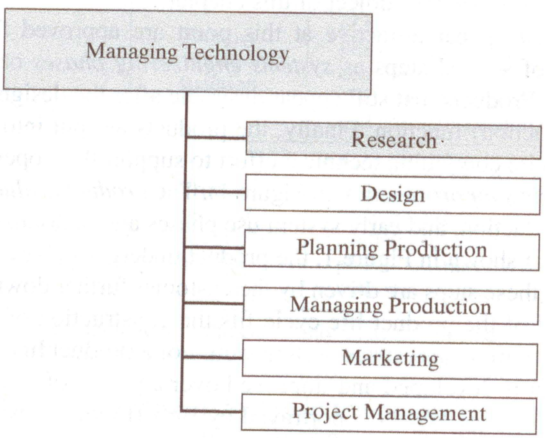
Managing Research and Development

PREVIEW

The four basic management functions are as follows: leading, planning, organizing, and controlling. The first topic under the management of technology is generally research and development (R&D)—examining new product strategies, organization for research, and the sequential process of winnowing the many ideas for product research and development to an affordable level, according to technical, market, and organizational considerations. Next follows a contributed section on the important topic of protecting ideas through patents, trade secrets, and other means. Finally, creativity, which is essential to effective research, is considered carefully.



From Chapter 9 of *Managing Engineering and Technology*, Sixth Edition. Lucy C. Morse, Daniel L. Babcock.
Copyright © 2014 by Pearson Education, Inc. All rights reserved.

LEARNING OBJECTIVES

When you have finished studying this chapter, you should be able to do the following:

- Explain product and technology life cycles.
- Describe the legal means to protect a person's ideas.
- Discuss the nature of creativity.

PRODUCT AND TECHNOLOGY LIFE CYCLES

A new product begins as an idea for the solution of a problem or the satisfaction of a need. In nature only a few out of a hundred tadpoles survive to become frogs; in research only a few out of many research ideas will be vigorous enough to survive and will reach the right environment to mature into a successful product. Like the buggy whip, our product will have its day and will then be replaced by newer ideas that satisfy newer needs. This cradle-to-grave sequence is known as the **product life cycle** (Figure 1).

This product life cycle begins with an *identification of need* or suggestion of a product opportunity, which might come from the customer, researchers, observation of a competitor, or fear of a potential enemy. The product idea must then be subjected to a screening process to select from the many ideas available that are technically and economically feasible. Then a program is proposed for their successful design and development. These preliminary steps (the *product planning and research* functions in Figure 1) are the subject of this chapter.

Proposed products that appear attractive at this point are approved for the *product design* function, itself a process of several steps as *systems engineering phases* or *engineering stages of new product development*. Products that still appear desirable after the design process then go to the *production* (and/or construction) function. Finally, the products are put into use, and if they are at all complex, they will require continuing technical effort to support their operation and maintenance (the *product use and logistic support* function in Figure 1). The *product evaluation* function is spread throughout the design, production, and early system use phases and is discussed under each of these topics. Finally, in a step not shown in Figure 1, the product undergoes phase-out, disposal, reclamation, and/or recycling. All these steps are driven by the customer further down the line.

The preceding model of the product life cycle fits the construction of a building or a ship or the design and development of an aerospace system well. For a product line (or family of products) based on a technology that is developed and improved over a period of years of product manufacture, the model of the *technology life cycle* portrayed by Betz (Figure 2) is more appropriate. Betz illustrates this model using the automobile as an example:

> When a new industry (based on new technology) is begun, there will come a point in time that one can mark as the inception point of the technology. In the case of the automobile, that was 1896, when Duryea made and sold those first 13 cars from the same design.

Product life cycle	Consumer	Identification of need	"Wants or desires" for products (because obvious deficiences/problems are made evident through basic research results)
	Producer	Product planning function	Marketing analysis; feasibility study; advanced product planning (product selection, specifications and plans, acquisition plan-research/design/production, evaluation plan, product use and logistic support plan); planning review; proposal
		Product research function	Basic research; applied research ("need" oriented); research methods; results of research; evolution from basic research to product design and development
		Product design function	Design requirements; conceptual design; preliminary system design; detailed design; design support; engineering model/prototype development; transition from design to production
		Production and/or construction function	Production and/or construction requirements; industrial engineering and operations analysis (plant engineering, manufacturing engineering, methods engineering, production control); quality control; production operations
		Product evaluation function	Evaluation requirements; categories of test and evaluation; test preparation phase (planning, resource requirements, etc.); formal test and evaluation; data collection, analysis, reporting, and corrective action; retesting
	Consumer*	Product use and logistic support function	Product distribution and operational use; elements of logistics and life cycle maintenance support; product evaluation; modifications, product phase-out; material disposal, reclamation, and/or recycling

*Some of the specific supporting functions indicated may be accomplished by the producer throughout and/or at various stages in the product life cycle.

Figure 1 Steps or functions and typical activities in the product life cycle. (From Benjamin S. Blanchard, *Engineering Organization and Management*, © 1976, p. 16. Reprinted by permission of Prentice-Hall, Inc., Englewood Cliffs, NJ.)

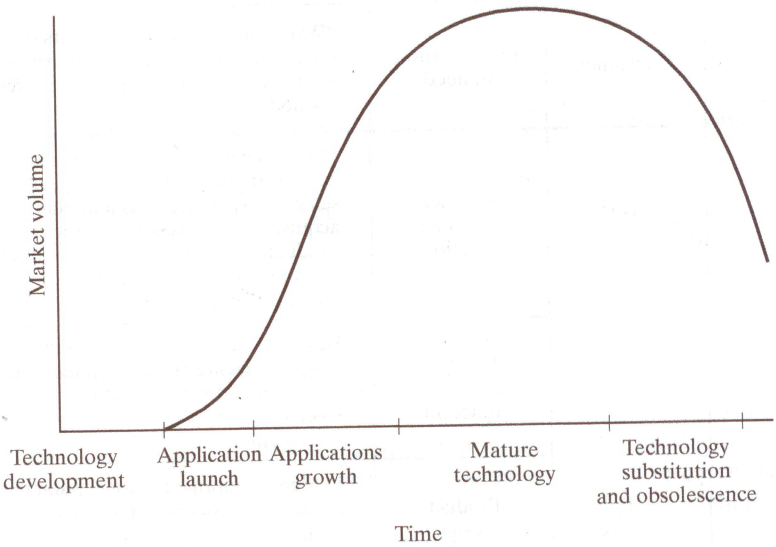


Figure 2 Technology life cycle. (From Frederick Betz, *Managing Technology: Competing Through New Ventures, Innovation, and Corporate Research*, 1987, pp. 72–74. Reprinted by permission of Prentice-Hall, Inc., Englewood Cliffs, NJ.)

