Managing R&D Alliances Within Government: The "Virtual Agency" Concept

Miguel Castro, Roger S. Foster, Kevin Gunn, and Edward B. Roberts

***Abstract*—The virtual agency concept is now used within the United States Government as an alliance approach to manage large research and development (R&D) processes across departments. This paper examines the history of the virtual agency concept and its important characteristics. The paper identifies the potential benefits and associated risks involved in managing R&D within a virtual agency. Three cases are examined where the virtual agency concept has been applied to R&D programs: the High Performance Computing and Communications initiative, the Next Generation Internet, and the Partnership for a New Generation of Vehicles. The case studies indicate that the R&D process is attempting to balance formal process controls with the agility to adapt rapidly to new research opportunities. Virtual agencies can be used to improve organizational efficiency, improve knowledge transfer, increase interoperability through standards, provide better alignment of agency missions with national policy, and introduce increased flexibility into the R&D process. At the same time, the virtual agency concept has major risks including inefficiencies due to organizational complexity, the danger of collective myopia, the problem of adopting standards too early, the difficulty of reaching objectives in a loose organizational structure, and the problem of properly balancing the tension between agency mission objectives and national policy agendas.**

***Index Terms*—Alliances, cooperative R&D, government R&D, R&D organizations, technology policy, "virtual" R&D.**

I. Introduction

The past decade has witnessed dramatic growth in the use of various forms of alliances to facilitate corporate technology development and acquisition [1]. In the United States, one outcome of the previous Clinton/Gore administration's stated goal of making government cost less and work better was the emergence of a federal government parallel to corporate partnerships. The "virtual agency" concept has become the public sector equivalent of the "virtual corporation," [2] i.e., cooperation among government departments and agencies to manage processes that cut across departmental boundaries. As that administration launched a number of large research and development (R&D) programs to achieve broad social and economic goals it widely applied the virtual agency concept in the implementation of these R&D programs, broadened to include industry and academia as participants. Thus far, these programs continue under the Bush administration.

This paper explores the recent evolution and application of the virtual agency concept as a "strategic alliance" equivalent for government R&D management. The paper presents a brief history of the virtual agency concept in the U.S., defines its main characteristics, identifies potential benefits and risks of using virtual R&D agencies, and discusses the critical issues for the success of this organizational approach. The paper includes three case studies of virtual government agencies in the United States: the High Performance Computing and Communication (HPCC) initiative, the Next Generation Internet (NGI) initiative, and the Partnership for a New Generation of Vehicles (PNGV).

Our analysis suggests that the virtual agency concept is a potentially excellent structure to manage large R&D portfolios across government departments and agencies. The decentralized budget process and strong mechanisms for coordination and cooperation result in a natural structure for increasing R&D efficiency, improving technology transfer, coordinating the development of standards, aligning research goals, providing flexibility, promoting R&D diversity, and increasing technical communications among agencies. At the same time, the lack of a strong central management, characteristic of most corporate alliances as well, is likely to make the virtual agency less effective for mission oriented activities with clear objectives, budgets, and deadlines. A better understanding of the applicability of the virtual agency concept may help to improve the structure and operation of current government technological programs using the virtual agency structure and facilitate the design of more effective future efforts.

II. History of the Virtual Agency Concept

Cooperative undertakings among governmental departments, as distinct from government-industry collaborations, no doubt go back as far as government itself. But as the discussion and examples here will clarify, the "virtual agency" concept is broader and more specific in its features than its general predecessors. The first of this new generation of U.S. virtual R&D agencies emerged around a technology crucial to the missions of several government agencies—high-performance computing and networking. Beginning in the early 1980s, several U.S. federal agencies advanced independent programs in high-performance computing and networking. In 1987–1989, these agencies discussed and formalized the structure and strategy of a cooperative high-performance computing program to reduce duplication of effort and leverage each other's investments

Manuscript received April 10, 2002. Review of this manuscript was arranged by previous Editor-in-Chief, Dundar F. Kocaoglu.

M. Castro is with Microsoft Research Ltd., Cambridge, U.K (e-mail: mcastro@microsoft.com).

R. S. Foster is with High Performance Technologies, Inc., Arlington, VA 22203-1839 USA (e-mail: RFoster@HPTI.com).

K. Gunn is with the United States Air and Space Operations Center, Langley Air Force Base, VA 23681 USA (e-mail: kgunn@mitre.org).

E. B. Roberts is with the Massachusetts Institute of Technology, Alfred P. Sloan School of Management, Cambridge, MA 02142 USA (e-mail: eroberts@mit.edu).

Digital Object Identifier 10.1109/TEM.2003.817300

in this area [3]. A strong political interest in improving the efficiency and return on investment of government supported R&D led the U.S. Office of Management and Budget (OMB) and the former Federal Coordinating Council on Science, Engineering, and Technology (FCCSET) of the Office of Science and Technology Policy (OSTP) to sponsor this program. The OSTP provided a vehicle for interagency coordination through a number of ad-hoc committees. A similar cooperative R&D strategy was then applied to advanced materials, biotechnology, and advanced manufacturing technologies [4].

The HPCC initiative received a more formal status when the United States Congress passed the High Performance Computing Act of 1991 (PL 102-194) authorizing a 5-year program in high-performance computing and communications. The program already involved cooperation between ten federal agencies and this legislation affirmed its interagency nature. The initial program goal was to develop high performance computers and networks to solve scientific "grand challenges."

Even though the essence of a virtual R&D agency was present in the formation of the HPCC initiative, the term "virtual agency" was coined only in 1993 in then Vice President Gore's *National Performance Review* (NPR). The NPR proposed to "reinvent government" [5] to work better and cost less by applying the principles of "reengineering" [6] to government. The key premise of this "reengineering" was to break down traditional hierarchical systems, empower workers, create trusted suppliers, and integrate the entire manufacturing/service process across organizational boundaries through effective use of information technology. This would allow the creation of "virtual corporations" that should work more efficiently and meet customer needs better . The virtual agency emerged conceptually as the public sector equivalent of the virtual corporation.

