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Metrics to Evaluate R&D Groups
Phase I: Qualitative Interviews

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Abstract

We describe the results of in-depth qualitative interviews with Chief Executive Officers, Chief Technical Officers, and researchers at ten large research-intensive organizations. In these interviews we explored how these organizations measure success in the R&D mission and how they provide incentives to managers and researchers in R&D. We gained insight into the three tiers of the R&D mission: exploring the tools of the future, creating the tools, and pioneering the use of the tools. We learned how these tiers relate to the university and the business units. Metrics of success vary by tier, in part, because the role of corporate investment, the role of managers, and the role of internal customers vary by tier.

This report provides an initial perspective on R&D metrics from the viewpoint of practicing managers and researchers. This perspective, which is Phase I of our research project, suggests research topics which we will explore in greater depth in subsequent Phase II. We summarize these research directions at the end of this report.

In 1990, in the U.S. alone, private corporations spent over $70 billion on research and development (R&D). This was approximately 3.4% of total sales and 46.8% of total profits. Similar spending occurred in Japan (over $27 billion) and Germany (over $19 billion). In order to justify investments of this magnitude, private industry must believe that the return on investment (ROI) for R&D exceeds the firms' targets.

However, investments in R&D are inherently difficult to evaluate. While the costs are clearly visible and are recorded as they incur, the return on R&D investment may occur many years in the future and may be hard to attribute to a specific project. This is particularly true if R&D develops a strategic technical competence that is applied across many projects and pervades everything that the organization does. Furthermore, decisions on which projects to fund or which strategic competence to pursue must be made under considerable market uncertainty and technology uncertainty.

Our long-term goal is to understand how best to allocate R&D investments, but in order to allocate investments we must first understand how firms evaluate the R&D function. We want to know how firms decide whether a project, a program, or a strategic direction succeeds and we want to know how top management rewards and motivates R&D scientists, engineers, and managers based on their past performance and/or their potential. Once we understand how firms now perform these tasks we will be better able to develop a theory to describe and to improve these actions.

In this paper we describe phase I of our research. In this phase we spoke to managers and researchers at a variety of firms who invest heavily in R&D. We report here what they told us. We have purposefully chosen not to structure this description within any previously published framework. Instead we have attempted to allow the managers and researchers themselves to describe the world in which they operate. We chose this strategy because many of the organizations in our sample have recently changed the way they evaluate R&D or are in the process of doing so[1]. This report provides a snapshot of the current beliefs; later phases of

[1]For example, one organization, which was once run as a central laboratory, is now aligned with the business units, another organization has given the business units more power by allowing them to fund R&D directly, another organization reorganized so the manufacturing and R&D were "laid together," another organization moved its R&D from a center of excellence to the divisions, and another organization has restructured its R&D division to focus them on developing projects that result in profitable products and services.

our research will evaluate these beliefs from the perspectives of history and theory.

The paper is structured as follows. We provide a brief description of the sample and our methods. We then describe a tiered perspective on the R&D mission and within that structure describe the role of customers, managers, and corporate investment. We describe the metrics that firms use and relate those metrics to motivation and incentives. We close with a set of suggested research directions for the continuation of this research stream.

Sample and Methods

This report is based on qualitative interviews at AT&T Bell Laboratories, Robert Bosch GmbH, Cable & Wireless, Chevron Petroleum Technology Company, Electricité de France (Direction des Etudes et Recherches), Hoechst Celanese Advanced Technology Group, Polaroid Corporation, Schlumberger (Measurement and Systems), the U.S. Army (Missile RD&E Center, Army Research Lab), and Varian Vacuum Systems. We feel that this group of firms is sufficient to raise many of the issues of measuring R&D success. Later phases of this research will attempt to quantify these issues through a larger scale survey. At each firm we attempted to speak to the Chief Technology Officer (CTO), the person(s) to whom the CTO reported, the person(s) who reported to the CTO, and researchers within the R&D organization. In total we interviewed 43 managers or researchers.