> Then the first technological phase of the industry will be one of rapid development of the new technology—technology development. For the automobile this lasted from 1896 to 1902, as experiments in steam-, electric-, and gasoline-engine-powered vehicles were tried....
>
> In any new technology, the early new products are created in a wild variety of configurations and with differing features....Finally, when enough experimentation has occurred to map out the general boundaries of possibilities of the product line, some managerial genius usually puts all the best features together in one design and creates the model which then becomes the standard design for the industry. Thereafter all product models generally follow the standard design. This makes possible large market volume growth. For the automobile, this occurred [in 1908] with Ford's Model T design.
>
> After the applications launch, there occurs a rapid growth in the penetration of technology into markets (or in creating new markets). After some time, however, the innovation rate slows and market creation will peak. This is the phase of technology maturity. Finally,... when competing or substituting technologies emerge, the mature technology begins to degrade in competition with the competing technologies.

NATURE OF RESEARCH AND DEVELOPMENT

R&D Defined

Research and development are commonly lumped together under the catchall term "R&D." To distinguish between them, let us adopt the definitions commonly used by the National Science Foundation:

Research, both basic and applied, is systematic, intensive study directed toward fuller scientific knowledge of the subject studied.

Basic research is...research devoted to achieving a fuller knowledge or understanding, rather than a practical application, of the subject under study...[although when funded by commercial firms, it] may be in fields of present or potential interest to the company.

Applied research is directed toward the *practical application* of knowledge, which for industry means the discovery of *new* scientific knowledge that has specific commercial objectives with respect to either products or processes.

Development is the systematic *use* of scientific knowledge directed toward the production of useful materials, devices, systems, or methods, including design and development of prototypes and processes.

Distribution by Expenditure and Performance

U.S. investment in research and development amounted to approximately $397.0 billion in 2008, as itemized in Table 1. Basic (fundamental or pure) research of $69.1 billion, primarily paid for by the federal government, but performed at universities and industry under contract to the National Science Foundation and other government agencies. Few corporations can afford to invest much of their own funds in the search for fundamental knowledge for its own sake, since it would benefit competitors as much as themselves. Before the breakup of the Bell system and its near monopoly, Bell Telephone Laboratories was an exception, and much of the basic research underlying statistical quality control (for example) was performed there in the 1930s.

Applied research was $88.6 billion in 2008; industry funded over one half of this, but performed over two-thirds of it, funding the rest by federal contracts. Applied research may be divided into materials research, product research, and equipment and process research.

The nature of U.S. government spending for R&D has changed over the years with external military threats and internal political administrations. In 1980 about half of the $30 billion federal expense was for military purposes; by 1989 about two-thirds of the $62.5 billion federal R&D

Table 1 R&D Expenditures in 2008, Currently $ Billions

Source	Federal	Industry	University	Other Nonprofit
Expenditures				
Basic	39.4	12.2	10.2	7.5
Applied	28.6	53.8	3.2	2.9
Development	35.7	201.8	0.7	1.7

Source: National Science Board, 2010. *Science and Engineering Indicators 2010,* Arlington, VA: National Science Foundation (NSB 10-01).

Table 2 International Comparisons of R&D Expenditures as Percentage of Gross Domestic Product, 2009

Year	United States	Japan	Germany	France	United Kingdom	Canada	Russian Federation	China
2001	2.7	3.1	2.5	2.2	1.8	2.1	1.2	1
2006	2.6	3.4	2.5	2.1	1.8	1.9	1.1	1.4
2009	2.88	3.33	2.78	2.21	1.85	1.82 (2008)	1.12	1.7

Source: http://www.nsf.gov/statistics/nsf12321/content.cfm?pub_id=4185&id=2, April 2013

expense was military; considering inflation, federal investment in nondefense R&D had shown no significant increase over the "Reagan years."

Although R&D expenditures in the United States, Japan, and Germany had been comparable in the late 1980s as a percentage of gross domestic product (about 3 percent), in the United States about one-third of the total (and two-thirds of federal) R&D funding had been for military purposes, so that the United States spent less proportionately than these two major competitors on nonmilitary products for the global marketplace (about 3 percent of GDP for Japan, 2.7 percent for Germany, and 1.9 percent for the United States in 1990). Today, as shown in Table 2, the percentages remain much the same in 2001 and 2009. In the economic situation of 2012 federal budget cuts are predicted that would slash federal investment in science by an estimated 8.4 percent between now and 2017. Alan Leshner, chief executive officer of the American Association for the Advancement of Science, has stated that not only is this bad for science, but it is bad for the economy whose growth is driven by advances in science and technology.

RESEARCH STRATEGY AND ORGANIZATION

New Product Strategies

Within a specific industry, deciding the relative investment a company should make in R&D is a part of strategic planning and should be based on the organization's concept of its fundamental mission and objectives. Ansoff and Stewart suggest four alternative new product strategies:

> *First-to-market.* This...demands major expenditures for research before there is any guarantee of a successful product. It also demands heavy development expenditures and perhaps a large marketing effort to introduce an innovative product. The possibilities of reward from the R&D, however, are tremendous.

> *Follow-the-leader.* This strategy does not require a massive research effort, but it demands strong development engineering. As soon as a competitor is found to have had research success that

could lead to a product, the firm playing follow-the-leader joins the race and tries to introduce a product to market almost as soon as the innovator.

Me-too. A me-too strategy differs from follow-the-leader in that there is no research or development. In its purest form this strategy means copying designs from others, buying or leasing the necessary technology, and then concentrating on being the absolute minimum-cost producer. The firm following this strategy will try to maintain the lowest possible overhead expenses.

Application engineering. This role involves taking an established product and producing it in forms particularly well suited to customers' needs. It requires no research and little development, but a good deal of understanding of customers' needs and flexibility in production.

Corporate Research Organizations

Through the end of the nineteenth century, industrial support of research was unknown. The first corporate research laboratory in the United States began when General Electric Company observed that newer inventions were making its principal product, the carbon filament lamp, technically obsolete, and hired MIT Professor Willis R. Whitney to organize what became the GE R&D Center in 1900. Other early corporate research laboratories that were very successful were those of AT&T (Bell Labs), DuPont, Dow Chemical, and General Motors. Today, most large corporations consider corporate research at some level essential. Although some companies are extremely successful in creating profitable new products from research, others are not. Robert Frosch, in charge of the $200 million effort at General Motors Research Laboratories, recently identified three ways a corporate research laboratory could fail:

> Many research laboratories have been opened with great fanfare, only to fail later because they had the idea that producing great science, whether or not it had anything to do with the business, was why they were there. There *is* a role for the production of good science—provided you can eventually make it relevant to the business. But if a laboratory goes for a long period of time doing nothing relevant to the business, then it probably deserves to fail, because a corporation is not a university.
>
> The second reason laboratories fail is because of what can best be described as rampant short-termism. Financial support for business seems to come increasingly from markets and groups who regard two and a half weeks as an eternity and a quarter [year] as the age of the universe. So, sometimes research and development fail because nobody has enough patience to let them succeed.
>
> The third way in which research efforts fail is that the connection between research and development and the business breaks down. What is done in the research and development laboratories may be applicable to the business. The business may need these useful developments. But somehow the developments never get out of the laboratory and into the business. This is a failure of technology transfer.