The Clinton/Gore administration wanted to achieve broad societal and economic goals through the development and application of advanced technology, launching a number of large R&D programs for that purpose, e.g., the PNGV, and continuing to support the HPCC initiative. The high performance computing initiative was especially important to Vice President Gore. As a senator he had sponsored a series of bills that were eventually enacted as the High Performance Computing Act of 1991. He also introduced the Information Infrastructure and Technology Act of 1992 to broaden the goals of the initiative to address issues such as manufacturing and health care, the so-called "national challenges" [7].

The virtual agency concept evolved and was widely applied in the implementation of these R&D programs and, in the reengineering spirit of closeness to suppliers and customers, it was broadened to include industry and academia as partners. Industry and academia have long cooperated with federal agencies in the execution of R&D projects, e.g., a significant fraction of computer science research in U.S. universities in the last twenty years has been funded by the Defense Advance Research Projects Agency (DARPA) of the Department of Defense (DOD). The "novelty" associated with the virtual agency concept is in the increased involvement of industry and academia in strategic planning. This is especially clear in the PNGV and in the role of the Presidential Advisory Committee on HPCC (see Section VI).

TABLE I
MAIN CHARACTERISTICS OF A VIRTUAL R&D AGENCY

- **Cooperative R&D between different government departments or agencies**
- **Development and application of technology to achieve:**
  - **Agency mission goals**
  - **Government economic and societal goals**
  - **Partnership with academia and industry**

III. CHARACTERISTICS OF A VIRTUAL R&D AGENCY

Table I summarizes the main characteristics of a virtual R&D agency. Above all it is a form of cooperative R&D involving several government departments and/or agencies. The agencies join forces to develop and apply technology in order to achieve three types of goals: 1) mission goals that are specific to a given agency; 2) broad economic goals; and 3) societal goals that transcend any single agency. An example of an agency mission goal is the Department of Defense's goal of ensuring military supremacy. An economic goal is to ensure U.S. economic competitiveness by developing a strong technology base to spur product and process innovations. Societal goals include improved health care and environmental management. Virtual agencies that include pieces of multiple government agencies then partner with industry and academia with the desire of further improving the effectiveness of the R&D process.

IV. POTENTIAL BENEFITS

This section discusses potential benefits of virtual R&D agencies from the perspective of the federal government and the individual agencies. The methodology used to identify these objectives is based on two observations. First, a virtual R&D agency is a form of cooperative R&D. Therefore, it has many benefits in common with cooperative R&D or alliance-type ventures in the private sector. Second, all agencies ultimately report to the same entity—the federal government. Hence, a virtual R&D agency can be compared with forms of organizing the R&D function of large corporations. We started by collecting an initial set of potential benefits from the literature on these two areas. Then we analyzed the case studies in Section VI to identify additional benefits and to filter out from the initial set those potential benefits that are unlikely to apply in the virtual R&D agency case. Table II lists the potential benefits characteristic of virtual R&D agencies.

1) Efficiencies (Cost and Time): All the case studies discussed in Section VI and the initial government documents that proposed the virtual agency concept indicate that increased efficiency, both cost and time reduction, is the key motivation for setting up a virtual R&D agency. A virtual R&D agency can reduce the cost of performing R&D in three fundamental ways: 1) by reducing duplication of agencies' investments in R&D; 2) by exploiting scale economies in R&D; and 3) by exploiting synergies [8]–[10]. By partnering with industry and academia, virtual agencies can further increase scale and can select R&D performers from a broader set to maximize synergies.

Duplication of effort can be avoided when different agencies share a common technological goal, e.g., fuel cells are used by National Aeronautics and Space Administration (NASA) to

TABLE II
POTENTIAL BENEFITS OF A VIRTUAL R&D AGENCY

• **Efficiencies (cost and time)**
• **Technology transfer**
• **Standards and interoperability**
• **Alignment of agency and national policy goals**
• **Flexibility**

power its space shuttles, and can potentially be used by DOD as a silent propulsion system for military vehicles [11].

Building up scale can improve the efficiency of R&D by raising the number of people working on the same area above critical mass or by allowing the implementation of expensive research facilities that could not be funded by any individual agency but are more efficient. For example, one of the objectives of the NGI initiative is the development of a very high-speed computer network that agencies can use to develop applications relevant to their specific missions [12]. The private sector is expected to share the cost of this network.

2) Technology Transfer: A virtual government agency can facilitate and speed up the transfer of R&D results to applications that can benefit from them [9]. Some of the federal agencies that participate in the NGI are focusing on applications of computer networks rather than on research to advance the performance of the network. For instance, the National Institutes of Health (NIH) is focusing on medical applications of networked computers. The simple participation of NIH in the NGI virtual agency can help it monitor computer networking technology.

The virtual agency acts as an important organization for strategic planning inside the government. Part of the planning includes collecting the requirements of applications and aligning the research projects to achieve these requirements [12]. This should encourage R&D results to be more relevant and more quickly applied to applications. For example, the PNGV Operational Steering Group and Technical Task Force include representatives from the major U.S. domestic automobile manufacturers [11]. Their inputs, based on superior market knowledge, should enhance the likelihood that the R&D results are applicable to commercial automotive products.

A virtual R&D agency can also provide individual agencies with access to complementary scientific knowledge, technology, and management skills. In particular, cooperation is a particularly effective way to access tacit knowledge that is not codified and easily transmittable [11]. For example, the NGI initiative is combining DARPA's strength in managing long term research in advanced networking capabilities with the National Science Foundation's (NSF) expertise in deploying experimental high-speed networks.

