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Collaborative Engineering for Research and Development

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Abstract: Research and development (R&D) organizations are being required to be relevant, to be more application-oriented, and to be partners in the strategic management of the business while meeting the same challenges as the rest of the organization, namely: 1) reduced time to market; 2) reduced cost; 3) improved quality; 4) increased reliability; and 5) increased focus on customer needs.

Recent advances in computer technology and the Internet have created a new paradigm of *collaborative engineering* or *collaborative product development (CPD)*, from which new types of relationships among researchers and their partners have emerged. Research into the applicability and benefits of CPD in a low/no production, R&D, and/or government environment is limited. In addition, the supply chain management (SCM) aspects of these relationships have not been studied.

This paper presents research conducted at the NASA Glenn Research Center (GRC) investigating the applicability of CPD and SCM in an R&D organization. The study concentrates on the management and implementation of space research activities at GRC. Results indicate that although the organization is engaged in collaborative relationships that incorporate aspects of SCM, a number of areas, such as development of trust and information sharing merit special attention.

Introduction

Federal research laboratories are implementing new ways to manage their Research & Development (R&D) activities. As in other R&D organizations, National Aeronautics and Space Administration (NASA) scientists must show that the research and resultant technologies that they are engaged in will benefit the Agency and the Nation by enhancing or enabling current or planned missions. There are "new changes, challenges, and opportunities for NASA… some of these require a transformation in the way we plan and operate programs" [1].

This situation is very similar to that documented for many other organizations involved in R&D activities, where researchers are being asked to be relevant, to be more application-oriented, and to consider themselves key partners in the strategic management of the business, bringing benefits to the bottom line [2,3,4,5]. R&D is being asked to meet the same challenges as the rest of the organization, namely: 1) to reduce time to market; 2) reduce cost; 3) increase focus on customer needs; 4) increase quality and reliability; and, 5) increase value [2,6,7]. These must be accomplished while using congruent project management methods and system engineering processes and tools throughout the enterprise and while bringing in external resources and expertise.

Advances in computer technology and the Internet have created new types of external relationships among researchers and among organizations. As a result of these advances, a new paradigm, called *collaborative engineering*, *collaborative product development (CPD),* or*, the collaborative Enterprise* has emerged. This new paradigm can have significant implications for product development and especially for the complex aerospace technologies and systems that are developed by the NASA and its partners. This new, collaborative way of developing technologies and aerospace systems will produce changes in the ways aerospace systems are designed, produced, operated, maintained, and disposed of. By combining the strength, expertise and know-how of the best diverse, geographically dispersed technical teams, better mission scenarios, designs, and the corresponding technologies can be developed in less time. The potential benefits of these collaborative, distributed environments for product development and scientific research have led government agencies to start several CPD efforts [8-11].

Collaborative engineering, or CPD, is the application of team-collaboration practices to an organization's total product development efforts. It builds upon the systems engineering [12], project/program management foundations of primarily in-house cross-functional product development teams introduced by concurrent engineering (CE) [13]. However, while CE has historically been concerned with the structuring of products, the flow of work, teams, and organizations, CPD is more concerned with creating the necessary environments for effective, free flowing information and ad-hoc collaboration among peers involved in these frequently external knowledge worker partnerships [14]. The implementation of CPD united with developments in technology and globalization have resulted in the creation of virtual teams, which allow managers to assemble the best knowledge worker talent they can find from wherever they can find it [15].

Research into the applicability and benefits of CPD into a low/no production, service, research and development, and/or government environment is limited. Most experts agree that aspects of CPD should be applicable to any kind of R&D setting, however there is a deficiency of information and research on the subject, as it applies to a government R&D environment. In addition, although government agencies, including NASA [11], have recently undertaken CPD efforts, little or no research has been done on the application of these collaborative design environments to this type of organizations.

Since CPD is an "extension" or evolution of concurrent engineering (CE), it can be expected that many of the benefits attained by CE practitioners would be achieved with a CPD environment. These benefits have been widely documented [16-19]. The research on collaborative engineering has documented benefits and challenges that are similar to those for CE, as well as some unique ones due to CPD's unique characteristics [20-28]. Others have documented the very important role that "suppliers" and supply chain management (SCM) play in these collaborative endeavors [29-34]. These research activities, however, have been concentrated on the manufacturing, telecommunications and information technology industries.

Whether or not these potential benefits, barriers, and implementation models for CPD are applicable to an environment such as a federal research laboratory has not been studied in depth. Furthermore, the role of federal research centers as suppliers of technology and expertise presents an opportunity to explore this new collaboration paradigm while incorporating aspects of SCM.