Large corporations normally have two kinds of research activities: applied research staffs attached to each of the major business units, and a central laboratory with a broader scope of scientific expertise and a long-range outlook. In General Electric, for example, the central laboratory represents only about 10 percent of the research effort, but it plays an essential role. Central corporate laboratories also make their special expertise available to the business units to solve current problems, but they must be careful that this does not cripple their basic function.

SELECTING R&D PROJECTS

Need for Selection

Any successful technology-based manufacturing firm will have many more ideas for research projects than it has resources to invest in them. Booz, Allen, and Hamilton, Inc. has suggested approximately the following ratio of raw new product ideas to profitable products (also illustrated in Figure 3):

- Sixty ideas (from researchers, other employees, customers, and suppliers) need to be screened quickly down to
- Twelve ideas worthy of preliminary technical evaluation and analysis of profitability, to produce
- Six defined potential products worth further development, to obtain

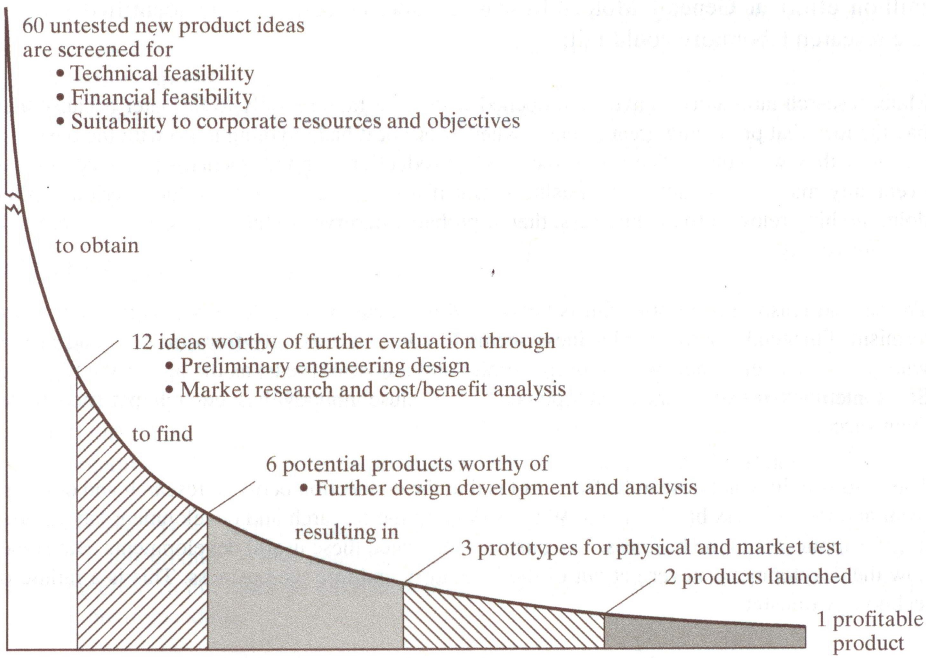


Figure 3 Screening of research project ideas.

- Three prototypes for detailed physical and market testing, resulting in
- Two products committed to full-scale production and marketing, of which
- One product should be a real market success.

Initial Screening

To slash 60 crude ideas into 12 worthy of any significant evaluation requires a method that is quick and inexpensive. A common method is use of a simple *checklist,* in which the proposed product is given a simple judgmental rating (poor/fair/good/excellent or $-2/-1/+1/+2$, for example) for each of a number of characteristics. Seiler suggests, for example, scoring 10 items:

1. *Technical factors* (availability of needed skills and facilities; probability of technical success)
2. *Research direction and balance* (compatibility with research goals and desired research balance)
3. *Timing* (of R&D and market development relative to the competition)
4. *Stability* (of the potential market to economic changes and difficulty of substitution)
5. *Position factor* (relative to other product lines and raw materials)
6. *Market growth factors* for the product
7. *Marketability* and compatibility with current marketing goals, distribution methods, and customer makeup
8. *Producibility* with current production facilities and manpower
9. *Financial factors* (expected investment need and rate of return from it)
10. *Patentability* and the need for continuing defensive research

Only slightly more sophisticated is the use of a *weighted checklist* or *scoring model* in which each factor is scored on a scale, often from 0.0 to 1.0. A relative *weight* representing the importance of that factor is then used as a multiplier, and the weighted scores for all factors are added. Table 3 provides an example of such a scoring model. In this example, a potential new product

Table 3 Example of a Weighted Scoring Model

PRODUCT CONCEPT EVALUATION SHEET

Criteria	Weight	Score	Weighted Score
Technical factors			
Compatibility with research objectives	1	9	9
Compatibility with production facilities and capabilities	2	8	16
Probability of technical success	2	9	18
Marketing factors			
Compatibility with marketing goals, distribution, customers	4	4	16
Probability of marketing success	4	2	8
Potential profitability	2	4	8
Totals		36	75

has been given a raw score of 36 (60 percent of the maximum 60) and a weighted score of 75 (only 50 percent of the maximum 150). The product was judged very favorably on technical factors and could be developed with some confidence of technical success. However, it was rated poorly on its marketing factors (which had been assigned greater weight in the model) and therefore probably would not be developed.

Quantitative Approaches

Once the large number of ideas for research projects has been screened to a more manageable number, the remaining proposals justify more detailed consideration of their technical and financial merits. The technical evaluation can take place in several stages increasing in depth and detail (such as the conceptual, technical feasibility, development, and commercial validation stages of new product development), with a decision point at the end of each phase. Hand in hand with evolution of the technology should come an increasingly detailed analysis of costs of producing the proposed product and market estimates of potential sales and profits.