3) Standards and Interoperability: The setting of standards is frequently crucial for a technological innovation to result in significant economic and social benefits. A virtual agency can be a privileged forum to discuss standards and interoperability issues. It can help create a common technology vision to guide public and private R&D investments [10]. Furthermore, the government can make regulatory decisions to influence the standards settings process and agencies can use their collective buying power as lead users of advanced technology to tip the balance toward specific standards.

4) Alignment of Agency and National Policy Goals: The federal government can be compared with a very large corporation and the federal agencies can be viewed as business units. The leadership of the virtual agency, like corporate leadership, has the ability to make the portfolio management decisions that balance the member agencies' goals and national policy objectives.

Each agency has a particular mission and it optimizes its organization and processes to fulfill that mission. In particular, it performs R&D that will likely help it achieve mission specific goals, e.g., DARPA carries out and funds research in defense technology. The government also has broad economic and societal goals that frequently cut across several agencies. A virtual agency can help the government align agency R&D with these goals [13]. For example, the PNGV has the goal of improving the competitiveness of U.S. car manufacturers. To help achieve this goal, the major U.S. automotive manufacturers are part of the virtual agency and cooperate with the federal agencies to set the R&D agenda for the initiative. This type of activity has been especially difficult to carry out in the United States, which has long had major debates about the appropriateness of a "national technology policy" in areas relating to most commerce and industry.

5) Flexibility: Flexibility is another benefit of virtual R&D agencies. The virtual agencies can be set up very quickly by composing existing resources under some coordination layer [7]. This is important because the creation of a normal new governmental agency requires Congressional approval and is a time consuming process. For example, the National Information Infrastructure initiative was set up as a virtual agency and did not even appear in the federal budget. The funds for the initiative were contributed from the cooperating agencies' own budgets.

Program managers also have the ability to move their programs more quickly [14]. Without the burden of a complicated Congressional budget process, the member agencies' internal R&D funds can be more easily realigned to support the new program. Ongoing activities within the member agencies can be redirected in support of the virtual agency when needed. Resources can be reassigned to respond to program requirements.

V. POTENTIAL RISKS

The overarching risk of virtual agency programs is that alliance-based programs may lead to worse results than the traditional approach in which each agency pursues R&D programs independently that are centered on its own mission goals. Table III lists the potential risks of a virtual agency. The methodology used to identify these risks was identical to the one described in Section IV for the benefits.

1) Inefficiencies (Cost and Time): A virtual R&D agency may increase the cost and time of the R&D process due to the overhead of managing cooperation, identified in the economics literature as "transaction costs" [15]–[16]. This overhead can be high due to problems like culture clashes, which are especially likely in a virtual agency due to the diversity of R&D performers (national laboratories, academia and industry), and divided loyalty. One of the biggest "time sinks" is the need for consensus given the absence of an agreed upon leader [14].

TABLE III
POTENTIAL RISKS OF A VIRTUAL R&D AGENCY

- **Inefficiencies (cost and time)**
- **Collective myopia**
- **Pushing the wrong standards**
- **Poor interoperability and integration**
- **Conflicts between agency and national policy goals**
- **Volatility**

Dealing with the several agendas involved in the process and getting one agency to give up its priority for another's is a difficult and time-consuming process. Furthermore, if the participants in the virtual agency are chosen poorly and lack complementary or common goals, the exploitation of synergies and reduced duplication are unlikely to offset the overhead of managing cooperation. This mirrors phenomena encountered in corporate R&D alliances.

2) Collective Myopia: One of the advantages of a virtual R&D agency is that it can help create a common technology vision to focus private and public R&D investments. This can also be a disadvantage because of the uncertainty involved in R&D, which is particularly high in basic research. A virtual R&D agency may reduce the diversity of scientific and technology alternatives explored, thereby increasing the risk of collective myopia [10]. For example, the 1998 National Research Council review of the PNGV recommended that the partnership devote more resources toward developing alternative energy conversion and storage technologies rather than strongly focusing on a single alternative [17].

3) Pushing the Wrong Standards: One possible side effect of collective myopia is setting or embracing a bad standard. This is particularly serious due to the government's power to use regulatory measures and its buying power to select standards rather than relying on the market. Making the wrong bet early in a new technology could lead to embracing a "standard" that is overtaken by other, commercially accepted, standards. The government needs also to be careful not to use its influence in small markets to attempt to "pick winners," particularly when it comes to specific firms, as studies of past government efforts indicate that this policy is particularly ineffective [18].

4) Poor Interoperability and Integration: The loosely coupled nature of a virtual R&D agency makes the issue of system interoperability and integration particularly important. Without an explicit effort toward interoperability and integration the individual technologies developed by different participants are unlikely to work well as a system. This problem has been pointed out in the National Research Council review of the PNGV [17].

5) Conflicts Between Agency and National Policy Goals: In some cases, a virtual R&D agency may favor government policy goals over agency goals. For example, the Clinton/Gore administration set as a major policy goal increasing the investment of the Department of Defense in "dual-use technology" (i.e., technology with both military and civilian applications). This has the potential of broadening the benefits of defense R&D investments but it may deprive the DOD of unique technologies that are important to secure military supremacy.

At the other end of the spectrum is the danger of departments and agencies putting their own agendas ahead of national policy objectives. There are several reasons for this: no one has central budget-making authority, each agency makes its own decisions, and each usually make decisions that protect the agency [14].

The HPCC programming experienced the pain of this mismatch. Dr. Anita Jones, the Director of Defense Research and Engineering, also served as the Chair of the Committee on Computing, Information, and Communications (which oversees the HPCC program). Dr. Jones was a very strong and forceful leader who controlled over $2 billion of R&D funding authority for the Defense Department and could use this power to force coordination and cooperation among the agencies participating in the HPCC program. After Dr. Jones' departure from government service in May 1997, the budget coordination process became more difficult, with ultimate budgetary decisions being made primarily at the agency level, rather than in a strong coordinated manner. The result is that HPCC has been perceived by some as having its dollars spread across programs for political reasons instead of programmatic priorities [14].