The interviews varied from approximately one hour to a full day of interviews. In some situations the interviewee showed us around the facility and introduced us to many people in the organization. In each interview we sought to understand how the interviewee affected and was affected by the organization, how the interviewee believed that the organization measured R&D success, and how he or she believed it should measure R&D success. We discussed the motivation and evaluation of employees and how formal and informal incentives (if any) affected employee behavior and the firm's profitability. Because the interviews were exploratory, they were freewheeling. We allowed each interviewee to explore the topics in any way that he or she found comfortable and we encouraged each person to speak about related topics which they found interesting.

Because of the seniority of the people in our sample and because of the sensitive nature of the interviews, we did not use audio recording. We promised that we would not tie any interviewee (or organization) directly to a quote. (The only exceptions are quotes from widely circulated documents that were given to us by the interviewees.) Instead the interviewer kept detailed notes which where later transcribed. An analysis of the content suggested 37 interrelated topics. We attempt to cover each of these topics in the following sections.

Tiers of the R&D Mission

To understand metrics and incentives we begin by describing a tiered structure of the R&D mission. We draw the word, "tier," from one of our interviewees, but we found the basic structure at each interview site. For example, the U.S. Army uses funding numbers such as 6.1, 6.2, ..., 6.6 to describe their tiers. We feel that this tiered structure is important to our story because metrics and incentives vary as the mission of R&D varies from one tier to another.

Table 1. Tiers of the R&D Mission

	Activity	Performed by	Example
Tier 0	Laying the foundations	University or Basic Research Lab	Mathematics for coding
Tier 1	Exploring the tools of the future	R&D	Algorithm development
Tier 2	Creating the tools	R&D	Algorithm implementation
Tier 3	Pioneering the use of the tools	R&D	Pilot system
Tier 4	Using the tools routinely	Business Units	Technology transfer to business units

The tiered structure is described in Table 1. Tiers 1, 2, and 3 describe the missions of the R&D laboratory. Tiers 0 and 4 are included to describe the interface between R&D and its suppliers and customers. (The boundaries vary by firm, e.g., in some cases tier 0 is the university; in some cases it is a basic facility within the firm.)

We illustrate the role of each tier through an example from one of our interviewees. Consider an organization that wants to communicate thousands of high-resolution detailed 3-dimensional (3D) images to and from a remote field site. If the firm could do this then the firm could do its job more effectively and with significantly lower cost than having to analyze the images on-site. However, the sheer volume of data means that today's technology does not have the bandwidth to accomplish the goal.

Tier 0 is the basic research that lays the foundations for later tiers. In the case of 3D images, tier 0 might be the development of the fractal mathematics that allows these images to be coded for transmission. These mathematics may or may not have been developed for this application, but they prove important to its solution. Most likely they were developed at a university or a central facility. The R&D laboratory may not need to develop these tools, but it must have the ability to identify whether these mathematics exist, to find out where they exist, and access the knowledge.

Tier 1 uses basic foundations to explore the tools of the future. In the case of 3D images, tier 1 might include the development of algorithms that use fractal mathematics to code the images. Once developed, the algorithms might have other uses within the firm and, once developed, the algorithms might give the firm a competitive advantage. The tier 1 researchers might have focused only on 3D imaging or they may have been trying to explore tools that could solve a portfolio of problems.

Tier 2 creates the tools. For example, tier 2 researchers might write the software and develop (or buy) the hardware to implement the algorithms. Although the knowledge might be generalizable, tier 2 researchers are usually problem driven. They often work with customers in the business units and focus on solving the customers' problems.

