SAND REPORT

SAND 2003-0132
Unlimited Release
Printed February 2003

Attributes in the Research Environment That Foster Excellent Research: An Annotated Bibliography

Gretchen B. Jordan, L. Devon Streit and Jennifer Matiasek

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia is a multiprogram laboratory operated by Sandia Corporation,
a Lockheed Martin Company, for the United States Department of Energy's
National Nuclear Security Administration under Contract DE-AC04-94-AL85000.

Approved for public release; further dissemination unlimited.

Sandia National Laboratories

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

Printed in the United States of America. This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Telephone: (865)576-8401
Facsimile: (865)576-5728
E-Mail: reports@adonis.osti.gov
Online ordering: http://www.doe.gov/bridge

Available to the public from
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Rd
Springfield, VA 22161

Telephone: (800)553-6847
Facsimile: (703)605-6900
E-Mail: orders@ntis.fedworld.gov
Online order: http://www.ntis.gov/help/ordermethods.asp?loc=7-4-0#online

SAND 2003–0132
Unlimited Release
Printed February 2003

Attributes in the Research Environment That Foster Excellent Research: An Annotated Bibliography

Gretchen B. Jordan
Science and Technology Program Evaluation
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185- 1393-

L. Devon Streit and Jennifer Matiasek
McNeil Technologies, Inc.
Springfield, VA 22150

Abstract

This annotated bibliography has been prepared as part of a study sponsored by the U.S. Department of Energy's Office of Basic Energy Sciences to assist in understanding the key elements in research environments that contribute to the ability of staff to accomplish excellent research. There is increasing concern that better methods are needed for assessing the health and effectiveness of research organizations during the process of doing research, not just the tangible outcomes of that research, such as cited publications and innovative products. There are also many managers of research and technology development (R&D) organizations who wish to improve even the best environment, and would like to know and report best practices, successes, and problems. This bibliography includes selected literature on the management and evaluation of R&D organizations. The books and articles briefly summarized have different scopes and foci, but this review concentrates on the authors' discussion of attributes in the research environment that foster excellence, be that creativity, innovation, new product development or something else. The review concentrates on more recent writings, primarily the 1990s, with few exceptions. Where a book or article has an extensive bibliography that is indicated.

Attributes in the Research Environment That Foster Excellent Research: An Annotated Bibliography

G.B. Jordan, L.D. Streit, J. Matiasek[1]

This annotated bibliography has been prepared as part of a study sponsored by the U.S. Department of Energy's (DOE) Office of Basic Energy Sciences to assist them in further understanding the key elements in research environments that contribute to the ability of staff to accomplish excellent research. From this understanding, assessment instruments, including an employee survey, will be developed and existing assessment methods, such as program and peer review, may be modified to better evaluate and improve these research environments.

This bibliography has wider appeal, however, because there is an increasing concern that better methods are needed for assessing the health and effectiveness of research organizations during the process of doing research, not just the tangible outcomes of that research, such as cited publications and innovative products. In addition to the desire to improve even the best environment, many would like better management information for accountability and to be able to know and report best practices, successes, and problems. Demonstrating that an organization is "effective" in the sense of optimizing the chances for producing new ideas and products—which are hard to predict in research—would indicate to investors that an organization is likely to provide a good return on their investment.

This annotated bibliography includes literature on the management and evaluation of research and technology development (R&D) organizations. The review concentrates on more recent writings, primarily the 1990s, with a few exceptions, such as Pelz, that were targeted to this study. Earlier references, such as Zuckerman, are represented in the several survey articles that summarized earlier works.

The articles summarized have different scopes and foci, but this review concentrates on the authors' discussion of attributes in the research environment that foster excellent R&D. Some sources mention a few specific factors that they believe influence innovation and R&D performance while other sources include a larger and broader range of factors. Hull, for example, is concerned with the structure of organizations and discusses how management strategies must relate to the work performed to effectively produce innovative ideas. Udwadia, however, considers the factors that are needed in organizations to enhance creativity from an all-encompassing perspective that includes individual, technical, and organizational aspects. He discusses individual traits and skills, human and technical resources, and organizational characteristics and structure.

Acknowledgement

The work presented here was completed for the U.S. DOE by Sandia National Laboratories, Albuquerque, New Mexico, USA under Contract DE-AC04-94AL8500. Sandia is operated by Sandia Corporation, a subsidiary of Lockheed Martin Corporation.

[1] For more information, or to suggest additional references, contact Gretchen B. Jordan at gbjorda@sandia.gov or 202-314-3040. Dr. Jordan is a principal member of the technical staff at Sandia National Laboratories, Albuquerque, New Mexico and Livermore, California. L. Devon Streit and J. Matiasek are with McNeil Technologies, Springfield, Virginia.

BIBLIOGRAPHY

J. W. Altschuld and H. Y. Zheng, "Assessing the Effectiveness of Research Organizations: An Examination of Multiple Approaches," Evaluation Review, vol. 19, 1995, pp. 197-216.

This review identifies key issues in evaluating effectiveness and provides insights on the application of major assessment approaches. It discusses the best methods for dealing with education and social science research organizations whose outputs are not tangible products but instead intellectual works. The approaches to assessing effectiveness that are examined include

- The goal-attainment approach—an organization is effective to the extent that it accomplishes its stated goals or missions. This approach includes the assumptions that specific goals are agreed upon and understood, goals are few in number, progress toward the goals is measurable, and the organization knows how to reach the goals and has the resources to do so. It is more appropriate in private organizations than in education or social science because goals must be clear and measurable and not vague.

- The strategic constituency/stakeholder approach—an organization needs to satisfy its stakeholders' demands for effectiveness. It is most appropriate in organizations where indicators such as cost-benefit ratios are not easily defined. The drawback is if stakeholders are not objective observers.

- The systems approach—an organization's effectiveness is based on its ability to acquire the resources it needs for survival and growth. New ideas and discoveries may not have a directly observable impact and research may not produce significant outcomes even after a long period of funding.

- The competing values framework—there cannot be a single, universally accepted model of organizational effectiveness therefore the framework integrates different approaches into a single perspective and provides guidance for recognizing value biases.

The authors state that using these approaches as well as understanding organizational focus, structure, and outcomes will aid in the choice of effectiveness criteria and evaluation strategies.

Auditor General of Canada, "Attributes of Well-Managed Research Organizations," 1999 Report of the Auditor General of Canada, chapter 23, 1999.

The Canadian Federal Government and the Auditor General of Canada have produced, over the last 10 years, a number of reports assessing the management and activities of Canadian science and technology organizations. This document draws on the information in these audits and reports as well as visits to several U.S. and Canadian R&D organizations in order to create a list of attributes that can be used to identify how well a research organization is being managed. The objectives of this study were to

- Inform the Canadian parliament about attributes of well-managed research organizations that can be used to assess the management of research activities in federal departments and agencies; and
- To provide guidance to federal research managers on ideal outcomes of good management, together with examples of practices followed by respected research organizations outside the federal system, to achieve the performance ideals described by the attributes.

The study team identified four key perspectives on organizational success. The ten attributes of well-managed organizations are divided between these four perspectives.

People Focus
- Management knows what research and other talent it needs to accomplish the mission and recruits, develops, and retains the right mix of people.
- Employees are passionate about their work, have confidence in management, and are proud of their organization.

Leadership
- The current and anticipated needs of dependent constituencies drive the organization and its research programs.
- Employees and dependent constituencies share management's vision, values, and goals.
- The portfolio of programs represents the right research, at the right time, and at the right investment.