6) Volatility: When we discussed benefits earlier, we noted that flexibility is a key advantage of virtual agencies. However, the same reasons that lead to flexibility lead to volatility. A virtual agency relies on continued funding and active engagement of its participants and may be unable to sustain a long-term commitment to a project. The problem may be ameliorated by formally creating an entity to manage the virtual R&D agency, e.g., the National Coordination Office that managed the HPCC program.

VI. CASE STUDIES

How can a virtual R&D agency achieve its potential benefits while avoiding the risks? The virtual R&D agency strategy in the United States is still too recent to draw definitive conclusions but this section attempts to develop insights from three virtual R&D agencies: the HPCC initiative, the NGI initiative, and the PNGV. Despite the fact that all three cases include extensive public-private partnerships, we do not focus upon those aspects. Rather we look more at the cross-agency alliance issues, including:

- the organizational structure that supports the virtual agency,
- the strategic planning process, and
- R&D project selection, execution and funding.

A. High Performance Computing and Communications

The HPCC initiative has been managed by the federal government as the quintessential virtual agency since its formal creation in 1989. Initially it involved four agencies—the Department of Defense, the Department of Energy, the National Science Foundation, and the National Aeronautics and Space Administration. Today twelve agencies are involved in planning and performing R&D in cooperation with U.S. academia and industry [13]. The goals of HPCC can be summarized as [13]:

- Extend U.S. leadership in high-performance computing and networking technologies,
- Help federal agencies fulfill their evolving missions,

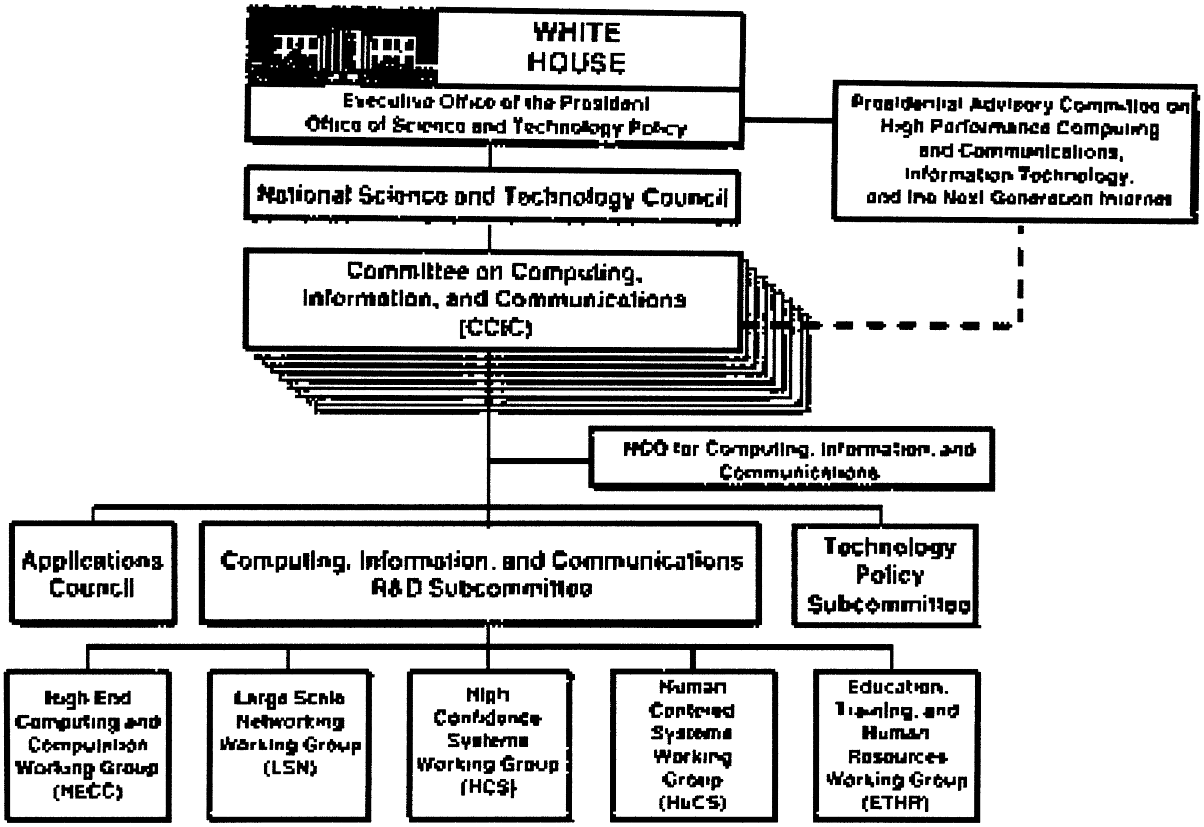


Fig. 1. The organization of the virtual agency created to administer the HPCC program in 1997 .[1]

- Disseminate the technologies to accelerate innovation and serve the economy, national security, education, and the environment, and
- Spur gains in U.S. productivity and industrial competitiveness.

Because these goals relate advances in computing and communications technology to the achievement of benefits from their use, HPCC has from the start attempted to provide for the joint advancement of technology and its applications. A key role of HPCC is helping to meet federal agency mission needs that are unlikely to be addressed by industry in the short-term due to the absence of market pull [14].

1) Organization: Fig. 1 depicts the organization of the virtual agency created to administer the HPCC program. At the highest level, the National Science and Technology Council (NSTC) coordinates science and technology policy across the government. The National Coordination Office (NCO) coordinates management of the nation’s R&D investment portfolio in the computing and communications fields. Workgroups of the Committee on Computing, Information, and Communications (CCIC) Research and Development coordinate the project portfolios in specific subareas (e.g., large-scale networking) at the agency program manager level.

Agency employees (i.e., employees on a participating agency’s payroll that report primarily to the agency) staff these committees and workgroups. Thus, the virtual agency management organization is analogous to a matrix organization in industry with dual reporting relations. Academia and industry have an indirect participation in this organization through the Presidential Advisory Committee, which includes leaders from academia and industry. The Applications Council links the program with agencies that are not part of HPCC.