Tier 3 pioneers the use of the tools. In tier 3, the laboratory might develop a pilot application to demonstrate the 3D imaging system and to solve the problems of implementation. The tier 3 pilot system may not pay for itself, but, if tier 3 is successful, the system that is developed will become cost effective in subsequent applications. In many cases the experience gained with the pilot system can be used by more than one business unit, hence there are benefits that can be shared. In such cases, if a single business unit paid for the tier 3 research, the other business units would reap the benefit without the risk or direct cost.

Tier 4 uses the tools routinely. In tier 4, the laboratory might hand over the 3D imaging system to the business units. By this time, the costs and the benefits of the system can be projected and each business unit can make an ROI-based decision. The R&D laboratory might be involved in the technology transfer and might play an ongoing support role, but the bulk of tier 4 investment is within the business unit rather than with the R&D laboratory.

Recursion

Tier 1 is the R&D laboratory of the R&D laboratory. If R&D provides the firm with the core technological competencies that allow it to compete effectively, then tier 1 provides the R&D laboratory with the core technological competencies that allow it to serve its customers better. Many R&D managers in our sample are facing greater pressure to "sell" R&D services to the business units. Indeed, in some cases, the business units can buy R&D outside the firm. Rarely do the business units "buy" tier 1 research directly, but tier 1 gives the R&D laboratory the ability to sell tier 2 and tier 3 research, just like R&D gives the firm the ability to sell its products or its processes. By the same analogy, tier 0 gives the laboratory the ability to carry out tier 1 research. The firms that we interviewed recognized the need for tier 1 research and the need to facilitate access to the knowledge generated in tier 0.

This recursive property suggests that tier 1 research may be more difficult to evaluate than tier 2 and tier 3 research. On the other hand, the recursive property suggests that if business unit metrics can be used to evaluate tier 2 or tier 3 research, then analogous tier 2 or tier 3 metrics can be used to evaluate tier 1 research.

For example, in an earlier research paper in this project (Hauser, Simester, and Wernerfelt 1995) we suggest that one can use internal customers to evaluate internal suppliers. For example, we might ask a product-development group within a business unit to set sales-and-satisfaction targets for a new product and then use those targets to evaluate the R&D laboratory. (Here we assume that better R&D will enable the product-development group to choose more aggressive targets, hence the targets measure the success of R&D.) In that paper we demonstrate that such an internal customer-internal supplier system will encourage both groups to choose the actions and technology that maximize the long-term profits of the firm. Thus, if we were to ask R&D's customers to evaluate the R&D laboratory with this linked system, then the customers would be really evaluating tier 3 or perhaps tier 2. We could, in turn, use the tier 2 and tier 3 researchers to evaluate tier 1 and the tier 1 researchers to evaluate tier 0.

Balance the Short-term and the Long-term

Tier 3 researchers are short-sighted! We heard comments like this from a number of interviewees. The customers of tier 3 research often have a 3-5 year time horizon and they put pressure on tier 3 R&D to deliver so that fruits are visible within that horizon. This means that tier 3 researchers will take fewer risks. They prefer knowledge and technology that is currently available. We contrast this time horizon with that of tier 1 which might be 8-15 years away and highly uncertain. Thus, the long-term vs. short-term focus is implicit in the allocation of effort among the tiers. Any organizational structure, such as funding all R&D through business-unit projects, implies a short-term vs. long-term tradeoff. (Our interviewees perceived the organizational changes in footnote 1 as a shift by top management to a focus on short-term goals.)

Evaluation Criteria Vary by Tier

Each organization recognized that the evaluation criteria (and the evaluator) vary by tier. For example, tier 1 research is often evaluated by peers or by committees based on informed judgments of the long-term viability and value of the research direction. Tier 3 research can be evaluated by R&D's customers directly on measured returns. One organization stated that you look for "milestones" in evaluating tier 1, but you look for "deliverables" in evaluating tier 3. Many of the formal methods, like PRTM[2], are viewed as better for evaluating tier 3 than tier 1.

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[2] See e.g. McGrath, Anthony, and Shapiro (1992)

To explore this variation further, we provide more detail on how our interviewees described the role of each tier. We begin with tier 3.

