*, Summer, Vol. 16 No. 3, pp. 1-4.

Hughes, R.L, Ginnett, R.C. and Curphy, G.J. (1996), *Leadership: Enhancing the Lessons of Experience*, Irwin Publisher, Chicago, pp. 354-66.

Hamel, G. and Prahalad, C.K. (1994), *Competing for the Future,* Harvard Business School Press, Boston, MA, USA.

Hammer, M. (1990), "Re-engineering work: don't automate, obliterate", *Harvard Business Review*, Vol. 68, July-Aug, pp. 104.

Hartshorn, K. (1997), "A humane workplace is a productive workplace", *National Productivity Review*, Vol. 16 No. 2, Spring, pp. 1-8.

Hirschhorn, L. (1991), *Managing in the New Team Environment: Skills, Tools, and Methods,* Addison-Wesley, Reading, MA.

Huthwaite, B. (1994), *Strategic Design: A Guide to Managing Concurrent Engineering*, The Institute of Competitive Design, Rochester, MI.

Imai, M. (1986), *Kaizen, The Key to Japan's Competitive Success*, McGraw-Hill and Random House, New York.

Katzenbach, J.R. and Smith, D.K. (1993), "The Discipline of Teams", *Harvard Business Review,* Vol. 71, March-April, pp. 111-20.

Kimbler, D.L. and Ferrell, W.G. (1997), *TQM-based Project Planning*, Chapman and Hall, London, UK.

Luther, D.B. (1997), "Want to, asked to, able to: using targeted strategies to achieve competitive advantages", *National Productivity Review*, Vol. 16 No. 4, Autumn, pp. 95-100.

Malone, T.W. (1991), "Towards an interdisciplinary theory of coordination", in the Proceedings of the Ist International Conference of Enterprise Integration Modeling Technologies, ICEMIT, Hilton Hotel, South Carolina, USA, June 8-12, 1991.

Margolias, D.S. and O'Connell, M.H. (1990), "Part 3 – implementation of a concurrent engineering architecture", SME, Paper No. MS90-205, WESTEC'90, Los Angeles, CA, March.

McCusker, J. (1992), "Simultaneous engineering at cadillac", presented at the SME Clinic, *How to Implement Concurrent Engineering*, May 5-6, Southfield, MI.

McGrath, J.E. (1984), *Groups: Interaction and Performance*, Prentice Hall Inc., Engelwood Cliffs, NJ.

McKenzie, G.A. (1997), "How United and Boeing worked together to design and build the 777 airplane", *National Productivity Review*, Vol. 16 No 1, Winter, pp. 7-14.

Pasmore, W.A. (1988), *Designing Effective Organizations: Sociotechnical Systems Perspective,* John Wiley and Sons Inc., New York, N.Y.

Pipp, F. (1990), "Organizational strategies for concurrent engineering at Xerox", presented at the Concurrent Engineering Conference, *The Paradigm of the 90's*, Colorado Springs, Colorado, June 8.

Prahalad, C.K., and Hamel, G. (1990), "The core competence of the corporation", *Harvard Business Review,* Vol. 68, May-June, pp. 43-59.

Prasad, B. (1996), *Concurrent Engineering Fundamentals, Volume I: Integrated Product and Process Organization,* New Jersey, Prentice Hall PTR, 1996.

Prasad, B. (1997), *Concurrent Engineering Fundamentals, Volume II: Integrated Product Development*, New Jersey: Prentice Hall PTR, 1997.

Schulte, T. (1997), "Synchronized team thinking: the secret to continuous improvement at Lucent Technologies", *National Productivity Review,* Vol. 16, No. 3, Summer, pp. 5-12.

Schuster, J., Carpenter, J. and Kane, M.P. (1996), *The Power of Open Book Management*, John Wiley and Sons.

Senge, P.M. (1990), *The Fifth Discipline: The Art and Practice of the Learning Organization,* Doubleday.

Shonk, J. (1992), *Team-based Organizations,* Business One Irwin.

Stryer, R. (1990), "How I learned to let my workers lead", *Harvard Business Review*, November-December, pp. 66-83.

Sullivan, L.P. (1988), "Policy management through QFD", *Quality Progress,* Vol. XXIII, No. 6, June, ASQC, Milwaukee, WI.

Taylor, J.C. and Felton, D.F. (1993), *Performance by Design: Sociotechnical systems in North America*, Prentice-Hall, Englewood, NJ.

Tuckman, B.W. (1965), "Development sequence in small groups", *Psychological Bulletin*, Vol. 63 No 6, pp. 384-99.

Walton, G.F. (1991), *Concurrent Engineering,* Special Feature of IEEE Spectrum, July.

Wellins, R.S. (1992), "Building a self-directed work team", *Training and Development,* December, pp. 24-8.