Research Management
- Research projects embody excellent science, involve the right people, are on track, and within budget.
- Research projects leverage external resources.
- Organizational knowledge is systematically captured and turned into needed work tools.

Organizational Performance
- The organization is widely known and respected.
- The organization meets the needs of its dependent constituencies.

W. Bennis and P. W. Biederman, Organizing Genius: The Secrets of Creative Collaboration (Reading, MA: Addison-Wesley, 1997).

This book is part history, part how-to-manual, and part meditation on why a few groups rise to greatness while most flounder. The authors analyze six case studies of extraordinary achievements and tease out the crucial ingredients of groups that have been notably creative. By analyzing the histories of six Great Groups – from the Manhattan Project to the teams that developed today's personal computer – the authors uncover the secrets of collective genius. All Great Groups, they conclude, aim to do more than fix a problem; they're out to change the world.

Organizing Genius describes the free-form organization of such teams more interested in their mission than their hierarchy and discusses how Great Groups believe both that they're underdogs up against a powerful foe and that they're bound to succeed. It also illuminates the roles of a Great Group leader as a gatherer of talent, a source of inspiration, and a bridge to the outside world. Each Great Group had important lessons to contribute, some positive, some cautionary. The top fifteen lessons learned from Great Groups are that

- Greatness starts with superb people,
- Great Groups and great leaders create each other,
- Every Great Group has a strong leader,
- The leaders of Great Groups love talent and know where to find it,
- Great Groups are full of talented people who can work together,
- Great Groups think they are on a mission from God,
- Every Great Group is an island – but an island with a bridge to the mainland,
- Great Groups see themselves as winning underdogs,
- Great Groups always have an enemy,
- People in Great Groups have blinders on,
- Great Groups are optimistic, not realistic,
- In Great Groups the right person has the right job,
- The leaders of Great Groups give them what they need and free them from the rest,
- Great Groups shift, and
- Great work is its own reward.

C. J. Bland and M. T. Ruffin, "Characteristics of a Productive Research Environment," Academic Medicine, vol. 67, no. 6, 1992, pp. 385-397.

This source explored studies from 1960 to 1990 and found a set of characteristics which in the authors' assessment were consistently related to research productivity. The set includes

- Clear goals that serve as coordinating mechanisms,
- Research emphasis,
- Distinctive culture,
- Positive group climate,
- Assertive participative governance,
- Decentralized organization,
- Frequent communication,
- Accessible resources, particularly human ones,
- Sufficient size, age, and diversity in the research group,
- Appropriate rewards,
- Concentration on recruitment and selection,
- Leadership with research expertise and skill in initiating appropriate organizational structure, and using participatory management practices.

E. A. Brown, "Measuring Performance at the Army Research Laboratory: The Performance Evaluation Construct," The Journal of Technology Transfer, vol. 22, no. 2, 1997, pp. 21-26.

This article presents the Performance Evaluation Construct, a system for measuring progress toward meeting strategic and annual performance goals developed by the Army Research Laboratory (ARL) to comply with the Government Performance and Results Act of 1993 (GPRA).

The ARL Performance Evaluation Construct is a rational, logical, semi-quantitative methodology that allows assessment of the health of ARL's technical programs and functional operation. The Performance Evaluation assesses performance by answering three questions: Is the work relevant? Is the program productive? Is the work of the highest quality? Work quality is assessed through a peer review process conducted by a Technical Assessment Board. Program productivity and work relevance is assessed by customer evaluation. Feedback is obtained from surveys for the internal ARL customers, and from a Stakeholder Advisor Board for external customers. ARL uses metrics to indicate the functional health of the organization and as a tool to help steer the organization. Performance metrics for FY97 do not look at the environment, but do look at the outputs that reflect aspects of the environment when measured. These performance indicators reflect back on what is important in the environment: facilities and equipment, trained staff and a number of technicians per S&E, intellectual crossroads including guest researchers and cooperative R&D, indirect overhead, and a small purchase cycle time.

S. L. Brown and K. M. Eisenhardt, "Product Development: Past Research, Present Findings, and Future Directions," Academy of Management Review, vol. 20, 1995, pp. 343-378.

Brown and Eisenhardt state that innovation literature is growing into a diverse and fragmented body that includes an organization-oriented tradition of product development and an economics-oriented tradition of innovation development. The authors concentrate on the factors necessary for successful product development including effective product production, product marketing, and generation of financial gain. They organized the product development literature into three streams of research and created a model of factors that affect product development.

For their model, the authors identified factors that influence the success of the product development process. These factors include the

- Project leader,
- Senior management,
- Customers,
- Suppliers,
- Team composition,
- Team organization of work,
- Team group process,
- Product concept effectiveness,

- Process performance,
- Financial performance, and
- Market characteristics.

This model includes what the authors believe to be all the links between process performance, product effectiveness, and financial success. Many of the aspects of their model overlap with what is necessary for organizational effectiveness but they point out that product development requires different strategies than generation of innovation.

J.-T. Chiang, "Government Funding Strategy in Technology Programs," Technological Forecasting and Social Change, vol. 39, 1991, pp. 391-395.

Industrial R&D in a market economy is mainly implemented in the private sector, therefore public funding is a very important tool of government to guide private R&D activities. This paper investigates the experience of funding national programs in a number of industrialized countries and reaches some preliminary conclusions:

- To reduce opportunistic behavior and ingrain intrinsic incentive in firms, both competition and cost-sharing principles should be used concurrently in underwriting firms' R&D projects.
- Competition principles can be applied across many candidate projects around the same time or a series of one-of-a-kind projects over a longer time horizon.
- The major threat to application of competition principles is that there is not "real competition" due to few qualified candidates in specific technological fields or in some, especially small, countries.
- In practice, the appropriate cost-sharing level is difficult to determine. Fifty-fifty is used as a rule of thumb in many countries to simplify the decision making and circumvent "bounded rationality."
- Full cost endorsement may be another "quantum" alternative for projects urged by government but not felt to be very relevant by firms.

V. Chiesa, P. Coughlan, and C.A. Voss, "Development of a Technical Innovation Audit," Journal of Product Innovation Management, vol. 13, 1996, pp. 105-136.

In this article, Chiesa, Coughlan, and Voss present a framework to help organizations evaluate their innovative performance as well as identify ways to improve performance. The authors believe that it is necessary to focus not on indicators of input and output but on an explanation of how and why organizations arrive at their particular level of innovative performance. Their audit model measures performance in seven areas of innovation and allows organizations not only to identify their strengths and weaknesses but also to determine methods to improve innovation processes and capacity.

The framework that the authors developed for evaluating an organization's innovation processes includes five dimensions of performance:

- Resource availability and allocation,

- Understanding competitor's innovative strategies and industry evolution,
- Understanding the technological environment,
- Structural and cultural context, and
- Strategic management to deal with entrepreneurial behavior.

The first step the authors took was to create a model that can be used to improve innovative performance and enhance competitiveness. The model included seven processes that lead to innovation and competitive advantage. Central to the model are the interacting core processes of concept generation, product development, product innovation, and technology acquisition. These core processes are fed by enabling processes that include leadership, resources, and systems and tools.

The next step used the model to develop a comprehensive audit method that
- Assessed current practices and performance,
- Identified gaps between current and target performance, and
- Developed an action plan to close gaps.