Many mathematical models have been proposed for evaluating the financial suitability of proposed projects (see, for example, Balderston et al., Dhillon, and Shannon). Typically, they involve estimating the relationship between the investment required and the benefits to be gained. Easiest to calculate is the **simple payback time** T_{pb}, which is the ratio of required investment I and mean annual gross profit A:

$$\boxed{T_{pb} = \frac{I}{A}} \tag{1}$$

Simple payback time is often used to justify investments that need to be recovered quickly because of uncertainties, but it is unsuitable for longer-term investments because it ignores profits expected beyond the point of payback and does not consider the time value of money (the fact that a dollar profit returned at some future time has less value than a dollar available today). Many engineers learn these valuable methods of justifying investment in a new project or purchase of new equipment in a course in engineering economy and return to tell their teachers that it was one of the most useful, practical courses they took in college. Using the standard engineering economy nomenclature for **time value of money**, consider the following:

P = present worth of future cash flow
A_j = cash flow (revenue less expense) in the j^{th} year
i = discount rate (minimum attractive rate of return) required by the organization to justify investment, expressed as a decimal
n = number of years of future cash flow

Any sum P today, placed at an (annually compounded) interest i would compound to $A_1 = P(1 + i)$ in one year, $A_2 = P(1 + i)^2$ in two years, and $A_j = P(1 + i)^j$ in j years. Therefore, the present worth of any future sum A_j can be calculated as

$$\boxed{P = \frac{A_j}{(1 + i)^j}} \tag{2}$$

MAKING R&D ORGANIZATIONS SUCCESSFUL

Three topics are treated herein: the relation of R&D strategy to business strategy, evaluating the effectiveness of R&D (both at the organizational and individual levels), and providing effective support for researchers.

R&D and Business Strategy

In the technology-driven organization, a carefully planned technology strategy must be thought through to support the overall strategy of the enterprise. This strategy should encompass research, product and process development, and manufacturing engineering. Erickson et al. identify *three broad classes of technologies* a typical firm must consider:

- *Base technologies*. These are the technologies that a firm must master to be an effective competitor in its chosen product-market mix. They are necessary, but not sufficient.... The trick for R&D management is to invest enough—but only enough—to maintain competence in these technologies.
- *Key technologies*. These technologies provide competitive advantage. They may permit the producer to embed differentiating features or functions in the product or to attain greater efficiencies in the production process.
- *Pacing technologies*. These technologies could become tomorrow's key technologies. Not every participant in an industry can afford to invest in pacing technologies; this is typically what differentiates the leaders (who do) from the followers (who do not). The critical issue in technology management is balancing support of key technologies to sustain current competitive position and support of pacing technologies to create future vitality.

Evaluating R&D Effectiveness

Organizational Effectiveness. Balderston et al. suggest the following 11 criteria for business enterprise R&D:

1. Ratio of research costs to profits
2. Percentage of total earnings due to new products
3. Share of market due to new products (usually computed as the volume of sales from a firm's new products in a specific product market to the total sales available from that market, which confounds the measure by including marketing proficiency as well)
4. Research costs related to increases in sales
5. Research costs to ratio of new and old sales
6. Research costs per employee
7. Ratio of research costs to overhead expenses such as administrative and selling costs
8. Cash flows (continuing evaluation of the pattern of outflows for research expense and actual and projected inflows from resulting revenue)
9. Research audits, including indicators of administrative and technical objectives such as costs, time, completion dates, probability of technical success, probability of commercial success, expected market share, expected profits, expected return on investment, design, and development. Blake provides a checklist of questions to ask in such an audit.
10. Weighted averages of costs and objectives (a measure of the extent the average R&D dollar contributed toward objectives with weights on a scale, such as 0.0 equals *project badly missed objectives* to 3.0 equals *project far exceeded objectives*)
11. Project profiles (a more complex weighted scoring of each project, using criteria such as those in the research audits, item 9).

A number of these measures (such as items 1, 4, and 5) are obscured by the lag between research expenditures and the sales and profits that result from them, as well as the contribution of production and marketing to sales and profits. Others (items 6 and 7) are measures of the intensity

Table 4 Patents Granted by the U.S. Patent Office, 2009

Rank	Company Name	2009 Patents
1	INTERNATIONAL BUSINESS MACHINES CORP	4,914
2	SAMSUNG ELECTRONICS CO LTD KR	3,611
3	MICROSOFT CORP	2,906
4	CANON K K JP	2,206
5	PANASONIC CORP JP	1,829
6	TOSHIBA CORP JP	1,696
7	SONY CORP JP	1,680
8	INTEL CORP	1,537
9	SEIKO EPSON CORP JP	1,330
10	HEWLETT-PACKARD DEVELOPMENT COLP	1,273

Source: http://www.networkworld.com/news/2010/011210-patents-2009.html October 2012

of research expenditures rather than research effectiveness. The last three are more time-consuming and require subjective opinion, but they also may be more effective.

A measure of R&D effectiveness is the number of patents a company receives in a given year as shown in Table 4. The U.S. Patent and Trademark Office (USPTO) issued a total of 167,350 utility patents in 2009. **IBM** is in the top slot, as it has been for the previous 16 years, with 4,914 patents. **Samsung** is next at number 2 with 3,611 patents, followed by Microsoft at number 3, Canon at number 4, and Panasonic at number 5.

Another measure of R&D effectiveness is the Patent Scorecard, as shown in Table 5, which determines the strength of a university's patents as measured by how frequently they are cited in subsequent patents.

Individual Effectiveness. The effectiveness of individual researchers can be evaluated by the normal techniques of performance appraisal, especially management by objectives (MBO), emphasizing research goals. A few quantitative measures such as the number of patents and publications, and citations by others of those publications, give limited insight into research effectiveness.

Support for R&D

Quality supporting services need to be supplied to make the work of the highly trained scientist and engineer more efficient and productive. A few special types of assistance that are needed in research and engineering are listed as follows:

1. Technician support to carry out repetitive testing and other functions not requiring a graduate engineer or scientist
2. Shop support of mechanics, glassblowers, and carpenters to produce test and research equipment based on researchers' sketches

Table 5 University Patent Scorecard

Ranking & Movement			Universities	Technology Strength™		Industry Impact™		Science Linkage™		Innovation Cycle Time™		Patents Granted	
2009		2010	Includes subsidiaries and majority owned entities unless otherwise noted	2010	5-Year Average	2010	5-Year Average	2010	5-Year Average	2010	5-Year Average	2010	5-Year Average
1	◁▷	1	MIT/Mass Inst of Technology	304	259	1.73	1.81	26.73	24.77	10.6	9.6	176	143
2	◁▷	2	University of California	280	303	0.84	0.86	27.16	24.86	10.1	9.3	333	349
5	△	3	University of Texas	155	112	1.14	1.06	39.11	35.09	11.1	10.0	136	106
3	▽	4	Stanford University	142	141	1.06	1.29	19.25	18.96	9.8	8.5	134	111
4	▽	5	California Inst of Technology	138	160	1.28	1.45	34.88	25.91	11.0	9.2	108	110
12	△	6	Columbia University	101	56	1.51	0.98	45.12	30.35	9.3	8.1	67	57
6	▽	7	University of Wisconsin	95	82	0.71	0.84	14.84	16.91	9.6	8.4	134	99
20	△	8	University of Central Florida	95	54	1.28	1.43	5.73	4.60	11.6	9.0	74	37
16	△	9	University of Illinois	93	52	1.05	1.02	67.90	38.61	10.3	8.5	88	51
18	△	10	University of Southern California	83	45	1.36	1.06	28.08	17.88	10.5	8.5	61	42

The 2010 Universities Patent Scorecard™ has ranked 132 of the top universities according to the relative strengths of their patent portfolios as measured by Technology Strength™. The Patent Scorecard™ is based on data from July 2009 through June 2010 and provides an overall assessment of a university's recent intellectual property quality and quantity at a broad level. The Patent Board continues to evolve its indicators as they advance the importance of Intellectual Property as the New Asset Class.