2) Strategic Planning: The HPCC program uses the matrix organization to plan the HPCC R&D activities. Broad government goals flow from the top of the hierarchy and participating agencies’ goals flow from the bottom. The Presidential Advisory Committee works as an advocate for academia and industry goals and the Applications Council for nonparticipating agencies. Moving down the hierarchy the various levels define strategy in increasing detail and narrower technological focus. The multi-agency staffing of workgroups and committees fosters communication and cooperation across agencies and the higher levels of the hierarchy foster cooperation across functional/technology areas.

An independent body, the National Research Council of the National Academy of Science, periodically reviews the program and the NCO issues a document called the Blue Book summarizing the program’s activities as a supplement to the President’s yearly budget.

3) R&D Project Selection, Execution, and Funding: The actual R&D project selection and management still takes place at the individual agency level. The strategic plans and the cross-

[1]In Fiscal Year 1998, the Committee on Computing Information and Communications (CCIC) was renamed the Committee on Technology (CT). The R&D subcommittees were reduced from five to two (HECC and LSN) due to an Office of Management of Budget assessment that they had weak performance metrics and poor coordination across agencies.

agency teams provide coordination but funding is completely decentralized. The teams at the working group level provide the forum for coordinating project selection and management. The strong interagency contacts of the program managers in these teams enabled sharing of reviewers for project proposals, which helped to eliminate duplication of efforts, and to exploit synergies and economies of scale [14].

Beginning in 1992 the HPCC program received a special line-item budget allocation in the annual Federal budget that has averaged approximately one billion dollars. These funds were distributed across the participating agencies with a specific amount allocated to each agency by the budget process. Furthermore, no single agency received a dominant fraction of the budget. The result was that the individual agencies actually had control of their parts of the HPCC budget and there was no real central control over funding and no clear lead agency. This tended to decentralize program and project selection with each individual agency favoring its own interests over cooperation [14].

Universities, federal laboratories, and industry execute the R&D projects. Any one of these performers may submit proposals to a specific federal agency to receive funds to pursue R&D on HPCC-related technologies. These funds are available in several forms from direct R&D contracts to cooperative R&D agreements with cost sharing between government and industry. The specific arrangements are negotiated on a project by project basis. For example, Cooperative Research and Development Agreements (CRADAs) are a mechanism through which industrial partners can join federal laboratories in a cooperative cost-shared research effort to pursue a project with mutual benefit. The laboratories are able to contribute personnel, equipment, and resources to the effort, but are specifically excluded from providing funds directly to an industrial partner. Grants or cooperative agreements (like CRADAs) allow joint pursuit of a common objective by government and industry, but in this case, some government funding can be provided. Industry is expected to incur a more significant portion of the cost when the research is closer to development of a marketable product.

B. Next Generation Internet

The NGI initiative was announced on October 10, 1996 with the following three goals [13]:

- conduct experimental research for advanced network technologies;
- build a prototype high-performance network testbed for system-scale testing of advanced services and technologies and for developing and testing advanced applications;
- develop and demonstrate a wide variety of nationally important applications that require high-performance networking.

The NGI pursues these goals using a virtual agency strategy with partnerships of a grand alliance among several government agencies (DARPA, NASA, NIST, NIH, and NSF) as well as academia and industry. According to the 1998 NCO Blue Book, "these activities will create an open technology transfer environment, continuing a strategy that determined much of the success of the original Internet" [13].

The applications will include agency mission applications, university and public sector applications, and private sector applications with the potential to improve U.S. competitiveness in vital business areas. "Revolutionary" applications will also demonstrate the potential for opening entirely new business areas based on commercializing the technologies that are developed within the NGI initiative. Some of the applications being pursued address important societal goals, e.g., medical and environmental applications.

1) Organization: The NGI program is coordinated within the same framework of the NSTC used to coordinate the HPCC initiative depicted in Fig. 1. The NSTC's Committee on Technology is responsible for the overall high level NGI strategy; the CCIC R&D is responsible for coordination across workgroups; and the Large Scale Networking (LSN) workgroup is responsible for the implementation strategy of the NGI. The structure is augmented with the NGI Implementation Team whose primary responsibility is the implementation of approved plans under the direction of LSN. According to the NGI Implementation Plan, [12] this team:

- contains one member from each of the funded agencies plus an applications advocate;
- uses advanced networking and computing for effective coordination and communications;
- reports to the LSN Working Group as a team (and to agencies as individuals);
- operates as an integrated project team for the overall NGI initiative;
- is jointly responsible for execution of approved implementation plans, initiative management and evaluation;
- recommends funding mechanisms and serve appropriately in the selection process;
- will establish contributing partnerships and relationships.

2) Strategic Planning: The strategic planning process is similar to the one described for HPCC with the additional role of the NGI implementation team whose responsibilities were already described. One interesting difference is the process to select revolutionary applications and collect requirements for goals 1 and 2 of the initiative. This process is based on a matrix organization whose rows and columns are *affinity* groups.

There are two types of affinity groups—disciplinary and technology. A disciplinary affinity group is a collection of end-user organizations that share common interests such as health care, education, or environment. They collaborate because they recognize that their applications have a great deal in common; and that by collaboration each will potentially realize its goals more efficiently and effectively.

A technology affinity group has the mission of coordinating and developing the middleware or tools that link the network to the applications. For example, many applications require the ability to collaborate over the NGI. Therefore, a collaborative tools affinity group has been established to minimize duplication and to maximize efficiency. They are to ensure that collaboration tools developed by one application are useful to all.