The comprehensive audit method they developed includes a process and a performance audit that evaluates all the components and impacts of innovation. Their process audit focuses on the individual core and enabling processes by identifying if the organization has the appropriate processes in place and if the processes are being used effectively to enhance innovation. The authors developed a scorecard by reviewing the literature to isolate characteristics of each core and enabling process that indicated innovative success or failure. The scorecard shows an organization its strengths and weaknesses and the gap between actual performance and best practice.

For the performance audit, the authors developed a menu of metrics and indicators for each core and enabling process. These metrics and indicators allow the authors to measure the impact of the organization's overall performance and measure its performance in individual processes on its competitive capacity.

Through beta testing and case studies, the authors found that their innovation was functional, usable, and useful for
- Identifying both core and enabling processes relevant to innovation,
- Developing performance measures for each process of innovation,
- Allowing organizations to audit their innovation capability through measuring their overall innovation performance and the performance of each innovation process, and benchmarking their process against world-class practices, and
- Providing qualitative and quantitative measurement of the innovative process.

R. G. Cooper and E. J. Kleinschmidt, "Benchmarking the Firm's Critical Success Factors in New Product Development," Journal of Product Innovation Management, vol. 12, 1995, pp. 374-391.

In this study of 135 companies, the authors focus on company performance rather than project performance. They began with 10 performance measures that are factor-analyzed and divided into program profitability or program impact. They then identified four groups of companies – solid performers, low impact performers, high impact technical winners, and dogs. Finally, they determined what distinguishes the solid performers from the dogs. The drivers of performance are

- High quality new product process,
- Clear and well-communicated new product strategy,
- Adequate resources,
- Senior management commitment,
- Entrepreneurial climate,
- Senior management accountability,
- Strategic focus and synergy,
- High-quality development teams, and
- Cross functional teams.

P. F. Drucker, Innovation and Entrepreneurship: Practice and Principles (New York, NY: HarperBusiness, 1985).

This book presents innovation and entrepreneurship as purposeful and systematic disciplines that explain and analyze the challenges and opportunities of America's new entrepreneurial economy. It explains what established businesses and new ventures have to know, have to learn, and have to do in today's economy and marketplace.

Knowledge-based innovation has three requirements: careful analysis of all the necessary factors, clear focus on strategic position, and the ability to learn and to practice entrepreneurial management. Innovation inherently involves risks, yet integrating new knowledge as the source of innovation, and accepting the unexpected incongruities the process generates, can substantially reduce the risks. In these areas, receptivity has either already been established or can be tested fairly easily and with good reliability. Also in these areas the knowledge or knowledges that have to be produced to complete an innovation can usually be defined with considerable precision.

The principles of innovation, representing the hard core of the discipline are captured in a number of "do's"—things that have to be done. The "do's" include an analysis of the opportunities, being conceptual and perceptual, simple and focused, starting small, and aiming at leadership.

L. Ellis, Evaluation of R&D Processes: Effectiveness Through Measurements (Boston, MA: Artech House, 1997).

This book discusses linking certain R&D management practices to desired effects, outputs, and outcomes. It is intended to help managers select quantitative measurements to guide their actions rather than continuing to operate with only subjective indications of effectiveness.

Part I: General Aspects of R&D Process Evaluation

- There is some association between the perceived importance of metrics, satisfaction with their performance, and effectiveness, but it is not universally complete. Finding measures of effectiveness is a continuing, high-rated effort by innovation managers.
- The R&D manager must span the financial boundary and manage within the firm's financial culture.
- Boundary spanning by managers covers commercial and technological external areas. Evaluation of the commercial boundary as an outcome is measured by market share.
- The key task for managers is to manage the innovation process using evaluation metrics for the transition stages from idea to concept to delivery to the customer.
- The use of concurrent engineering involving crossfunctional teams from marketing through delivery to the customer seems to be the appropriate way to manage the innovation process.

Part II: Time to Market: Measurement and Management

- Timeliness of the innovation process needs to be addressed in terms specific enough for the R&D manager to make operating decisions.
- After times have been recorded, they should be further diagnosed and managed by reducing time, consolidating time, and measuring contribution.

Part III: R&D Process Evaluation Measurements

- Combinations of several metrics are needed for higher levels of outcomes. Two leading indicators of outcomes and outputs were determined to be interactions with other organizational units and input metrics.
- Internal R&D processes are actions taken within the principal organizational unit most responsible for innovation. A 1992 study ranked internal processes by importance and determined that they could be grouped under three headings: motivation of R&D staff, quality and performance, and planning and management. The most important evaluation measurements of internal processes were determined to be to measure the rewards in use, the degree of flatness of the internal organization, and the commitment of top and R&D management.

Part IV: External Evaluation of R&D
From the 1993, 1994, and 1995 studies, the authors formulated a list of best overall innovation precursor metrics for general use. They include measure upstream relations with the customer, measure crossfunctional participation, measure upstream relations with marketing, measure downstream relations with implementation chain departments, and measure management of internal processes and inputs.

A. Endres, Improving R&D Performance the Juran Way (New York, NY: John Wiley & Sons, 1997).

This book demonstrates how to plan, design, implement, and improve quality systems in order to enhance R&D's handling of issues ranging from improving customer satisfaction levels to improving innovative product development. The authors discuss how quality R&D is dependent on establishing cross-functional communication within an organization, building strong relationships between R&D employees and the rest of an organization, and strengthening the customer's role in the design and development process.

The author presents research done at Bell Laboratories. Bell examined the human resources side of quality to determine the impact that structural changes in the company had on employees' personal lives, professional skills, and expertise. Results of a survey Bell conducted to determine the attributes that made them a premier R&D organization showed that conflicts arose between personal goals and corporate goals when cost and scheduling pressures infringed on continuing education and self-development, career mobility and opportunities for advancement, and job security. Bell also determined that R&D organizations must not only align themselves with the needs of customers and business units, they must also maintain effective mechanisms for inter-group or organizational learning—especially on-the-job-learning in groups that contain a critical mass of stimulating co-workers. A study conducted by GE to determine variables that could be used to measure, predict, and control the likelihood of success of proposed or existing research projects also emphasized the need to organize interdisciplinary expertise or cross-functional teams.

Bell determined that in order to improve the creative and innovative process, research efforts must be organized around a series of key competencies that include varied activities intended to spawn new competencies. Research should also be managed centrally and holistically with no reduction in commitment to basic research.

In summary, studies of leading R&D organizations show that organizations can increase the global competitiveness of their innovation efforts by pursuing continuous improvements and periodic process reengineering, inter-group learning and continuous education, and evaluations to measure results.

R. N. Foster, L. H. Linden, R.L. Whiteley, and A. M. Kantrow, "Improving the Return on R&D – II," Research Management, Mar-Apr 1985, pp. 13-22.

The authors present the results of a 64–company survey intended to identify high-return activities. The thirteen high-return activities they isolated are

- Identify customer needs,
- Professional personnel quality,
- Couple marketing to technical efforts,
- Identify projects,
- Identify technical possibilities,

- Demand outlook,
- Project staffing,
- Strategies of competitors,
- Couple manufacturing to technical efforts,
- Project planning,
- Identify limits,
- Project termination, and
- Characterize technology.