Source: http://www.iptoday.com/issues/2010/09/the-patent-scorecard-2010-universities-.asp October 2012

3. A technical library with technical information specialists conversant in the fields of the company's interest and willing and able to suggest sources to researchers, and structure and run searches in the appropriate databases for them
4. Technical publication support, including typing, editing, and graphical support to simplify researchers' production of reports, technical papers, and presentations
5. A flexible, responsive system for approving and acquiring equipment as needed by researchers
6. Ample computer facilities conveniently available to researchers, and programming assistance to provide consultation and programming to those researchers not wishing to do it themselves
7. A strong internal commercialization process in place to take research to product

Protection of Ideas

By Dr. Donald D. Myers
Professor of Engineering Management
Missouri University of Science and Technology

Strategic planning for competition implies searching for means of capturing a sustainable advantage. R&D is conducted to develop and improve technological products and processes that provide the organization a competitive advantage. Likewise, development of organizational goodwill through marketing and other means is used to gain a competitive advantage. If these advantages can be readily duplicated by others, then there are often insufficient reasons for expending the initial resources for a short-term advantage. As the more advanced nations develop products and services that have high creative value-added content, it is vital to the economic well-being of the creative organizations (and countries) that there be some means of protection of these intellectual properties. Fortunately, there are means for protection of ideas in all industrialized nations.

There are generally four legal means to protect an organization's (or individual's) ideas and right to benefit from those ideas. They are patents, copyrights, trade secrets, and trademarks and other marks. This area of law is generally referred to as *intellectual property law*. Through the efforts of the World Trade Organization, intellectual property law is becoming more uniform across national boundaries, although it is important to recognize that there are still significant differences.

Each of the legal protection means is discussed in a subsequent section based on U.S. law. It should be noted that intellectual property law is the most dynamic area of law in terms of the number of precedential cases. Rapidly advancing technology has pushed the boundaries of legal precedents and principles. Accordingly, although the concepts presented here may appear to be noncontroversial, be assured that there have been major legal battles all the way to the U.S. Supreme Court over the interpretation of those concepts, and it is likely to continue as rapidly as new technology emerges.

Patents

A U.S. patent is an exclusive property right to an invention issued by the Commissioner of Patents and Trademarks, U.S. Department of Commerce. The rights granted are limited to the "claims" of the patent. There are three classifications of patents: (1) utility, (2) design, and (3) plant. A *utility* patent may be obtained by the inventor(s) for a process, machine, article of manufacture, composition of material, or any new and useful improvement. The life of the utility patent is, generally, 20 years from the date of application. Utility patents cannot be obtained on laws of nature, scientific principles, or printed matters.

To be patentable, the invention must be (1) new or novel, (2) useful or have utility, and (3) nonobvious. If the invention has been used, sold, or known by others in the United States or patented or disclosed in a printed publication in the United States or a foreign country before the invention was made by the inventor, a patent is barred. It is also barred if the invention was patented or described in a publication or in public use or on sale in the United States more than one year prior to the application for the patent. An applicant would also be barred if it was made before the date of the invention by others not concealing it. Useful inventions must advance the useful arts and benefit the public. The test of obviousness is whether it is obvious to those "with ordinary skill in the art involved."

A design patent is granted to the inventor on the new, original, and ornamental design of an article of manufacture for a term of 14 years from the date the design patent is granted. *In contrast to the* utility patent, the design patent is not concerned with how the article of manufacture was made and how it was constituted, but with how it looks. The design must be primarily ornamental rather than primarily functional to be valid. *Plant patents* are granted for 20 years from date of application for anyone who invents or discovers and asexually reproduces any distinct and new variety of plant, with the exception of tuber-propagated plants or plants found in the uncultivated state.

Establishing Patent Rights The invention process includes (1) conception and (2) reduction to practice. In the United States, if the first to conceive makes a reasonable, diligent effort to reduce the invention to practice, he or she will receive the patent, even if someone else actually reduces it to practice earlier. Accordingly, it has been essential for the American inventor to maintain good records to establish the date of conception and diligence in reduction to practice in case of any later interference. The filing of the patent application satisfies reduction to practice if, from the patent specification, one skilled in the art to which it relates is capable of constructing or carrying out the invention.

A written disclosure of the invention should be made as soon after conception as possible. There is no specific requirement about the form a written disclosure must take to document the conception of an invention. A disclosure's primary purpose is to prove the date of conception where there is question of invention. The disclosure should include sufficient description and sketches to describe fully what has been conceived. The disclosure should be witnessed by at least two persons who fully understand its content.

To demonstrate diligence to "reduce to practice," a written record of developmental activities should be maintained in a bound notebook. Daily entries are encouraged. Each page should be signed and witnessed in proximity to the entries on that page. Each entry should be made in chronological order. Notebook pages should be consecutively numbered, with all entries made in ink. If an error is made in an entry, it should not be erased; it should be crossed out. All entries should be made by the inventor in his own handwriting. Although it is permissible for an inventor to file his or her own application, it is strongly advised that a patent attorney or patent agent be used to make and prosecute the application.

In almost all other countries, patents are awarded to the first person to file, rather than the first to conceive. There continues to be considerable pressure for the United States to harmonize with other countries by awarding patents to the first person to file. However, Congress has not chosen to modify the existing patent law. Private inventors, small businesses, and universities are opposed to such a change. The 2005 Patent Reform Act included provisions to change the United States to a first-to-file country, but was not passed.

Just over half of U.S. utility patents have been awarded to Americans in recent years; the first 10 companies that were awarded the most U.S. patents in 2005 included six Japanese companies. The other four companies included IBM, first; Hewlett-Packard Development Company, third; Micron Technologies, Inc., sixth; and Intel Corporation, seventh.

Trademarks and Other Marks

The Lanham Act defines a mark as "any word, name, symbol, or device, or any combination thereof." The U.S. Patent and Trademark Office recognizes four types of marks: trademarks, service marks, certification marks, and collective marks. A trademark is "used by a manufacturer or merchant to identify his goods and distinguish them from those manufactured or sold by others." A trademark differs from a trade name. *Intel* may be both a trademark and a trade name, but only the trademark attached to a product is protected by federal statutes and registered with the Patent and Trademark Office. The potential of a sustainable competitive advantage of the mark for technological products is readily recognized by recalling Intel's strategic decision to distinguish its memory chip in PCs from competitors by implementing the "Intel Inside" mark.