Each affinity area is reviewed by an affinity group to develop a cross discipline/technology matrix. There are seven disciplinary groups and five technology groups. The chairs of the

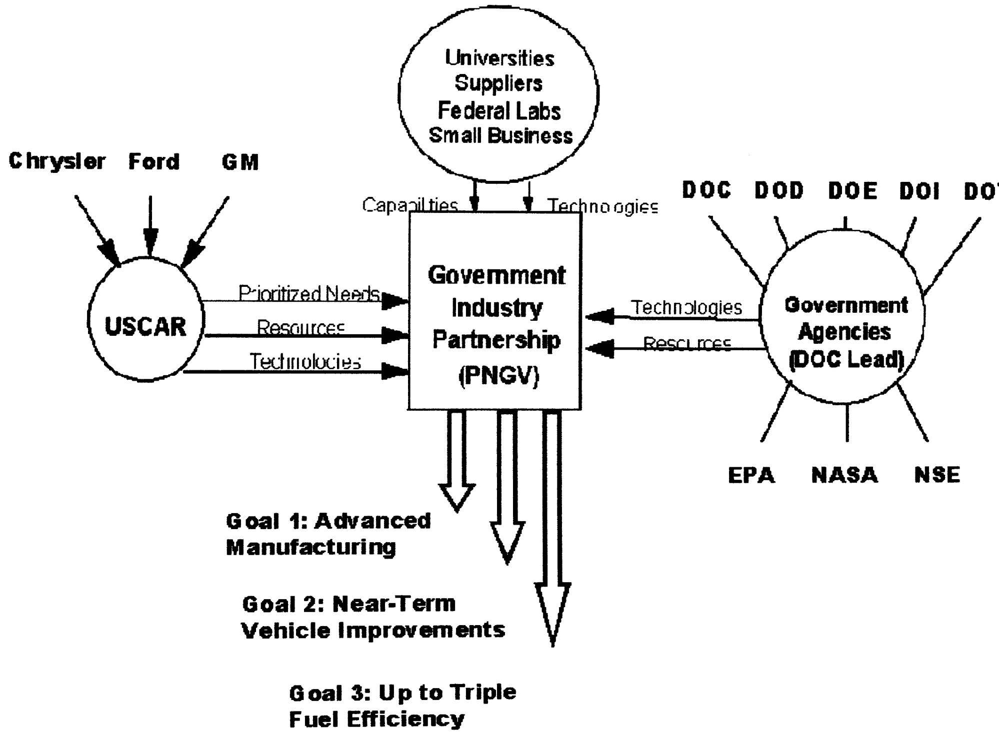


Fig. 2. The organization of the PNGV.

affinity groups work together to identify, select and prioritize applications, and to provide recommendations and requirements to goals 1 and 2 [12]. This rather novel "affinity groups" approach has also been used by ICI in the UK to help coordinate and fund its cross-divisional more basic chemical research.

3) R&D Project Selection, Execution, and Funding: Project selection, execution and funding is similar to what we described for HPCC with the difference that the NGI implementation team and the affinity groups provide more structure to support coordination and cooperation at this lower level.

As in HPCC, the government funds allocated to NGI are distributed by the participating agencies, which conduct their own calls for research and approve expenditure of agency resources in support of the NGI initiative. NGI does not include significant funds for goal 3 (i.e., revolutionary applications); instead, participants developing each application will provide most of the funds. The NGI funds allocated to goal 3 are used to support the coordination efforts of the affinity groups.

C. Partnership for a New Generation of Vehicles

In September 1993, President Clinton and the Chief Executive Officers of Chrysler, Ford, and General Motors announced the formation of the PNGV. The partnership had three goals [11]:

- reduce manufacturing costs and development times to improve national competitiveness in manufacturing;
- achieve near-term advances by implementing innovations from ongoing research in standard vehicles to increase fuel efficiency and reduce emissions;
- develop a new class of breakthrough vehicles with up to three times the fuel efficiency while maintaining performance and cost of ownership.

PNGV has focused on the third goal. The accomplishment of these three goals could yield significant energy, environmental, and economic benefits to the U.S. Government support of long-term R&D in this area was intended to accelerate progress beyond the market pull for high efficiency automobiles.

1) Organization: PNGV was established as a virtual R&D agency that includes eight government agencies: the Departments of Commerce (lead agency), Defense, Energy, Interior, and Transportation, and the Environmental Protection Agency, National Aeronautics and Space Administration, and National Science Foundation. The three major U.S. automotive manufacturers—Chrysler (now Daimler-Chrysler), Ford, and General Motors—participate in the virtual agency through the United States Council for Automotive Research (USCAR), which is a cooperative R&D consortium formed by the three manufacturers to develop technology in precompetitive research areas. Universities, federal laboratories, suppliers of the automotive industry and small businesses are also expected to contribute to the partnership by executing specific R&D projects. Fig. 2 illustrates the overall organization of the partnership.

The partnership is managed by two teams, the Operational Steering Group and the Technical Task Force. The responsibilities of the steering group are strategic planning, program review and prioritization, budgeting and resource allocation, and direction of the task force. The task force is responsible for short-term planning, development and implementation, project management, and coordination of technical expertise among government and industry. Both teams include members from industry and the federal agencies to provide for shared leadership and ensure solid technical guidance for the program. For example, the chair of the steering group rotates between government and industry and this team includes senior officers of the government agencies and the vice-presidents of R&D of Chrysler, Ford, and General Motors. This team structure is aimed at improving diffusion of technical knowledge and helping industry access government technology that is relevant to PNGV.

2) Strategic Planning: Strategic planning is the responsibility of the Operational Steering Group. The strategic plan for the partnership included three phases—technology selection, concept vehicles, and production prototypes. During the first phase, R&D focused on a number of candidate technologies that could significantly contribute to the goals of the partnership, e.g., fuel cells, and ultra-capacitors. This phase ended in 1997 with the selection of a subset of the technologies for further R&D and incorporation in the concept vehicles that are being developed in phase two by Chrysler, Ford, and General Motors. The final prototype phase is expected to end in 2004. The last two phases have limited government involvement. Instead, the three automotive manufacturers focus on proprietary R&D while the government continues to fund long-term research relevant to the goals of PNGV.