This research explored the application and impacts of CPD in a high technology R&D organization (NASA Glenn Research Center), as well as the organization's potential role as supplier of technology or competencies within a larger supply chain. The NASA Glenn Research Center (GRC) is NASA's premier center for aerospace research and development in the areas of space power, electric propulsion, and communications. In addition, GRC is the NASA Center of Excellence for Turbomachinery and Lead for Aeropropulsion Research. With these roles, GRC leads or supports a wide variety of programs and projects, primarily as a provider of technology and expertise. Because of the diverse nature of its R&D projects envelope, GRC provides an excellent model for this type of research.

Research Methodology

The research was carried out in two phases via a combination of interviews and a mail-in survey to personnel involved in the implementation of space technology development activities. An extensive literature review helped develop the interview protocol used to interview six managers. The interviews were analyzed via a detailed content analysis process [35-36]. Preliminary findings from these interviews have already been reported [37]. These results were also used to refine the mail-in survey, which was sent to 222 potential respondents, of which 115 replied.

The survey results were analyzed using accepted methodology for organizational management research [38-39]. Demographic data gathered included information on the respondents' functional responsibilities, experience level, and organizational affiliation. Parametric analyses were also conducted to look for any significant differences among the various demographic groupings.

The research investigated the following factors of the organization's CPD implementation and how they might influence CPD success:

- Organizational readiness
- The business environment or context in which the organization operates
- Supply chain management factors
- Management support
- Knowledge management and information technology
- Customer focus

This paper discusses the results of the research as it pertains to the supply chain issues associated with CPD.

Collaborative Product Development

In the future, companies will have to cooperate and collaborate more with their suppliers, their customers, and other relevant parties [24,28,27,40,41]. As defined previously, collaborative engineering, or collaborative product development (CPD), is the application of team-collaboration practices to an organization's product development efforts. It builds upon the nature of cross-functional product development teams introduced by concurrent engineering (CE).

To develop the case for collaborative engineering, Willaert et al [28] first discussed Cleetus' [42] "enhanced" definition of CE, which addressed product development efficiency, quick translation of customer requirements into manufacturable products, cross-functional collaboration, and CE as a strategic issue. Cleetus viewed CE as a business strategy requiring the integration of people, business methods, and information technology. This definition, however, did not address the drivers for CE: control over life-cycle cost, product quality, and time to market. In addition, the enabling role of information technology (IT) is not directly specified. Also, supplier involvement is not explicitly mentioned, even though supplier input is vital to achieving optimized designs [29-34]. They determined that decision-making should proceed **collaboratively**, and defined CPD as: *a systematic approach to control life cycle cost, product quality and time to market during product development by concurrently developing products and their related processes with response to customer expectations, where decision making ensures input and evaluation by* ***all life-cycle disciplines****,* ***including suppliers****, and* ***information technology*** *is applied to support* ***information exchange*** *where necessary.* It is clear that CPD encompasses concurrency, attention to the life-cycle, suppliers, and information technology, all while maintaining a customer-focused environment.

Littler et al. [20] summarized previous research on collaboration, and stated that collaboration is an evolutionary process, dependent on inputs, outputs, management influences, and environmental influences. They define these factors as:

- Collaboration inputs: brought to the start of the collaboration by the parties involved and are ingredients which might affect the collaboration process and its eventual outcome
- Management influences: factors relating to ongoing collaboration management which are likely to influence the eventual collaboration outcome
- Environmental influences: factors which are not under the direct control of management but which may have significant impact on the outcome
- Collaboration outcomes: need for a broader view of collaboration outcomes besides “success” or “failure”

Sakakibara [28] states that there are two competing motives for participating in collaborative R&D: cost-sharing vs. skill-sharing. Sakakibara summarizes prior research and lists three primary motivations for cooperation from an economic perspective: fixed cost sharing among participants; the realization of economies of scale in R&D; and the avoidance of wasteful duplication. These imply that the principal motive is to set cost-sharing rules. From an organizational perspective, the motives for cooperation can be: opportunities for one partner to internalize the skills or competencies of the other(s) to create next generation competencies; the transfer of knowledge; shortened research time; or, the fact that complementary knowledge enhances innovative productivity. These are mostly skill-based. Table I summarizes the cost-sharing and skill-sharing motives.