J. R. Hauser and F. Zettelmeyer, "Metrics to Evaluate R,D&E," Research–Technology Management, Jul-Aug 1997, pp. 32-38.

Metrics affect research decisions, research efforts, and the researchers themselves. From a review of the literature, interviews at ten research-intensive organizations, and formal mathematical analysis, the authors conclude that the best metrics depend upon the goals of the research, development and engineering activity as they vary from applied projects to competency-building programs to basic research explorations. A summary of the research findings and implications for research environments include

- Basic research explorations:
  - Research tourism encourages research spillovers that enhance long-term profitability.
  - Match R,D&E's incentives with those of the firm.
  - Don't reward people only for internal ideas.
- Programs to match or create core technological competence:
  - The choice of research program is critical.
  - Market-based outcome metrics should be used but given a small relative weight when choosing research programs.
  - However, after the program is chosen, R,D&E must encourage the right balance of cost metrics with scientific, engineering, and process effort metrics.
- Applied projects with or for business unit "customers:"
  - Good project decisions balance customer-driven and research-driven foci.
  - Subsidies can be used to adjust for short-termism, risk aversion, and narrow scope.
  - The value of an R&D project reflects investment contingencies.

★ J. R. Hauser, "Metrics to Value R&D: An Annotated Bibliography," Working Paper for ICRMOT, Mar 1996.

The International Center for Research on the Management of Technology sponsored a project to assess current R&D metrics. This included interviews with Chief Technical Officers, Chief Executive Officers, and researchers at 10 research-intensive international firms; a literature review; the development of formal mathematical theory; and empirical applications and tests of the theory. This working paper presents an annotated bibliography of 147 articles published between 1959 and 1996 in the R&D, marketing, and economics literature. Included are short descriptions of the authors' viewpoint and conclusions as well as direct quotes from the literature.

P. A. Herbig and J. E. Golden, "How to Keep that Innovation Spirit Alive," Technology Forecasting and Social Change, vol. 43, 1993, pp. 75-90.
In this article, Herbig and Golden examine which factors are responsible for the rise and fall of innovation hot spots and what is required to develop and maintain these hot spots. Some of the factors that they cite as essential to the growth and development of innovation include

- Association with prestigious, independent, technically-oriented educational institutions.
- Access to highways, airports, and good labor sources.
- Culture oriented toward hard-work, risk-taking, and entrepreneurial attitudes.
- Political environments that promote research and business ventures.
- Availability of funds and resources from private and government sources.

These and other factors also contribute to the maintenance of innovation hot spots. Specifically the authors mention that areas must have structural elements such as low cost of living, government support, and economic policies that are conducive to business. Another factor they believe is important to continuing innovation is a constant focus on advancements in the industry that lead to development of new ventures and technology. Innovation also requires facilities, laboratories, transportation, communication networks, government support and funding, and especially the ability to recruit, motivate, and reward human resources. A final requirement the authors include for maintaining and promoting innovation is time, patience, consistency, and persistence.

F. M. Hull, "Inventions from R&D: Organizational Designs for Efficient Research Performance," Sociology, vol. 2, 1988, pp. 393-415.

This paper suggests how industrial organizations can be designed to generate inventive ideas more efficiently. The principal argument is that the output of invention is more proportional to R&D input if organization design is 'organic.' The concept of organic design was first proposed by Burns and Stalker in 1961 as an alternative to 'mechanistic' or bureaucratic design which is often productive but non-adaptive. The authors strive to show that efficient performance is partly a function of the match between organization design and type of work performed.

Mechanistic-bureaucratic systems are best for

- Transforming a large quantity of similar qualities per unit of time,
- Stable situations where accurate forecasts can be made,
- Non-complex products, and mass production, and
- Large organization size.

Organic systems are best for

- Transforming a small number of qualitatively different qualities per unit time,
- Dynamic contexts where product definition is fluid,
- Complex product batches, and
- Small organization size.

The reasons that the organic system works include
- It allows for integration of innovation and production processes.
- R&D is more often located at the factory site, which facilitates interfunctional integration.
- Barriers are reduced so face-to-face communication is enhanced.
- It allows for adaptation and competition in rapidly changing markets.

The authors suggest there may be more than one best way to organize for innovation:
- For organizations performing non-complex work, organic design rules are unnecessary.
- For organizations performing large-scale, complex work a mixture of organic and mechanistic methods are needed to achieve both innovation and productivity.
- For organizations performing small-scale, complex work organic design is consistently associated with higher yields of inventions from R&D input.

★ J. Hurley, Organisation and Scientific Discovery (New York, NY: John Wiley & Sons, 1997).

This book addresses the question of how scientific research can be most effectively organized in order to best facilitate creativity and discovery in science. In this study, the author worked with 16 Nobel laureates, each completing two interviews and four questionnaires on the subject of organization. Drawing on his background in organizational psychology, the author interprets and explores the results to show how the chances of discovery can be increased, contributing to the quality of future scientific research. He proposes a model of the workings of research organizations and groups to guide experimental research, to test the theory, and to establish the parameters of organization in relation to discovery.

Organizations play a central role in facilitating or inhibiting discovery in science. The contribution to discovery in science of such organizational matters as the selection of scientists, their development and training, scientific leadership, and management and supervision are all explored in this book, along with important questions raised about the relationship between individual scientists and the laboratories in which they work. The author's list of factors in the research environment that are necessary for technical productivity and excellence include
- Exceptional scientific talent,
- Well trained and highly developed technicians,
- Well resourced laboratories,
- Advanced computer and library services,
- Good technical and other supports,

- Good supervision and leadership,
- Organization supports, facilitates and encourages unusual and imaginative work, with all the risks associated,
- Freedom and autonomy of scientist is respected, though some formal objectives are understood,
- Size and staffing allows cross disciplinary discussion,
- Need for differing methods of experimentation and training,
- Need to be free to think and experiment,
- Ability to take advantage of chance,
- Need to have the right colleagues within a project,
- Pressure from peers,
- Being able to choose what to work on,
- Working as part of a team, and
- Pressure from being supervised.

P.B. Joly and V. Mangematin, "Profile of Public Laboratories, Industrial Partnerships and Organisation of R&D: The Dynamics of Industrial Relationships in a Large Research Organisation," Research Policy, vol. 25, 1996, pp. 901-922.

Drawing on an empirical study of 20 laboratories in the plant breeding and biochemical industries, this paper presents a typology of public research laboratories that is based on three dimensions: scientific production and visibility, type of funding (public or private), and homogeneity of research themes. The authors use three modes of analysis (bibliometric tools to assess scientists' production, financial databases to analyze funding, and interviews to assess laboratories' degree of autonomy in determining research themes) to understand the logic and effects of relationships between public laboratories and industry.

Three types of public laboratories emerge. The first, called "research centres for profession," is composed essentially of laboratories with close ties with small and medium firms and industry associations. The second, called "designers of generic tools and methods," is oriented towards basic research themes of general interest to the industry as a whole. The third type, called "basic and specialised laboratories," strives to develop its academic and scientific visibility. Each type of laboratory has its own mode of justification, type of scientific and technological production, preferred industrial relationship logic, and favorite type of partner.

To obtain resources, researchers in each type of laboratory ally themselves with partners who may provide finances, biological materials, technical devices, industrial credibility, academic recognition, human resources, or justification of research usefulness. Thus, a laboratory's financing, its role in economic life, its relations with firms, and the nature of its scientific production are all related.

The authors identify three categories (logics) of relationships that laboratories have with private partners: proximity, market, and club. Laboratories form proximity relationships in order to supplement the research capacity of smaller partners. The research that is conducted is meant to test specific hypotheses and involves frequent communication. Market partnerships form when industrial firms select the most competent laboratory to solve a specific scientific problem. The expertise of both parties is required to complete the project. Club partnerships form in order to solve problems of general interest to manufacturing firms and industry associations and they often bring together several competing organizations.