The industry partners have helped align the strategic plan with market realities. For PNGV to have economic and environmental impact, the total cost of ownership of the new generation of cars must be as low as the current cost of ownership. Industry's expertise in mass production for domestic and international markets is essential to convert any advanced technical idea into a practical product [11].

The agreement between the government and the U.S. auto industry establishing PNGV called for a Peer Review on technologies selected for research and progress achieved. These reviews have been performed regularly by the National Research Council.

3) R&D Project Selection, Execution, and Funding: Contrary to strategic planning, R&D project selection, execution, and funding involve less cooperation among the PNGV virtual agency participants. The strategic plan and the Technical Task Force provide some centralized guidance on the selection of R&D projects but funding is highly decentralized. The virtual agency does not own a pool of resources from which it can fund projects. Instead each participant selects and funds specific R&D projects in a relatively decentralized way.

The federal budget includes an annual PNGV item of approximately $250 million, but this budget is divided among the participating agencies and each agency is responsible for managing its portion of the budget. Some agencies like DOD and NASA do not receive PNGV-specific funds from the federal government. Instead, they only fund projects that contribute to their specific missions. As in HPCC, universities, federal laboratories, and industry execute R&D projects. These performers submit project proposals to specific federal agencies and funds are available in the forms described for HPCC.

D. Comparison of Cases

The three virtual agency case studies share three important features: 1) cross-participant teams; 2) partnering with industry and academia; and 3) decentralized funding.

Cross-participant teams have members from each participating organization that report as a whole to the virtual agency and as individuals to each participant. These teams can help achieve all the potential benefits we have identified for virtual R&D agencies; they can foster communication and consensus building while ensuring that each participant's view is heard. On the other hand, they introduce a significant management overhead, e.g., the consensus-building process can be extremely time consuming. These teams exist at two levels: 1) high-level strategic planning and 2) project selection, execution, and funding. The three initiatives all provide strong support for coordination at the high level but the HPCC program provided less structure to support cooperation at the lower level than the others did. More recent initiatives that are managed within the organizational structure that was set up for HPCC seem to remedy this flaw by adding additional structure; e.g., NGI added a cross-agency implementation team and a matrix of affinity groups.

In all three case studies, the government agencies partnered with industry and academia to some degree. Partnering occurred at three levels: as full participants in the virtual agency (in the case of PNGV), as an advisory board (in HPCC and NGI), as performers of specific R&D projects (in all cases). The participation of industry in the virtual agency is important to help align the agency's technology strategy with market realities. In the case of PNGV, this alignment was crucial to achieve the partnership's goals. HPCC and NGI favor meeting agencies' mission goals over improving U.S. industrial competitiveness; industry and academia have only an indirect participation in the formulation of technology strategy through the Presidential Advisory Committee and informal interactions with the virtual agency's management teams. Yet in both cases aligning R&D with industry's market knowledge and improving technology transfer to industry may be the best way to meet the agencies' mission goals.

Each of the virtual agencies has used the National Research Council as an impartial third body to perform periodic review and assessment of the virtual agency program. This seems to reduce the risk of collective myopia [11].

The three virtual agencies select R&D performers from a wide group, which includes national laboratories, academia and industry. These R&D performers submit project proposals that are selected using peer review which should help reduce the risk of collective myopia and increase synergies. Furthermore, industry performers can share the cost of some projects, which increases scale and provides a superior alignment of incentives that seems appropriate for the virtual agency at the project level.

In the area of funding, the three programs all had decentralized budget structures. Funding authority still remained with the individual agencies and not with a central decision-maker. This resulted in structures where no single agency or entity had control. While this is probably good for generating a diversity of ideas, it also results in a difficult problem of reaching consensus to take a particular action. Decentralized funding is likely to be effective for basic research and the funding of a diverse portfolio of generic technologies, but is likely to result in large inefficiencies for coordinating large multiagency mission-oriented projects.

VII. Conclusion and Recommendations

All organizational structures represent a trade off between formal process control and agility. Government agendas include complex sets of reasons to support R&D projects: 1) the promotion of national or economic security; 2) building a solid base of generic technologies; 3) supporting applications that meet agency mission goals; and 4) actively investing in building new markets from key technologies. The government plays a broad and complex set of roles in the nation's R&D process. The virtual agency concept offers a unique and potentially powerful organizational tool for the government effectively to meet conflicting technological and applications demands from evolving technologies.

The advantages associated with using the virtual agency concept include: 1) improved organization efficiency in terms of cost and time; 2) better transfer of technological knowledge, both tacit and codified; 3) improved mechanisms for creating and establishing interoperability through standards; 4) better alignment of department and agency mission goals with national policy agenda; and 5) the flexibility to change programs as the political or technological environment change.

The major risks associated with a virtual agency include: 1) inefficiencies due to the complexity of interagency cooperation; 2) the danger of collective myopia, or over-coordinating and picking the wrong scientific or technological path; 3) collectively supporting a standard prematurely; 4) the difficulties associated with reaching objectives in a loose organizational structure; and 5) conflicts between agency mission objectives and broader national policy agendas when the two are not well aligned.

Both conceptually and from our three case studies, the virtual agency appears likely to be most effective in the early stages of the R&D process. A virtual agency is likely to support the coordination of broad top-down policy agendas, making sure the various government departments and agencies are aligned with these goals. A virtual agency will also work well in coordinating the broad scope generic technologies associated with basic research. Virtual agencies are less likely to be effective at coordinating client-oriented mission specific projects. Finally, experience has shown that government organizations and policies are even less capable of "picking winners" or pushing particular technologies into the market place [18].

References

[1] E. B. Roberts, "Benchmarking global strategic management of technology," *Res./Technol. Mgmt.*, pp. 25–36, Mar.–Apr. 2001.