Tier 3 -- The Role of R&D's Customers

Many organizations in our sample are making the R&D function more customer responsive. Business units are viewed as the customers of R&D, especially tier 3 R&D which provides an internal market with which to value R&D. Consider the following examples:

✓ One CTO felt that top management now recognizes the importance of his function because R&D is viewed as a partner of the business units.

✓ Another CTO sees the business units as customers and feels that his organization will be evaluated by how well it delivers new business opportunities to those customers.

✓ Another CTO told us that business units can "buy" R&D from his organization and, if their needs are not met, they can buy outside the firm.

✓ In one organization, when the corporation introduced a business unit structure in the last five years, it aligned R&D with the business units.

✓ In another organization different laboratories compete with one another for tier 3 funding.

This orientation toward customers appears to imply three trends. Customer satisfaction as a metric, attempts by R&D laboratories to determine customer needs, and a profit-center-like evaluation of tier 3 research.

Customer Satisfaction

In many organizations customer satisfaction is a key metric for tier 3 research.[3]

✓ "Customer satisfaction is the number one priority." (from a facility with mostly tier 3 funding)

✓ "R&D has to be developed in the marketplace." (from a facility that does mostly systems

[3] All quotes in this document are paraphrases and not actual quotes.

integration)

✓ Technology assessment is "What does it do for the customer?" (from a facility recently reorganized)

✓ "the development organization wants to develop a new product and asks research specifically for a new technology -- that process has a lot of power"

✓ "customers have direct input on the team performance and hence on the evaluation of technical staff" (from a facility that depends upon business unit funding)

Also in a non-profit organization such as the U.S. Army, tier 3 funding is becoming much more customer oriented and can depend upon customer satisfaction surveys.

However, customer satisfaction feedback is not universal. One CTO told us that he wished that his people would be more comfortable stepping out of the lab and going to the market. Another interviewee pointed out that there are other evaluation criteria and that researchers could get good performance ratings even if the customer was unsatisfied. Furthermore, although there is customer feedback for research in tier 1 (and presumably tier 2), it is usually based on qualitative judgment of perceived value after a reasonable period of time.

Understanding or Predicting Customer Needs

A consequence of a customer-satisfaction orientation is that R&D laboratories are attempting to measure or predict customer needs. For example, Hewlett-Packard (HP) was not in our sample, but researchers in our sample cited what they believed to be the HP principle. They believed that the "only thing that successful companies have in common is that they identify customer needs two years before the customer knew the need." While this may refer more to technological solutions to underlying needs than the needs themselves, this belief does demonstrate that customer input is key to the success of tier 3 research.

Our interviewees suggested many ways to obtain information on customer needs including:

✓ taking the customer's business metrics and figuring out what your research is worth to them

✓ encouraging the business units to express needs that are independent of the current programs

- ✓ have scientists initiate proposals based on informal contacts with customers
- ✓ "most development effort is initiated by marketing" (from a facility that deals with a few large customers)

We did not probe on whether tier 3 research uses formal methods such as the voice of the customer (Griffin and Hauser 1993) to obtain information on customer needs, but we know from previous research that such formal methods are growing in popularity. (Such methods also uncover the needs of leading-edge users and uncover those needs that the customer has difficulty articulating.) However, the desire by R&D for methods to measure customer needs is clear. As one interviewee said, "When starting from scratch, the key is to become customer focused." These comments imply that the set of metrics for tier 3 should include (1) a measure of the ability of the R&D laboratory to identify customer needs and (2) a measure of whether the laboratory fulfilled specific customer needs.