Table I: COMPARISON OF MOTIVES: COST-SHARING VS. SKILL-SHARING [28]

MOTIVE	Cost-Sharing/Scale-Based	Skills-Sharing/Learning-Based
Nature of competition in R&D consortia	Single-industry competition	Wide industry participation
Nature of firm capabilities in R&D consortia	Homogeneous Substitutable	Heterogeneous Complementary
Role of R&D consortia	Vehicle to divide tasks	Vehicle to create/transfer knowledge
Private R&D spending	Can decrease	Can increase
Major constraints firms face	Financial resources	Research capabilities

Sakakibara concludes that current direct competitors might be unwilling to share skills because of the potentially lasting effect this sharing would have on competitors’ capabilities, which implies that skill-sharing may have a negative effect on an organization’s current competitive position. In contrast, cost-sharing is a one-time gain for all the participants, which might make current competitors more agreeable to sharing costs than to sharing skills.

Supply Chain Management

Another aspect of this research was to investigate the SCM paradigm, in the context of technology and mission development for NASA applications. SCM encompasses all activities associated with the flow and transformation of products through their life cycle through a partnership between buyers, suppliers, and customers, with attention being paid to logistics, and to the coordination and integration of these flows both within and among organizations. SCM is an emerging research field that has generated much interest, and that requires collaboration among the organizations involved [33,43]. It is proposed that the R&D organization can be considered a supplier of competencies or specific technologies.

With CPD and with SCM, cross-functional teams usually extend beyond organizational boundaries to include key suppliers and customers. Hurmelinna et al. [44] described how an innovative environment in supplier relations for specific R&D activities is crucial for new product development. Thus, supplier involvement in R&D requires joint efforts, with good processes, smooth communication methods, technological competency, and trustful relationships.

The driving force behind effective SCM is collaboration [34,45-47]. Collaborative SCM goes beyond mere exchanging and integrating information between suppliers and their customers, and involves tactical decision-making among the partners in the areas of planning, forecasting, distribution, and product design. It also involves strategic joint decision-making about partnerships and network design, commitment and trust over an extended period of time and includes the sharing of information, risks, and rewards [47-48].

The benefits of supplier integration in the new product development process (NPD) have been widely investigated. These benefits are: reduced development time and cost, access to new technologies or capabilities, and increased quality [29-34,44-48]. However, the goals of supplier involvement can be short or long-term. Short-term goals usually deal with effectiveness or efficiency of development. Long-term collaborations are more focused on developing the underlying technologies and capabilities than on designing a specific new product. They describe this difference as the *creation* of technological resources versus the *exploitation* of these resources [48].

Ragatz, Handfield and Scannell [29] identified supplier membership in the NPD team as the greatest differentiator between most and least successful integration efforts. There are, however, a number of barriers, such as resistance to sharing proprietary information, and the “not-invented-here” syndrome. The results of their study suggested that overcoming such barriers depends on relationship structuring and the sharing of intellectual, physical, and human assets.

Chen [49] noted that as organizations learn about new business processes, they recognize that behavior changes needed to support new ways of doing business are the most critical to acquire these new competencies. Chen and Small [50] also point out that closer working relationships among all functions of the organization are required to achieve the innovation objectives.

Role of Information Technology

The growing impact of Internet networking tools on R&D is seen in the transformation of the processes by which organizations acquire technical knowledge, develop new products, and connect with others [41]. More than one third of businesses now use cyberspace for everything from finance to product development to virtual prototyping. Penetration in corporate research has been greater, as almost 95 percent of researchers have started using the Internet in some form or another to improve their design and development work [51]. Information technology advances are having a positive impact on quality and reliability [52] and are crucial to the implementation of virtual teams [15] and of adequate knowledge management systems [53].

Volkoff, et al. [25] found that although the enabling technologies for these collaborative networked Inter-organizational Systems (IOS), are not mature, managerial rather than technological challenges are more likely to constrain future development. Two strategic drivers will affect the choices made with respect to these (collaborative) systems:

- Business strategy, which gives rise to an Information Systems (IS) infrastructure that can support the appropriate organizational business operations infrastructure, and
- IS strategy, which focuses on either improving the efficiency and effectiveness of the services provided to the existing business, or transforming the business through new technological capabilities, i.e., integrated mechatronics systems [54].

Supply Chain Management Findings

Summary findings from the interviews and survey are presented here as they pertain to the Supply Chain Management factor. This factor measured how the organization is handling supply chain issues such as changes in technology, motivations for collaborative activities, how the organization works with its partners, what are the selection criteria, formality of the relationship, trust between the partners, and whether the organization is experienced at working across organizational boundaries.

The results of the parametric analyses support the notion that the organization is engaging others as a member of supply chains with appropriate policies and understanding of these types of relationships. This was true for the total sample as well as for all the different demographic groups. The interview and survey results indicated that the motivations can be risk-sharing or cost-sharing [28], and that the goals can be short of long-term [48] depending on the activity and partners.