[2] W. Davidow and M. Malone, *The Virtual Corporation*. New York: Harper Business, 1992.

[3] Committee to Study High Performance Computing and Communications, National Research Council, *Status of a Major Initiative: Evolving the High Performance Computing and Communications Initiative to Support the Nation's Information Infrastructure*. Washington, DC: Nati. Acad. Press, 1995.

[4] D. Hart, "Managing technology policy at the white house," in *Investing in Innovation: Toward a Consensus Strategy for Federal Technology Policy*, L. Branscomb and J. Keller, Eds. Cambridge, MA: MIT Press, 1997.

[5] A. Gore Jr., "From red tape to results: Creating a government that works better and costs less," U.S. Government Printing Office, Washington, DC, Report of the National Performance Review, 1993.

[6] M. Hammer and J. Champy, *Reengineering the Corporation: A Manifesto for Business Revolution*. New York: Harper Business, 1993.

[7] B. Kahin, "The U.S. national information infrastructure initiative: The market, the net, and the virtual project," in *National and International Initiatives for Information Infrastructure Conference*. Cambridge, MA: John F. Kennedy School of Government, Harvard Univ., 1996.

[8] K. Brockhoff and T. Teichert, "Cooperative R&D and partners' measures of success," *Int. J. Technol. Manage.*, vol. 10, no. 1, 1995.

[9] L. Branscomb, "Research partnerships in public policy," *Testimony at the National Science Policy Study Hearing: Defining Successful Partnerships and Collaborations in Scientific Research*, Mar. 11, 1998.

[10] D. Mowery, "The roles and contributions of R&D collaboration: Matching policy goals and design," *Testimony at the National Science Policy Study Hearing: Defining Successful Partnerships and Collaborations in Scientific Research*, Mar. 11, 1998.

[11] *Partnership for a New Generation of Vehicles Program Plan*. Washington, DC: Partnership for a New Generation of Vehicles, Nov. 1995.

[12] NGI Implementation Team, *NGI Implementation Plan*. Washington, DC: National Coordination Office for Computing, Information and Communications, Feb. 1998.

[13] *Computing, Information, and Communications: Technologies for the 21st Century, Blue Book 1998*. Washington, DC: National Coordination Office for Computing, Information, and Communications, Nov. 1997.

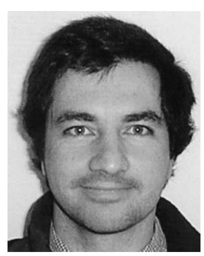
[14] K. Howell, Director of the National Coordination Office for Computing, Information and Communications, Executive Office of the President, private communication, May 1, 1998.

[15] O. Williamson, "Transaction cost economics: The governance of contractual relations," *J. Law Econ.*, vol. 22, pp. 233–262, 1979.

[16] D. J. Teece, "Profiting from technological innovation: Implications for integration, collaboration, licensing, and public policy," *Res. Pol.*, pp. 285–305, 1986.

[17] Standing Committee to Review the Research Program of the Partnership for a New Generation of Vehicles, *Review of the Research Program of the Partnerships for a New Generation of Vehicles: Fourth Report*. Washington, DC: National Academy Press, 1998.

[18] R. R. Nelson and R. N. Langlois, "Industrial innovation policy: Lessons from American history," in *Readings in the Management of Innovation*, 2nd ed, M. Tushman and W. Moore, Eds. Cambridge, MA: Ballinger, 1988, pp. 661–669.



Miguel Castro received the Ph.D. degree in computer science in 2000 from the Massachusetts Institute of Technology, Cambridge, MA, for his work on practical Byzantine fault tolerance.

He is now a Researcher with Microsoft Research Ltd., Cambridge U.K. His interests are centered on distributed computer systems and operating systems.

Roger S. Foster received the M.S. degree in management of technology from the Sloan School of Management, the Massachusetts Institute of Technology, Cambridge, and the Ph.D. degree in astronomy from the University of California at Berkeley.

He is a Senior Practice Director in the Advanced Systems Group with High Performance Technologies, Inc., Reston, VA. He has more than 14 years of increasing responsibility in business and technology management. He has directed business and technology strategy assignments for large commercial and government organizations. He was formerly a Project Manager for the U.S. Department of Defense High Performance Computing Modernization Program. As a practicing research scientist he has considerable experience developing computational codes on a variety of high-performance computing platforms.

Kevin Gunn received the B.S. degree from Clemson University, Clemson, SC, and the M.S. degree from the Massachusetts Institute of Technology, Cambridge.

He has been a Systems Engineer for the U.S. Air Force and the MITRE Corporation for the past nine years, and had nine years of operational communications experience in the U.S. Air Force prior to that. Currently, he is a Systems Engineer with the Air and Space Operations Center Weapon System Program Office at Langley Air Force Base, VA, and an Air Force Reserve Communications Officer with the U.S. Joint Forces Command, Norfolk, VA. His current research interests include enterprise application integration and system-of-systems engineering.

Edward B. Roberts is the David Sarnoff Professor of Management of Technology at the Massachusetts Institute of Technology (M.I.T.), Cambridge, where he has long chaired the Sloan School's Management of Technological Innovation & Entrepreneurship research and education programs. He is co-founder and until recently co-chairman of the M.I.T. Management of Technology Program, a 12-month mid-career Master's Degree program for aspiring technical managers, founder and chairman of the MIT Entrepreneurship Center, and has also co-directed the School's International Center for Research on the Management of Technology. Over the past 40 years he has become internationally known for his studies and active involvement in many aspects of technology management, including technology strategy, corporate venturing, product innovation management, and technology-based entrepreneurship. He has also been a co-founder and/or director of numerous emerging technology companies and venture capital funds. He has authored over 150 articles and 11 books, one of the most recent being *Entrepreneurs in High Technology* (Oxford, U.K.: Oxford University Press, 1991), winner of the Association of American Publishers' award as Outstanding Book in Business and Management.