★ W. Q. Judge, G. E. Fryxell, and R. S. Dooley, "The New Task of R&D Management: Creating Goal-Directed Communities for Innovation," California Management Review, vol. 39, no. 3, 1997, pp. 72-85.

This article presents a study that examines two fundamental questions. First, what kind of workplace cultures are conducive to creativity and innovation in an R&D unit? Second, how can managers create and maintain an innovative workplace culture? The study was based on multiple interviews conducted at eight publicly-held biotechnology firms located in the United States. For the firms in this study, the ability of management to create a sense of community in the workplace was the key to innovation. The authors identified four managerial practices that had a major influence on whether there was a goal-directed community atmosphere in the R&D unit:

- Balanced autonomy—a compromise between freedom to determine one's own agenda and the freedom to determine ways of approaching company-set agendas.
- Personalized recognition systems—monetary and nonmonetary rewards.
- Integrated sociotechnical systems—cohesive groups with reasonable goals and de-emphasized deadlines.
- Continuity of slack—continuous flow of actual or potential resources that allow for both internal and external changes.

The authors conclude that the four managerial practices interact to generate an organizational sub-culture that can best be described as a "goal-directed community" that is key to the innovation process. The study offers four actionable levers of change for R&D managers to consider:

- The better the balance between the operational autonomy of the researchers with the strategic autonomy of the managers, the more innovative the R&D unit.
- The more emphasis placed on personalized intrinsic rewards, the more innovative the R&D unit.
- The more integrated the sociotechnical system, the more innovative the R&D unit.
- The more continuous the slack resources, the more innovative the R&D unit.

In addition, the study provides a "north star" for management to focus its time and attention: the greater the level of goal-directed community achieved in the R&D unit, the more innovative it is.

★ R. M. Kanter, "When a Thousand Flowers Bloom: Structural, Collective, and Social Conditions for Innovation in Organizations," Research in Organizational Behavior, vol. 10, 1988, pp. 169-211.

In this article, the author uses her research, fieldwork, and literature review experience to argue that recognizing the conditions that stimulate innovation first require understanding the factors involved in the innovation development process. In her analysis, Kanter looked at individual researchers, organizational structure, and the social and legal environment.

Kanter indicates that four distinctive characteristics of the innovation process must be taken into account when trying to cultivate new ideas or improve current innovation processes. The innovation process is uncertain, knowledge-intensive, controversial, and it crosses boundaries. With these characteristics in mind, Kanter identified four main tasks that are important to follow the progression of an innovation:

- Idea generation and activation of the drivers of the innovation.
- Coalition building and acquisition of the power necessary to move the idea into reality.
- Idea realization and innovation production, turning the idea into a product, plan, or prototype that can be used.
- Transfer or diffusion, the commercialization of the product, the adoption of the idea.

Kanter links these four tasks to the individual characteristics, organizational structure, and external environments that will successfully generate and nurture a developing innovation.

V. Kumar, A. N. S. Persaud, and U. Kumar, "To Terminate or Not an Ongoing R&D Project: A Managerial Dilemma," IEEE Transactions on Engineering Management, vol. 43, 1996, pp. 273-284.

This empirical study attempts to develop a framework to assist managers in deciding whether to abandon an ongoing R&D innovation project at various stages of R&D. Success/failure variables were drawn from the literature and from formal discussions with five R&D managers. Eight variables were identified that could distinguish between the possible success or failure of a proposed innovation in the course of its development:

- Its relevance to the overall corporate goals and strategies or "corporate fit."
- The availability of the science and technology base on which it will depend.
- Its alignment with the interests of other groups in the organization.
- Potential applications of the innovation including uniqueness and superiority of project, size of potential market, product's price range, and responsiveness of the market to price changes.
- The extent to which the firm's resources in terms of physical assets, personnel, and finances are adequate to support the project.
- Development process efficiency is dependent on the relative availability of critical components, among other things.

- Effecting coupling of a project's commercial and technical aspects is critical for a project's success.
- The extent of marketing proficiency can be a critical factor in getting market approval for a project.

E. Mansfield, "Basic Research and Productivity Increase in Manufacturing," American Economic Review, vol. 70, 1980, pp. 863-873.

The author's results indicate that there is a statistically significant relationship between the amount of basic research carried out by an industry or firm and its rate of increase of total factor productivity, when expenditures on applied R&D are held constant.

★ B. R. Martin and J. E. F. Skea, "Academic Research Performance Indicators: An Assessment of the Possibilities," Science Policy Research Unit, University of Sussex, UK, April 1992.

The authors examine the results from a three-year project to explore the feasibility of constructing research performance indicators for science and engineering departments in British academic institutions. The overall objective is to establish what role, if any, such indicators might play in complementing conventional peer-review-based procedures for assessing university departments. The study identifies 14 factors affecting departmental research performance:

- Staff caliber,
- Funds,
- Time,
- Leadership,
- 'Atmosphere'/morale,
- Equipment and facilities,
- Interaction with teaching and access to bright students,
- Good age/career structure,
- Attitude and support of university management,
- Staff with similar interests/groups of 3-4 working well together,
- Institutional location,
- Hiring policy/good appointments,
- Department size, and
- Department history/previous reputation.

The top four factors (in order) are caliber of staff, time available for research, departmental 'atmosphere,' and funding.

The conclusions the authors reached include

- University assessments are here to stay.
- Peer review must remain central to the assessment of university research performance.
- It is best to use a range of performance indicators.

- All departments do not concentrate on similar objectives so a multidimensional set of profiles is needed to rank departments.
- The results of this study, that performance indicators should be included alongside peer review, are currently valid only for science and engineering departments.
- The appropriate unit of assessing university research may not be the department.
- More consideration needs to be given to the long-term effects of assessment exercises.

G. C. McLaughlin, Total Quality in Research and Development (Delray Beach, FL: St. Lucie Press, 1995).

The book provides the management methods and social and technological skills to achieve total quality. Total quality is achieved when there is an equal interaction between a management system that provided leadership, a social system that empowers people, and a technical system that provides for innovation and creativity. Each system is explored in detail, along with strategies for implementing total quality.

The author discusses a case study involving total quality at Corning's RD&E. In discussing the evolutionary approach, he states that early in the process (1983-85) simple successes won over employees. The total quality approach emphasized better equipment, more efficient procedures, and more concern for executing experiments in a controlled manner. That is, total quality emphasized a certain logic for how to successfully execute an experiment.

The author identifies several key elements of what he calls the change process. First, "total quality principles have given RD&E a dialogue (common language) with their customers." That is, the division no longer operates in isolation but rather addresses customer requirements as a way of doing business. Second, total quality has infused the organization with the desire to do scientific research using best practices. The definition of failure and mistakes has changed over time. Next, by implementing the "Innovation Process scientists and engineers can now use their technical skills faster and better with more cost efficiency." Finally, as a result of using total quality principles, employees continue to maintain a positive attitude and feel good about the suggestions they make. In essence, employees are shaping the bottom line and reshaping their organization for the future.

M. M. Menke, "Essentials of R&D Strategic Excellence," Research–Technology Management, Sep-Oct 1997, pp. 42-47.

This extensive benchmarking study provides data on the relevance, importance, frequency of use, and quality of execution of 45 best practices for making excellent R&D decisions. Quantitative analysis of the R&D decision-making behavior of 79 leading R&D organizations identified the following ten best practices as essential for R&D strategic excellence:

- Understand the drivers of industry change,
- Coordinate long-range business and R&D plans,

- Focus on end-customer needs,
- Agree on clear, measurable project goals,
- Use a formal development process,
- Use cross-functional teams,
- Coordinate development with commercialization,
- Determine, understand and measure end-customer needs,
- Refine projects with regular customer feedback, and
- Hire the best and maintain expertise.