A service mark is associated with services rather than goods. A *certification mark* indicates that the marked goods or services meet standards established by the mark's owner—for example, Good Housekeeping. A *collective mark* identifies members of a group such as an organization, union, or association.

The rights to a mark can be lost, especially if a mark is abandoned or allowed to become a generic word. To avoid losing a mark, vigilance must be exercised even to the point of suing infringers. Under the Trademark Law Revision Act of 1988, beginning November 16, 1989, application for a mark can be made before any use has taken place. Previously, a mark had to be used and products bearing the mark sold and shipped to a commercial customer before the mark could be registered. Now the applicant need only indicate a bona fide intent to use the mark within the next three years.

Almost all states have their own trademark law. If a mark is to be used entirely within one state, the only protection it has, other than common law, is registration under the state's trademark law. Federal trademark law applies only to marks used in interstate commerce.

A mark does not have to be registered, but the symbol "®" or the notice "Reg. U.S. Pat. and TM Off." should be used with registered trademarks and, "TM" or "Trademark" with nonregistered marks. For example, the first edition of a book was written on an IBM Personal Computer® using Volkswriter® word processing software for the initial drafts and Total Word™ for subsequent drafts; the second edition was written in Word Perfect® 5.1. A nonregistered mark has common-law rights. Official registration, however, provides distinct advantages.

Copyrights

A copyright is a bundle of rights to reproduce, derive, distribute, perform, and display an original creative work in a tangible form for the life of the author, plus 70 more years thereafter. Exceptions to this term include work for hire, where the copyright lasts for 120 years from the date of creation or 95 years from the year of first publication. Copyright owners can sue anyone who infringes on their rights to stop illegal reproduction; impound infringing articles; collect lost profits, court costs, and attorney's fees; and in extreme cases, invoke criminal penalties.

Copyrights can be given for literary works; musical works, including any accompanying music; dramatic works, including any accompanying music; pantomimes and choreographic works; pictorial, graphic, and sculptural works; motion pictures and other audiovisual works; sound recordings; and architectural works. A copyright protects expressions, not ideas. A potentially patentable idea expressed in a copyrighted text may be used by others.

As a result of the United States joining the Berne Convention in 1988, a copyright is secured automatically when the work is first created. The fundamental tenet of the Berne Convention is that the enjoyment of copyright protection shall not be subject to any formalities. However, there are distinct advantages in registration and imprinting proper notice on copies, such as the right to bring suit for domestic works (not required for international works), proof of copyright validity if registration is within five years of publication, rights to statutory damages, and rights to attorneys' fees and costs. A copyright notice has the following three elements: (1) the copyright symbol ©, the word "copyright," or the abbreviation "copr."; (2) the year of first publication; and (3) the name of the copyright owner. A copyright notice can appear anywhere in or on the work as long as it can be readily seen, but in a book such as this the notice is usually on the back of the title page. Copyright registration is not a condition for protection, but is a prerequisite for an infringement suit. Copyrighted material is registered with the copyright office at the Library of Congress, which requires one copy of unpublished work and two copies of published work, plus a $30.00 fee for the processing of registration forms.

There are a number of exceptions to the rights of a copyright. The most notable and highly publicized is the "fair use exception." One may, without permission, make a fair use of a copyrighted work for purposes such as criticism, comment, news reporting, teaching, scholarship, or research. Fair use is determined by consideration of such factors as the purpose of the use, the nature of the work, the amount and substantiality used, and market effect.

Trade Secrets

Trade secrets, or confidential technological and commercial information, are the most important assets of many businesses. The law protects trade secrets as alternatives to patents and copyrights. Trade secrets have no precise definition, but to be protected by the courts, they must be secret, substantial, and valuable. The secret can be almost anything as long as it is not generally known in the trade or industry to which it applies. A trade secret provides its owner with a competitive advantage. It may be a formula, process, know-how, specifications, pricing information, customer lists, supply sources, merchandising methods, or other business information. It may or may not be protected by other means.

Unlike patents or copyrights, trade secrets have no time limitations and there is no registration with any government agency. A trade secret, however, has value only while it remains secret. For instance, a trade secret may lose its privileged status when it is ascertained through "reverse engineering" or when it is discovered independently. A trade secret revealed in these ways can be used without any obligation to the trade secret's originator or owner. If a trade secret is unlawfully obtained—for example, by breach of trust or violation of a confidential relationship—the courts could award the trade secret's owner compensation for damages incurred and forbid the infringer use and further disclosure of the trade secret.

It should be recognized that, although trade secrets have no direct cost in obtaining any property right, they in fact are generally expensive to establish adequate protection systems. These would include establishing security systems and confidentiality agreements, identifying confidential information with physical restrictions, limiting plant tours, making covenants not to compete, etc.

Comparison of Means of Protecting Ideas

Table 6 compares the various means of protecting ideas just discussed. Any innovator or author should be familiar with these options so that an intelligent decision can be made on the proper protection needed for each idea. Different options offer very different kinds of protection. For example, the Coca-Cola Company has elected to protect the ingredients, mixing, and brewing of its principal product, Coca-Cola, as trade secrets. This decision does not prevent another company that claims to have discovered these secrets from marketing a similar product. The trade-secret approach, however, protects the Coca-Cola Company's information for as long as it remains secret. Had the company patented these formulas, the knowledge would have been dedicated to the public 20 years after the patent application.

Many ideas that are protected as trade secrets cannot be patented. On the other hand, an item that is patentable can theoretically be protected as a trade secret. If the idea can be easily discovered through reverse engineering, however, a patent is the only practical choice for protection.

Computer software may be protected by copyright as literary works. It may be that a utility patent could be used to protect it. A utility patent protects the idea, whereas the copyright would only protect the expression. The distinction of what constitutes the idea and what constitutes the

Table 6 Comparison of Means of Protecting Ideas

Category	Utility Patents	Design Patents	Trademarks	Copyrights	Trade Secrets
Idea or subject matter	New and useful processes, machines, articles of manufacture, and compositions of matter	New ornamental designs for articles of manufacture	Words, names, symbols, or other devices that serve to distinguish goods or services	Writings, music, works of art, and the like that have been reduced to a tangible medium of expression	Almost anything that is secret, substantial, and valuable
Sources of protection	U.S. Patent and Trademark Office patent	U.S. Patent and Trademark Office patent	Registration with the U.S. Patent and Trademark Office	Federal law protects only a tangible medium of expression	Primarily common-law protection through courts
			Registration with the secretary of state	Enforceable only when registered with the copyright office	
			Common-law protection through courts as long as proper use continues		
Terms of protection	20 years from application filing date	14 years from issue date of patent	10 years from registration with federal office; renewable for additional 10-year terms	Life of author, plus 70 years	For as long as it remains a secret
Tests for infringement	Making, using, or selling invention described in patent claim	Making, using, or selling design shown in patent claim	Likelihood of confusion, mistake, or deception	Copying of protected subject matter	Taking of trade secret by breach of trust or violation of a confidential relationship

expression is one that is often decided by the courts. Recent practice has been to seek protection of software by utility patents to ensure the strongest protection.