Profit-Center-Like Evaluations

Some interviewees expressed the belief that one measure of customer satisfaction is whether customers come back for more funding. Not surprisingly, we found that some organizations have attempted to create internal markets. However, no organization (in our sample) has made R&D a pure profit center. Consider the following examples:

- ✓ At one organization the amount of money is a negotiation process among marketing, R&D, and manufacturing.
- ✓ At another organization the "development factories" are run as a hybrid between a profit center and a cost center.
- ✓ The development laboratories in one organization (as opposed to central R&D facilities) get as much funding as can be sold to clients.
- ✓ At one firm, development puts forth capabilities and marketing puts forth priorities and a binding contract is negotiated.
- ✓ In another firm development proposes projects and the business units decide whether or not to fund them.

It is clear that market measures can and are being used for tier 3 research. However, organizations seem to recognize that there are forces that prevent a pure profit-center approach. We speculate on explanations for this phenomenon later in the paper. Thus, market measures make sense within a portfolio of measures, not as the only measure. Market measures are not independent of customer satisfaction measures. We have shown in earlier research that customer satisfaction measures can be used to encourage a focus on long-term rather than on short-term profit (Hauser, Simester and Wernerfelt 1994) and we have shown that some internal customer satisfaction systems have profit-center-like interpretations (Hauser, Simester and Wernerfelt 1995).

Tier 2 -- The Role of Management

Tier 2 provides the bridge from basic research to development. It is in this middle ground that the role of managers and managerial judgment is most important. As one person said, "The customer knows the direction but lacks the expertise; researchers have the expertise but lack the direction." Tier 2 must match the expertise with the direction.

The strategic technological competencies of the firm are implicit in the choice of tier 2 projects. To make this decision, the tier 2 manager must understand the potential of the capabilities developed in tier 1 and must anticipate the needs of the customers of tier 3. Because of both technological and market uncertainty, these managers maintain a portfolio of projects. Because economies result from focus, these managers maintain continuity and attempt to build a bank of knowledge. In order to realize the synergies of focus, R&D must communicate the potential of core technologies across business units. We address each of these issues in turn.

Core Technological Competency and the Choice of Tier 2 Projects

In many cases the firm's strategic plan has a large influence on the choice of tier 2 (and sometimes tier 1) projects. In some cases the input is based on a formal document such as the "Marketing/Strategy Input to R&D," or facilitated by a formal office, while in other cases the strategy input comes from overseeing directors. Most sites have some mechanism to ensure that the projects that are selected are those that fit the strategic plan and those that build (or continue) the technological core competence of the organization.

While a strategic plan helps a laboratory choose technological directions, the choice of technological directions can, implicitly, determine an organization's core technological competency. For example, if the tier 2 managers consistently select projects that depend upon small electrical motors, then the laboratory and the organization quickly develop specialized knowledge in that technology. This knowledge is then be exploited in other projects in order to complete those projects more effectively, faster, and/or at lower cost. An interesting implication of this role in setting strategic technological directions is that R&D acts as a federator providing a link between the business units so that they coordinate their strategies around core technological competencies.

This interrelationship is recognized in tier 2 metrics. For example, at one firm 50% of the "at risk" compensation depends upon the contribution to the vision and culture of the organization. (An organization's culture is often cited as a core competency. See Wernerfelt 1984.) At another organization the tier 2 (and tier 1) researchers are evaluated on how well the research fits into the strategic plan.

Portfolio Issues

Tier 2 must anticipate the needs of tier 3's customers, but it can not do so perfectly. Tier 2 must create capabilities based on the ideas of tier 1, but not all tier 1 ideas prove feasible. Thus, most firms maintain a portfolio of projects in tier 2 in order to have the flexibility to respond to customers in tier 3 and in order to select an alternative direction should a promising idea fail.

While our interviewees varied in their estimates of how much money is allocated to technologies that ultimately fail (the estimates varied from 20% to 80%), they all acknowledged that failure is part of the territory. They felt that if you try to eliminate failure, you also eliminate success. They also indicated the value of taking risks early when less is at risk. It is much better to fail in tier 2 (or tier 1) when expectations are lower and less money is at risk than it is to fail in tier 3. The more expensive and time-critical tier 3 projects can then use technologies that are highly likely to succeed.