★ R. Miller, "Applying Quality Practices to R&D," Research • Technology Management, Mar-Apr 1995, pp. 47-54.

The quality movement has found successive applications in manufacturing, marketing and new product engineering. This article focuses on whether quality approaches are applicable to R&D. The author argues that not only is the quality movement applicable to R&D, but it brings a new mindset to the task of effective management. A study of 45 international firms (17 from North America, 14 from Europe, and 14 from Japan) identified 10 practices that were used most often in managing for quality in R&D, and revealed that the penetration of quality practices in R&D is uneven.

Most common practices in managing for quality in R&D:

- Analysis of strategic vectors that R&D must serve,
- Competitive positioning in technology and product,
- Interfunctional project teams,
- Ex-post evaluation of projects,
- Participation of R&D in strategic planning,
- Internal and corporate client surveys,
- Meetings between researchers and clients,
- Periodic reviews of processes for product development,
- Cross-functional exploration teams, and
- Common databases and design methodologies.

A. J. Montana, "Quality in R&D – If It Isn't Perfect, Make It Better," Research • Technology Management, Jul-Aug 1992, pp. 38-41.

Montana suggests that quality management can be successfully implemented within an R&D environment through a formal planning process, an assessment of education and training needs, an emphasis on continuous improvement, and establishing a relationship between the R&D quality process and the corporate quality process.

The key elements for successful quality management within R&D include the commitment of top management, a challenging vision and supportive corporate culture, an emphasis on teamwork, a mindset that encourages prevention, an accurate definition of customer requirements, and a quantitative approach to problem solving.

The author lists six ways quality can be incorporated into R&D:
- Develop a vision statement for the R&D unit,
- Establish measurement criteria to monitor the success of the quality process,
- Optimize the R&D process,
- Use a total team approach with communication across functions,
- Use cross-functional teams to stimulate inventions and breakthroughs, and
- Identify the internal and external customers and identify their needs.

National Research Council, "World-Class Research and Development: Characteristics of an Army Research, Development, and Engineering Organization," (Washington, DC: National Academy Press, 1996).

This report defines the characteristics of a world-class research, development, and engineering (RD&E) organization and the associated metrics, which will then be used to assess the U.S. Army Natick Research, Development, and Engineering Center. The Natick Standing Committee identified 25 characteristics that fall under "five pillars" and are most relevant to an Army RD&E organization:
- Customer focus includes satisfaction, involvement, and market diversification.
- Resources and capabilities include personnel quality, budget, RD&E capabilities, skill and talents, use of external resources, important technologies, organizational climate, information technology, and facilities and infrastructure.
- Strategic vision includes alignment of vision and mission, anticipatory strategic planning, stakeholder buy-in, and leadership.
- Value creation includes proper portfolio, product performance, cycle time and responsiveness, and value of work in progress.
- Quality focus includes capacity for breakthroughs, continuous improvement, commitment to quality, structured processes, learning environment, and quality of research.

Metrics (tables 4-1 through 4-5) with qualitative descriptors for four levels of performance (poor, adequate, good, and excellent) of the 25 characteristics are the preferred means of determining the extent to which an RD&E organization has achieved world-class performance. This concept should be used as an internal focusing mechanism for achieving excellence rather than as an external mechanism for advertising the virtues of an organization.

R. R. Nelson, <u>The Sources of Economic Growth,</u> (Cambridge, MA: Harvard University Press, 1996).

This book brings together a collection of essays on economic growth, technical advance as the key driving force behind economic growth, and the social institutions that mold technical advance and in turn are modified as an essential part of the economic growth process. The essays present a picture of a strongly path-dependent economic growth process with strong interdependencies among variables, and with technical advance (itself an evolutionary process) being both the principal driver and the key catalyst in calling forth and supporting necessary investments.

The book also discusses the role of science in technical advance, including the role of knowledge in R&D efficiency, the link between science and invention (the case of the transistor), the role of American universities, and technical advance in industry. The last chapter of the book reports findings from an international study on a national innovation system.

Aspects of the research environment mentioned include

- The strength of the knowledge base or level of competency in the area of the person's research.
- The ability to decide the direction of one's research, including ability to move off of unpromising, less exciting research.
- Teamwork characterized by mutual stimulation and help, shared interests, ease of communication, differences in viewpoints and experience.
- Levels of uncertainty and learning.
- Is there enough competition to keep at cutting edge?
- Ability to assess customer needs, and links to upstream and downstream markets.

★ D.C. Pelz and F. M. Andrews, Scientists in Organizations: Productive Climates for Research and Development, (Ann Arbor MI: Institute for Social Research, University of Michigan 1976).

This book is one of the first major studies to examine the relationship between scientist's performance and laboratory organization. In 1958, questionnaires were administered to 144 scientist-professors in seven departments of a large midwestern university. The same was done in 1959 for 526 scientists and engineers at five industrial laboratories and in 1960 for 641 research personnel in five government laboratories.

The findings include

- Effective scientists were self-directed by their own ideas, and valued freedom. But at the same time they interacted vigorously with colleagues.
- Effective scientists did not limit their activities either to the world of "application" or "pure science" but maintained an interest in both.
- Effective scientists were not fully in agreement with their organization in terms of their interests; what they enjoyed did not always help them advance in the structure.
- Effective scientists tended to be motivated by the same kinds of things as their colleagues. At the same time, they differed from their colleagues in the styles and strategies with which they approached their work.
- In effective older groups, the members interacted vigorously and preferred each other as collaborators, yet they felt free to disagree on technical strategies.

Part II contains four articles that were added to the original text:

- Problem solvers vs. decision makers: Technical performance is a result of repetitive reinforcement between individual resourcefulness and environmental facilitation.
- Creative process and professional security: Organizations seeking innovation may face a 'security dilemma.' Creative activities may erode professional security, yet without security the individual is unlikely to utilize his creative potential.
- Time pressure: A sense of time pressure, within the bounds felt appropriate by the people involved, can enhance technical achievement.
- Supervisory practices: The authors found that human relations skills mattered little; among other conditions, innovation occurred under supervisors who knew technical details of their subordinates' work, could critically evaluate that work, and could influence work goals.

W. A. B. Purdon, "Increasing R&D Effectiveness: Researchers as Business People," Research • Technology Management, Jul-Aug 1996, pp. 48-56.

This paper outlines how R&D can foster business-oriented mind-sets that lead to innovative contributions to the corporate mission. Cross-functional Market Segment Teams focus on the business's key market segments and provide the vehicle for the necessary "right interactions" and dialogue within R&D and among the functions that lead to continued innovation.

Four points about business dynamics need to be made: stakeholders need to be satisfied, profitability stems from relative competitive position, maintaining a strong RCP requires generating and delivering new value faster than the competition, and being innovative in generating value faster than the competition requires "seamless," fluid, responsive, internal partnering.

"Right interactions" for R&D are defined as the following set of interactive processes that researchers should engage in

- Continuously develop mastery of their field.
- Nurture and evolve core competencies essential to advancing the value-adding process of the business.
- Know and understand emerging customer and end-user needs as the basis for creating new value.

The authors believe that superimposing the structural form of a "market segment team" will ensure that right interactions take place among functions at a level in the organization where there is a significant current knowledge of the fields of science/technology and market/customer/competitors.

Finally, while business structure change of some form and empowerment for right interactions are necessary, the achievement of increased R&D effectiveness is dependent on leadership being committed to that goal.