Databases that consist of facts are not protectable by copyright. That leaves only the means of trade secret. However, if the value of the database is in making it available to the public, it cannot be protected. The European Union provides protection for databases, and consideration is being given to a means of protection in the United States.

In theory, a design may be protected not only by a design patent but also a copyright under the category of pictorial, graphic, or sculptural works. However, the design of a useful article may be considered a pictorial, graphic, or sculptural work only if the design features can be identified separately from, and are capable of existing independently of, the utilitarian aspects of the article.

In summary, intellectual property law is a rapidly changing environment with many nuances. The engineering manager must understand the fundamentals sufficiently to be able to know when and how to interact with the legal experts. Failure to do so can be costly in terms of lost sustainable strategic competitive advantages.

CREATIVITY, INNOVATION, ENTREPRENEURSHIP

Nature of Creativity

Creativity is the ability to produce new and useful ideas through the combination of known principles and components in novel and nonobvious ways. Another definition for creativity given by Lumsdaine is "playing with imagination and possibilities, leading to new and meaningful connections and outcomes while interacting with ideas, people, and the environment." Creativity exists throughout the population, largely independent of age, sex, and education. Yet in any group a few individuals will display creativity completely out of proportion to their number. To have an effective research organization requires understanding the creative process, identifying and acquiring creative people, and maintaining an environment that supports rather than inhibits creativity.

The Creative Process

There are a number of models for problem solving. One method, often inefficient, is simple trial and error. A second is the planning/decision-making process, which involves problem definition, identification of alternatives, and evaluating alternatives against objectives. Its major thrust is analytical reasoning, although its success is enhanced by some creativity in selection of alternatives to be evaluated. The creative process uses some of the same steps, but it emphasizes the insight that can occur subconsciously when a perplexing problem is not resolved through the analytical process and is temporarily set aside. Following are the steps usually identified in describing this process.

1. *Preparation.* Shannon describes this step as "a period of conscious, direct, mental effort devoted to the accumulation of information pertinent to the problem.... Quite often the problem is solved at this stage as one submerges oneself in the problem while trying to (a) structure the problem, (b) collect all available information, (c) understand relations and effects, (d) solve subproblems, and (e) explore all possible solutions and combinations that may lead to a satisfactory solution."
2. *Frustration and incubation.* Failure to solve the problem satisfactorily by the analytical process leads to frustration and the decision to set it aside and get on with something else. However, the problem, fortified with all the facts gathered about it, "stews" or incubates in the subconscious mind.
3. *Inspiration or illumination.* A possible solution to the problem may occur as a spontaneous insight, often when the conscious mind is at rest during relaxation or sleep. Many creative individuals are never without a notepad and pen on their person or bedside table, to write down these flashes of insight.
4. *Verification.* Intuition or insight is not always correct, and the solution revealed in a flash of insight must now be tested and evaluated to assure it is, indeed, a satisfactory solution to the problem.

Shannon defends this model:

> How do we know this process is true? Because thousands of creative people have described exactly this process when discussing their work. Over and over again we see this interplay between the conscious and the subconscious. For creative work we have this wondrously competent coupling where each part (conscious and subconscious) is indispensable in its own way, but each is helpless without the other. When applied to problem solving, the human mind has two aspects: (1) a judicial, logical, conscious mind that analyzes, compares, and chooses; and (2) an imaginative, creative, subconscious mind that visualizes, foresees, and generates ideas from stored knowledge and experience.

Brainstorming and Other Techniques for Creativity

Dhillon describes eight creativity techniques designed for one, two, or up to a dozen people. Best known is *brainstorming,* a modern method for "organized ideation" first employed in the West by Alex Osborne in 1938, although he reports that a similar procedure had "been used in India for more than 400 years as part of the technique of Hindu teachers" under the name *Prai-Barshana,* literally "outside yourself-question." The essence of brainstorming is a creative conference, ideally of 8 to 12 people meeting for less than an hour to develop a long list of 50 or more ideas. Suggestions are listed without criticism on a whiteboard or newsprint as they are offered; one visible idea leads to others. At the end of this session participants are asked how the ideas could be combined or improved. Organizing, weeding, and prioritizing the ideas produced is a separate, subsequent step.

The preceding description is of unstructured brainstorming. For a more structured brainstorming, the Nominal Group Technique is used. In this case, the problem is presented and participants write down their ideas quietly for a short period of time (5 to 10 minutes). Then each participant in an organized manner with no repetitions presents one idea at a time. When one pass is finished, another is begun until all the ideas are presented. Then the process continues as with the unstructured brainstorming. The advantage of this process is that everyone participates, and the quiet time often leads to ideas that otherwise would not have been considered.

Dhillon next lists two brainstorming techniques that can be used by two people. In one, known as the *tear-down* approach, the first person (person A) must disagree with the existing solution to a problem and suggest another approach; next, person B must disagree with both ideas and suggest a third; then person A must suggest yet another solution; this cycle continues until a useful idea clicks. In a variant, known as the *and-also* method, person A suggests an improvement on the subject under study; person B agrees, but suggests a further improvement; this sequential improvement continues until a sound solution is reached.

In a somewhat different group technique developed by W. J. Gordon, a team explores the underlying concept of the problem. For example, if a new can opener is desired the team would first discuss…the meanings of the word opening and examples of opening in life things. The method encourages finding unusual approaches by preventing early closure on the problem. Gordon used a team of six meeting for about a day on a problem.

Dhillon describes two approaches in which individuals are given a description of a problem and required to list solutions in advance of group effort. In the simpler method, each participant has to have a certain number of solution ideas, say 17, to the problem before he is allowed to attend the meeting. In a more complex version known as the collective notebook method each member of a team is given a notebook with a problem statement and supporting material a month in advance. Each day during that month, the team member writes one or more ideas in the notebook, and at the end of the month selects the best idea along with suggestions for further exploration. A problem coordinator collects and studies notebooks and prepares a detailed summary for distribution; if necessary, all team members then participate in a final meeting.

Finally, Dhillon includes two methods that individuals may use. In an *attribute-listing* approach, a person lists attributes of an idea or item, then concentrates on one attribute at a time to make improvements in the original idea or item. The other method tries to generate new ideas by creating a forced relationship between two or more usually unrelated ideas or items. For example, an office equipment manufacturer might consider the relationship between a chair and a desk, start up a line of free associations, and end up with a combined unit consisting of both desk and chair.