Tier 2 metrics must recognize portfolio issues. Too strong a penalty for the failure of a promising technology will force the researchers to take too few risks and may encourage only "safe" technologies. A focus on only "safe" technologies may mean too little variance in the portfolio. Metrics might also consider the externalities that result when a failed technology points the way to a technology that ultimately succeeds.

Two organizations discussed the tradeoff of software vs. hardware as a portfolio issue. One organization stressed taking charge of its software in order to gain flexibility in providing service to its tier 3 customers. Another organization decided to shift its portfolio toward software because it felt that, in its industry, advances in hardware were more rapid than advances in software, hence, a software portfolio had greater continuity.

Continuity and a Knowledge Bank

In order to manage the development of core technological competencies, in order to manage the portfolio, and in order to learn from failures, our interviewees stressed the need for continuity. This continuity, and its corollary of institutional knowledge, enables the R&D organization to react quickly when it needs to do so. It allows the organization to monitor technological expertise and it helps the organization identify and fill missing expertise. In some cases, tier 3 might need technology that must be purchased outside the organization. In these cases hard-won institutional knowledge becomes the basis for choosing what technology to buy.

Managers with R&D Expertise

To be an effective bridge between capabilities and needs, tier 2 needs managers with R&D expertise <u>and</u> a customer orientation. Such managers are also needed in the business units so that the business units can be intelligent customers of R&D and so that the business units can evaluate technical suppliers. Such people are rare.

One of the surprises from our interviews is the role of R&D as a source of such managers. One firm explicitly acknowledged R&D as a source of technical managers. Another organization stressed the need for continual renewal of the "helper ranks" because the new stars (managers and researchers) come from the "helper ranks." They felt that the organization would stagnate if the helper ranks were filled with non-growing staff. One organization explicitly recognizes this role by rewarding the development of people. In the same organization people are shifted between the business units and R&D in order to develop both an R&D and a customer expertise.

Of course not all organizations succeed. One interviewee complained to us that top management is R&D illiterate and that this accounts for bad decisions.

Mechanisms to develop managers vary, but one mechanism seems to be a Darwinian self-selection. Not all researchers have an interest in customers and not everyone with an interest in customers has technical expertise, but those that are promoted from the researcher ranks to the managerial ranks are more likely to have both skills. The greater the combined skills, the more likely they are to succeed.

Tier 1 -- A Corporate Investment

Tier 1 provides the raw material with which tier 2 matches technology to an organization's strategic plan. Tier 1 research develops the platform or the architecture that is used across the products of many business units. It is also more likely to consider a variety of tools to solve a basic problem. For example, the (corporate) Army Research Laboratory is more likely to consider a variety of weapon delivery systems, whereas the Army Missile Research Development and Engineering Center is more likely to solve the problem by designing a missile system.

Benefits that result from tier 1 research may not be recognized for 8-15 years and, when they are recognized, they may not be attributed to tier 1 research. Even if they are attributed to the tier 1 facility, the people in that facility may have changed in the interim. If the business units have a time horizon shorter than 8-15 years they may undervalue tier 1 research. If the researchers have a time horizon shorter than 8-15 years, it will be difficult to motivate them by market outcomes. This measurement and reward challenge is compounded with the issues of risk and free-riding.

The benefits from any one idea exploration are highly uncertain in terms of (1) technological feasibility, (2) market demand, and (3) fit with the organization's strategic needs. If we were to measure and reward a researcher only on the outcomes from the idea that he or she is exploring, we would expose the researcher to more risk than if he or she were compensated on the basis of the portfolio (equalizing both on expected compensation). That is, if the research portfolio is balanced appropriately, the mean outcome of the portfolio divided by a measure of uncertainty should be much higher than for the project. However, if we attempt to reward the researcher based on the portfolio, he or she might recognize that the portfolio is based on the entire tier 1 organization while his or her personal costs are tied to one project. The researcher might be tempted to free-ride on his or her colleagues.