D. Ransley and J. Rogers, "A Consensus on Best R&D Practices," Research • Technology Management, Mar-Apr 1994, pp. 19-26.

This article examines the practices reported in studies by four respected consulting companies: SRI International (a study for the French government that included 200 companies and 360 research facilities), Arthur D. Little (extensive consulting experience), Meritus Consulting (benchmarking study of 15 companies), and Pugh-Roberts (experience and an extensive literature search). The authors believe that those R&D practices that are common among these studies are further validated and should have broad applicability. Looking for agreement in three or more of the studies, the authors found seven best R&D practices:

- Technology strategies—Strong alignment of the technology strategy with the corporate business strategy.
- Program selection and management—Link technology programs with business needs, which are aimed at satisfying customer requirements.
- Core strengths —Identify, nurture, and exploit core technologies.
- Effectiveness—How well the technology meets the business objectives.
- External awareness—Technology threats and opportunities must be monitored.
- Technology transfer—Management leads in establishing communication and trust across functions.
- Personnel—Recruiting, training, and career development are integrated into the long-term R&D strategy.

E. B. Roberts, "Managing Invention and Innovation: What We've Learned, " Research • Technology Management, vol. 31, no. 1, 1988, pp. 11-29.

This article discusses and summarizes the history of technological innovation and management including the complexity of effective integration of people, organizational processes, and plans. The author defines innovation as a combination of all the processes that lead to invention as well as all the stages of commercialization, application, and transfer of the invention. Some of the points he includes are

- Technological innovation is a multi-stage process, and effective management of each stage requires a different strategy.
- Effective innovation requires the collaboration of "critical role-players:" the idea generator, the entrepreneur, the program manager, the gatekeepers, and the sponsor.
- Group diversity influences technical performance by increasing productivity.
- Product development success rates are highest with marketing and R&D collaborations.
- "Market pull" leads to successful innovation more often than "technology push."
- Transfer of RD&E results can be improved by the use of procedural, human, and organizational "bridges."

- Innovation strategy and technological resource allocation should differ depending on the evolutionary stage of the primary technology.
- Comparing technical performance of a product line with competitors' products is a useful method for initiating technical planning.
- External technologies need to be linked with internal capabilities.
- Top management commitment is essential for institutionalizing the development of effective product and process innovations.

N. Rosenberg, Exploring the Black Box, (Cambridge, UK: Cambridge University Press, 1994).

The principal focus of the book is the process by which information, new and old, comes to be imbedded in new technologies. By examining the particular sequence of events and institutions within particular industries, one can extract insights into the process by which technological knowledge grows. Serious analysis of technological change cannot proceed without an acceptance that technological advance is the results of a host of factors, of which guidance from science is only one.

Aspects of the research environment mentioned include

- Interdisciplinary approach, with internal and external collaboration or interaction, and quality research,
- Whether the work extends, exploits, or disrupts existing science or technology paths/trajectories,
- Relationship of research to existing technologies,
- Mechanisms to ensure that valuable findings or methodologies will rapidly be transferred to other points on the science/technology interface,
- Organization by problem rather than discipline. Rewards for helping solve problems encountered in fields other than their own. Transfer of concepts, methodologies, or instrumentation from one discipline or specialty to another, and
- Close interactions and information exchange between researchers and production and marketing managers.

R. Szakonyi, "Measuring R&D Effectiveness I," Research • Technology Management, Mar-Apr 1994, pp. 27-32.

This article reviews the efforts that have been made over the last 30 years to measure R&D effectiveness and presents a new approach to measuring R&D effectiveness—an approach that overcomes major shortcomings of these past efforts.

The new approach focuses on what R&D managers intuitively know is important about quality of R&D and its contribution to the company's business. Ten R&D activities are measured by identifying the level at which an R&D department is operating for that activity. With this approach, R&D managers can identify which activities in which their department needs to improve and how it needs to improve.

The six levels of operation are

- Issue is not recognized,
- Initial efforts are made toward addressing issue,
- Right skills are in place,
- Appropriate methods are used,
- Responsibilities are clarified, and
- Continuous improvement is underway.

The ten activities involving R&D effectiveness that the author identifies are consistent with the ideas that have existed for over 30 years:

- Select R&D,
- Plan and manage projects,
- Generate new product ideas,
- Maintain quality of the R&D process and methods,
- Motivate technical people,
- Establish cross-disciplinary teams,
- Coordinate R&D and marketing,
- Transfer technology to manufacturing,
- Foster collaboration between R&D and finance, and
- Link R&D to business planning.

The three benefits of this framework:

- Although one must make a qualitative judgement about how effectively an R&D department operates concerning a particular activity, the evaluator need only ask if something exists or is in place.
- Because there is a logical succession underlying the rankings, and because clear distinctions are made between the rankings, this system is more credible than one in which an evaluator is asked to judge the effectiveness of an R&D department.
- The author was able to establish a benchmark system for each of the ten activities (presented in Part II of this article).

R. Szakonyi, "Measuring R&D Effectiveness II," Research • Technology Management, May-Jun 1994, pp. 44-55.

In this article the six levels that were identified and used in part I to measure operation in ten R&D activities are each scored from 1 to 5. These scores are used to derive benchmark scores so that R&D departments can measure themselves against the author's "average" for each activity and identify which activities their department needs to improve.

The author's "average" department operates at various levels depending upon the activity. It operates best when selecting R&D and planning and managing projects but worst when long-range planning and fostering collaboration between R&D and finance.

J. W. Tipping, E. Zeffren, and A. R. Fusfeld, "Assessing the Value of Your Technology," Research · Technology Management, Sep-Oct 1995, pp. 22-39.

A Technology Value Pyramid (TVP) with a menu of 33 metrics was derived from almost two years of discussion and debate within Industrial Research Institute's Research on Research subcommittee.

R&D's role in the innovation process can be meaningfully represented by a hierarchy of managerial factors (The Technology Value Pyramid; TVP) that provide the foundations, links to strategy, and financial outcomes for the corporation. The recognition of these TVP factors, together with an assembled menu of metrics, allows the model to be used to track the contribution to innovation performance at different levels of the TVP. The TVP model can be used to track the performance both prospectively and retrospectively, to diagnose weaknesses in the R&D organization, and to plan for improvement in R&D contribution to the corporation.

The five factors of the TVP are divided into foundations, strategy, and outcome.

The foundations of the pyramid are

- Practice of R&D processes to support innovation (PRD)—The efficiency and effectiveness of R&D processes in producing useful output for the firm. The processes include project management practices, idea generation, communication, and other "best practices" in managing R&D.
- Asset value of technology (AVT)—The strength and vitality of the firm's technology (e.g., proprietary assets, know-how, people, etc.) foreshadows the potential of the R&D organization to create value for the firm.

The strategy level contains

- Integration with business (IWB)—The degree of integration with business, the commitment of the business to the R&D processes and programs, teamwork, and ability to exploit technology across the organization.
- Portfolio assessment (PA)—The total R&D program arrayed across various dimensions of interest, including time horizon, level of risk, core competency, exploitation, and new and old business. This allows optimization of the total program for the corporation's benefit.

The outcomes level includes

- Value creation (VC), which demonstrates the value of R&D activities to the positioning, profitability, and growth of the corporation and to the creation of shareholder value.

The menu of 33 TVP metrics (as of 1995) follow. They vary by industry type, vary within industry by firm's competitive strategy, and can be interpreted differently by stage of R&D.