Mindmapping combines aspects of brainstorming, sketching, and diagramming. A mindmap consists of a central word or concept with 5 to 10 main ideas that relate to that word, similar to creating a spiderweb. Tony Buzan, a British researcher, invented mindmaps in the 1970s, and they can be applied to a variety of situations including note taking, creative and report writing, studying, meetings, and think tanks. A procedure adapted from Lumsdaine for drawing a mindmap follows:

1. Start your mindmap (in a team or individually) by writing the main topic in the center of a large piece of blank paper.
2. Think about what main factors, ideas, concepts, or components are directly related to your topic. Write down the most important factors as main branches off the central concept. Connect them to the main topic.

3. Now concentrate on one of these headings or main ideas. Identify the factors or issues related to this particular idea. Additional branches and details can be added if needed. Use key words, not phrases, if at all possible, to keep the map uncluttered.
4. Repeat the process for each of the main ideas. During this process, associations and ideas will not always come to mind in an orderly arrangement—soon you will be making extensions all over the mindmap. Continue the process for at least 10 minutes until you can no longer add ideas to the map.
5. Next comes the organization and analysis phase of mindmapping. Connect the related ideas and concepts. Review, annotate, organize, and revise. Edit and redraw the mindmap until you are satisfied with the logic of the relationships among all the ideas.
6. Finally, you are ready to begin writing. The time spent thinking up and organizing the mindmap will make the writing task easier. The result will be a well-organized and well-understood product.

Characteristics of Creative People

There have been many studies comparing more creative with less creative people. Characteristics of creative people can be grouped into the following categories:

Self-confidence and independence. Creative people seem to be self-confident, self-sufficient, emotionally stable, and able to tolerate ambiguity. They are independent in thought and action and tend to reduce group pressures for conformity and rules and regulations that do not make sense.

Curiosity. They have a drive for knowledge about how or why things work, are good observers with good memories, and build a broad knowledge about a wide range of subjects.

Approach to problems. Creative people are open-minded and uncritical in the early stages of problem solving, generating many ideas. They enjoy abstract thinking and employ method, precision, and exactness in their work. They concentrate intensively on problems that interest them and resent interruptions to their concentration.

Some personal attributes. Creative people may be more comfortable with things than people, have fewer close friends, and are not joiners. They have broad intellectual interests: They enjoy intellectual games, practical jokes, creative writing, and are almost always attracted by complexity.

Providing a Creative Environment

Creative people tend to be independent, nonconformist, and to work intensively for long periods, but with a disregard for conventional work hours. They are most effective in an organization that will tolerate idiosyncrasies, remove as much routine regulation and reporting as feasible, provide support personnel and equipment as required, and recognize and reward successes. People doing routine work and those doing creative work should be separated where possible. One of Babcock's students provided an example in a homework assignment (answering Discussion Question 13) from an earlier cooperative work assignment at a nuclear plant:

> In our group was a man who was quite an oddball. He didn't like people, phones, or anyone using the computer when he was. To work normal hours unnerved him, so he was allowed to come in anytime he wanted to. Many people would have taken advantage of this, but he worked *longer* [and] more productive hours. Sometimes he would work 5 P.M. until 7 A.M. nonstop. They put a computer in his home and hooked it to the mainframe at work for those sudden brainstorms—the results were great!

The prolific production of ideas in the early phases of problem solving is a hallmark of creativity. Engineer managers, therefore, must be especially careful to withhold criticism until its appropriate place—at the conclusion (verification) of the creative process.

Creative people value working on problems of interest to themselves and working on their own schedule. It is important to explain the problem and its importance fully, agree on a timetable, and stay in contact without close supervision as long as reasonable progress is made.

Creativity and Innovation

Invention (the creative process) only produces ideas. Ideas are not useful until they are reduced to practice and use, which is the process of innovation. Kidder provides an excellent study of motivation and creativity in the development of a 32-bit computer at Data General. Roberts and Wainer have identified five kinds of people who are needed for technological innovation:

> *Idea generator—the creative individual*
> *Entrepreneur—the person who carries the ball*
> *Gatekeeper—discussed below*
> *Program manager—the person who manages without inhibiting*
> *Sponsor or champion—the person, often in senior management, who provides financial and moral support*

Technological Gatekeepers in R&D Organizations

Allen and Cohen found that only about 15 percent of the scientific and technical ideas being worked on in industrial laboratories came directly from the scientific and technical literature—most of it reached lab members in a two-step process involving **gatekeepers**. These are research staff members who, through their professional work habits, bring essential information into the organization. Gatekeepers (1) are more likely to read the more sophisticated (refereed) journals, (2) are in contact with outside specialists, and (3) form a network with other gatekeepers. They often are high technical performers, usually produce more than their share of conference papers and refereed articles, and are likely to be promoted to first- and second-line supervision ahead of their peers. Gatekeepers are not appointed, but the wise research manager recognizes them and their function. Professional staff who are hired away from other organizations or who transfer in from other parts of a corporation provide another important source of new ideas and ways of doing things.

Entrepreneurship

It takes a special kind of person to lead the innovation task successfully—the entrepreneur is one who undertakes the effort to transform innovations into economic goods. Betz extends this:

> The entrepreneur is a kind of business hero; and like all heroes, they have qualities to be admired: initiative, daring, courage, commitment. These values are especially admired in turbulent business conditions, when initiative is required for survival.

While the initial concept of an entrepreneur is of a person who creates a new business for personal profit, established corporations need continuing entrepreneurial activity to create the new products and new businesses that will assure future growth of the organization; the term **intrapreneurship** has been coined to describe this activity. The challenge in managing technology is to provide a climate where intrapreneurs are encouraged to take risks, are given needed resources and time, and are permitted early failures, while shifting to closer control of resources and costs as products become mature.

Creativity is the ability to produce new and useful ideas and there are a number of techniques for creativity. The creative process only produces ideas and the ideas are not useful until they are reduced to practice and use. This is called innovation. Some ideas might lead to being an entrepreneur, some might lead to a patent, some might lead to both, and other ideas might fall by the wayside.

DISCUSSION QUESTIONS

1. Contrast the application of Blanchard's product life cycle with that of Betz's technology life cycle.
2. Would the same kind of leader be suitable throughout Betz's technology life cycle? If not, what kind of leader would be effective in each portion of it?
3. Summarize the principal contributions to U.S. R&D activity by each of (**a**) the federal government; (**b**) industry; and (**c**) universities.
4. In an industry with which you are familiar, give an example of one or more firms that appear to have chosen each of Ansoff and Stewart's new product strategies.
5. Discuss the relationship between the central corporate research laboratory and divisional research in a corporation you know or have found described in the literature.
6. Why are simple checklists used as a first screening of ideas in research projects by many companies?
7. As an R&D manager, what actions might you take or programs might you implement to assure your organization got maximum benefit from patentable ideas?
8. How do the kinds of ideas best protected by patent differ from those best protected by keeping them a trade secret?