It was recognized that the organization no longer has all the resources (people, funding, facilities) to achieve all of its R&D objectives. This is partly due to changes in the Agency and at GRC, but also because of the pace of technological change. Advances in the technologies in which R&D is carried out have evolved many of these research activities into multidisciplinary activities. When these disciplines and competencies are not available in-house, the organization must find a partner who has them. This goes both ways, as the organization is also the supplier of key competencies for other external organizations. Respondents agreed that this environment of rapidly changing technology exists and impacts their work. Because of this, the organization is involved in a number of supply chain relationships, where the organization is either the customer, or the supplier. Because of its governmental roles, the organization can be customer or supplier (or even competitor) to the same organizations depending on the activity.

In order for these relationships to be successful, formal mechanisms are needed, including proper documentation of desired outputs. Some managers stated that the only measure of success was to achieve the desired end result(s) as specified in the documentation. Others recognized the unique nature of technological research, where goals are set but may have to be redefined as "knowledge" is created. Others pointed out the need for flexibility when addressing "results"—it is possible to be successful and not achieve the desired end result—if along the way a good working relationship has been developed—this could lead to additional collaborations in the future. Respondents agreed with this need for some flexibility when judging the success or failure of a supplier relationship. Also important was the need to exchange performance information with partners, but tailored to the particular activity. For example, reporting on a monthly basis may not be appropriate for all types of R&D activities.

Respondents agreed that reduced cost, an enhanced political environment, and improved quality were some of the benefits from collaborative activities. In addition, team members and team leaders had experience working across organizational boundaries. Some of the managers pointed out that as a result of functioning as a matrix organization for several years, some of the desired competencies for working across organizations are well developed and serve to support CPD with other external organizations. This finding was not consistent with the survey, which indicated that the matrix organization is not functioning optimally. This is something that may be best addressed via a case study, which would allow a more in-depth analysis of how these competencies have been developed (or not), as well as any issues related to the implementation of the matrix structure.

When addressing selection criteria for partners, managers mentioned leveraging resources, acquiring new competencies, and what kind of track record the partner had as some of the criteria. In general, the organization looks for synergy when choosing its partners. Sometimes GRC is approached to serve as a partner or supplier and sometimes they go out looking for partners. In both instances, the decision on whether to collaborate or not is usually based on whether they complement each other—although sometimes political considerations over ride all other criteria. Respondents agreed that financial resources, skills and qualified personnel, and a good track record should be relevant criteria when selecting a partner. Geographic proximity, however, was judged not to be important, reflecting the impact of information technology developments and the relative ease of travel if needed.

Development of trust is an issue that is prevalent in the collaboration and supply chain management literature. The content analysis of the interviews established that if there is proper documentation in place the relationship develops well. Part of this documentation is a good plan that describes common goals and objectives. There was, however, little or no discussion on the interpersonal issues that lead to development of trust that may address some of the existing concerns with sharing of information. The survey bears out the interdependence between the organization and its partners, and that the organization's partners see them as allies. Since this is a knowledge organization, there are issues related to the sharing of information that will depend on the level of trust and the type of activity being carried out. Trust must be developed at a personal level before it exists at an organizational level [26]. This was recognized as a key issue if long-term partnerships are to be developed and maintained.

Finally, regarding customers, suppliers, competitors, and/or collaborators, there was agreement that in the NASA environment, most other organizations can be any of the four depending on the activity. Coupled with the government's move towards increased competition for its research funds, this has required the R&D organizations to develop new partnering skills. This poses some interesting issues, such as trust and its impact on the development of long term working relationships that will need to be addressed in future research.

Collaboration is still a relatively new way of doing business, and although there are procedures in place on how to implement collaborations, there are still issues to be addressed regarding some of the "intangibles" such as trust and the sharing of knowledge, which is critical for any R&D organization.

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Research and development (R&D) organizations are being required to be relevant, to be more application-oriented, and to be partners in the strategic management of the business while meeting the same challenges as the rest of the organization, namely: (1) reduced time to market; (2) reduced cost; (3) improved quality; (4) increased reliability; and (5) increased focus on customer needs. Recent advances in computer technology and the Internet have created a new paradigm of collaborative engineering or collaborative product development (CPD), from which new types of relationships among researchers and their partners have emerged. Research into the applicability and benefits of CPD in a low/no production, R&D, and/or government environment is limited. In addition, the supply chain management (SCM) aspects of these relationships have not been studied. This paper presents research conducted at the NASA Glenn Research Center (GRC) investigating the applicability of CPD and SCM in an R&D organization. The study concentrates on the management and implementation of space research activities at GRC. Results indicate that although the organization is engaged in collaborative relationships that incorporate aspects of SCM, a number of areas, such as development of trust and information sharing merit special attention.

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