Financial return (VC)	Quality of personnel (AVT, PRD)
Projected value of R&D pipeline (VC, PA)	Development cycle time (AVT, PRD)
Comparative manufacturing cost (VC, AVT)	Customer rating of technical capability (AVT)
Product quality and reliability (VC, AVT)	Number and quality of patents (AVT, PRD)
Gross profit margin (VC, AVT)	Sales protected by proprietary position (AVT, VC)
Market share (VC, AVT)	Peer evaluation (AVT, PRD)
Strategic alignment (PA, IWB, AVT)	Customer satisfaction (AVT, PRD)
Distribution of technology investment (PA, AVT)	Development pipeline milestones achieved (PRD)
Number of ways technology is exploited (PA, AVT)	Customer contact time (PRD)
Number of project definitions having business/marketing approval (IWB)	Preservation of technical output (PRD)
Use of project milestone system (PRD, IWB)	Efficiency of internal technical processes (PA, PRD)
Percent funding by the business (IWB)	Employee morale (PRD)
Technology transfer to manufacturing (IWB, PRD)	Goal clarity (PRD)
Use of cross-functional teams (IWB, PRD)	Project ownership/empowerment (PRD)
Rating of product technology benefits (AVT, VC)	Management support (PRD)
Response time to competitive markets (AVT, PRD)	Project championship (PRD)
Current investment in technology (AVT)	

T. Turpin and A. Deville, "Occupational Roles and Expectations of Research Scientists and Research Managers in Scientific Research Institutions," R&D Management, vol. 25, no. 2, 1995, pp. 141-157.

This article focuses on the changing occupational roles of research scientists and research managers in the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO), one of the world's largest multidisciplinary research organizations. Two critical occupational pathways are discussed: one between science and science management and another between science management and commercial management. Key points where the pathways diverge are identified and linked to broader issues of organizational culture and human resource management. The authors argue that research institutes such as the Australian CSIRO require a 'multicultural' management approach that horizontally integrates the industrial, scientific, and commercial domains of the organizations' research cultures.

An enduring focus of management literature is on what has been described as the 'dual career path' that confronts researchers in R&D organizations as they and their employers make and provide occupational choices to follow either management or professional scientist trajectories. The 'dual career path' perspective generally assumes that curiosity and creativity are important components of being a scientist and of scientific excellence, and that curiosity-driven research cannot easily be reconciled with the economic values inherent in formalized management structures, responsibilities, and demands. As science has become increasingly organized into institutions and geared increasingly to applications and outcomes, organizations have increasingly sought to harness the knowledge potential of curiosity-driven scientists. An important research management task has therefore been to find a balance between the creative drive that produces scientific knowledge and the economic imperatives of commercial markets.

★ F. E. Udwadia, "Creativity and Innovation in Organizations: Two Models and Managerial Implications," Technological Forecasting and Social Change, vol. 38, 1990, pp. 65-80.

Based on analysis of the literature (particularly Amabile, Von Glinow and Kerr, Pelz, and Andrews) this paper highlights creativity as the most critical element for the effective management of innovation and presents two models to further our understanding of the dynamics of creativity in organizational settings and the place of creativity in the innovation process.

Udwadia develops a Multiple Perspective Model for a comprehensive understanding of creative behavior and performance in organizations. This model includes three perspectives: the individual, the technical, and the organizational, which focus respectively on the distinctively individual characteristics associated with creativity, the needed technical resources – material as well as human – for creativity, and the organizational practices and managerial actions that aid or stifle creativity. On page 74, the author states "technological organizations need to engender environments that provide a delicate balance between giving the creative mind freedom to conduct its work while maintaining external constraints like goal setting and time-tables which are essential for the conduct of profitable business."

Individual characteristics that affect creativity:

- Cognitive abilities, including intelligence, knowledge, and thinking style.
- Personality disposition including perseverance, high energy, hard work, curiosity, sense of self as creative, autonomy, independence of judgement, risk-taking orientation, and intrinsic motivation.

Technical resources necessary for creative performance:

- Climate marked by cooperation and collaboration.
- A great deal of interaction and interdependence with colleagues, local and at large (Zuckerman study of 286 Nobel laureates found that nearly two-thirds were honored for work they did collaboratively).
- Colleagues are needed, as well as a task group and supporting staff with their own technical skills.
- Physical resources including technical equipment, facilities, and supplies.
- Information resources such as databases and library collections.
- Communication resources such as electronic mail, audio and video conferencing, computer conferencing, and document search and retrieval systems.
- Funding (NSF report noted that U.S. investment in R&D has been credited with making the U.S. a world leader in S&T).

Organizational factors that determine creativity:

- Keeping external constraints to a minimum.

- The scientist has primary responsibility to decide the problem to be attacked and the way of attacking it.
- A generally open environment where ideas can be discussed without fear of negative consequences such as pressure to alter one's course.
- Openness to shifts.
- Encouragement of new ideas and risk taking and suitable recognition and rewards system.
- Challenge serves as a stimulant as does occasional pressure.
- Availability of sufficient time—time to think creatively about the problem and explore different approaches.
- Good project management.

To manage creativity management must

- Be informed in and able to communicate about the technical aspects,
- Have a high levels of interpersonal skills,
- Constrain scientists to focus their energies on realistic and relevant goals,
- Have a flexible management attitude where change is seen as necessary, though anxiety-producing (e.g., companion of progress),
- Maintain a climate conducive to generation of novel ideas,
- Help translate deserving ideas across organizational boundaries,
- Create appropriate teams,
- Promote trust and respect,
- Provide supportive feedback, especially when ideas are rejected,
- Plan for the steadily increasing resource requirements demanded, and
- Overcome rivalries and politics.

H. Van de Ven and Y. Chu, "A Psychometric Assessment of the Minnesota Innovation Survey," Research on the Management of Innovations: The Minnesota Studies (New York, NY: Harper and Row, 1989).

This article outlines and explains the components and validity of an innovation questionnaire developed and used by the Minnesota Innovation Research Program (MIRP). This questionnaire is one of several measurement tools that MIRP uses to track the development, over time, of a wide variety of innovations. The core framework of the MIRP centers on five basic concepts: ideas, people, transactions, context, and outcomes. The research examines the innovation process by tracking development and implementation of new ideas that are carried by people who over time engage in transactions or relationships with others in a changing institutional context.

In the overall MIRP framework, the outcome or perceived innovation effectiveness is hypothesized to be a function of internal dimensions, external dimensions, and situational/contingency factors.

The internal dimensions include

- Uncertainty and difficulty of the innovation idea,
- Competence and influence of the people involved in the innovation,
- Internal transactions (i.e., standard procedures, communication, and conflict resolution), and
- Organizational context (i.e., organizational climate, rewards, and resource scarcity).

The external dimensions include both external transactions and environmental uncertainty.

- External transactions between research groups and outside influences include
  - The extent to which a group believes they are dependent on another group for resources,
  - The extent to which the terms of the relationship have been verbalized and written out,
  - The extent to which each group believes the relationship is equal, worthwhile, and satisfying, and
  - The degree to which each group perceives that they have changed or affected each other.
- Environmental uncertainty pertains to the stability of the technological, economic, demographic, and legal or regulatory environments in which the organization exists.

Situational or contingency factors are inherent to the innovation idea and include the novelty of the innovation, the innovation's scope and size, and the stage of development of the innovation.

Distribution:

1	MS9018	Central Technical Files, 8945-1
2	MS0899	Technical Library, 9616
1	MS0612	Review & Approval Desk, 9612 for DOE/OSTI