There is another free-riding problem we must face when evaluating tier 1 research. To the extent that the core technological capabilities developed in tier 1 benefit more than one business unit, any single business unit can free-ride on investments by the other business units.

Taken together, the issues of difficult-to-observe linkages, time horizon, project vs. portfolio risk, free-riding by researchers, and free-riding by business units make it very difficult to measure the success of tier 1 and even more difficult to reward the efforts of tier 1 researchers. We found that organizations recognize these challenges by using funding systems and reward structures for tier 1 research that differ from those used in other tiers.

Corporate Funding

It is common for organizations to fund tier 1 research from central coffers. The amount of funding (as a percent of total R&D funding) varies from 10% to 70%, however, most of the firms in our sample allocated less than one-third of their R&D funding to tier 1. The reasons given for corporate funding vary but they seem to be related to the issues described above.

For example, many organizations provide a percentage of corporate funding to tier 1 and expect the business units to pick up the rest. In this way they lower the expected cost to the business units of tier 1 research. If the benefits remain the same, the corporate funding alters the net present value (NPV) calculations. For example, suppose that the corporate discount rate for money is less than the perceived internal rate for the business units, then a project may have a positive NPV with the corporate rate but a negative NPV with the business unit rate. (This would be especially true if the costs are front loaded as they are in tier 1 research.) Corporate cost reduction could then make the perceived business unit NPV positive, thus effectively lowering the discount rate and making the business unit more long-term oriented.

We found many comments in our interviews that are consistent with this interpretation. One CTO stated that business units had cut their R&D budgets to increase short-term profits but are willing to use his laboratory because corporate funding picked up part of the cost. A CEO told us that he must constantly justify the corporate R&D expenditure to his business unit managers. He stated that in the absence of corporate funding they would under-invest in R&D. The business units would look more profitable, but the firm would lack corporate renewal. One interviewee told us that they need a haven for tier 1 research and another told us that the business units are better judges of tier 1 research if they don't have to pay.

Of course, corporate funding can also address the issue of free-riding by the business units. In essence corporate funding is a way to enforce cooperation by the business units on the development of a technological core.

Managerial Judgment

An implication of the measurement and reward challenges cited above is that managerial judgment is more important in evaluating tier 1 research than in evaluating tier 3 research. Most organizations allow the CTO discretion in allocating part of the corporate funding. In one case the CTO leaves 20-25% of the corporate funding unallocated to fund serendipitous discoveries. In another case, each research manager is given a component of discretionary funding to explore new areas. In one organization tier 3 researchers have to follow the results of a formal prioritization process while tier 1 researchers need only treat it as information. Managerial evaluations of researchers also play a greater role in tier 1 than they do in other tiers.

This greater use of managerial judgment reinforces the need for managers who have both technical expertise and customer expertise.

Research Tourism

We found an interesting phenomenon in tier 1 that one interviewee called "research tourism." Research tourism recognizes the value of visitors to the laboratory which give feedback on the choice of tier 1 projects. In some cases research tourism was informal; in other cases it was formalized with an advisory board or a peer-review board with members from other firms, government organizations, and academia. The goals seemed to be two-fold. First, research tourism assures an influx of new ideas and broadens the portfolio of projects. Second, the peer-review board complements managerial judgment in the evaluation of people and projects and, hopefully, overcomes some of the difficulties with tier 1 evaluation.

Best People, Creative People, Experienced People

An alternative method to overcome the difficulties of tier 1 evaluation is to bet on good people rather than to evaluate tier 1 output on a project-by-project basis. To mitigate short-term risk and to encourage creativity (with its inherent risk), these "best" people are usually given "a bit more protected space" and are evaluated on longer-term measures such as publications[4], patents, or other measures of scientific success. They may be given special titles in order to free them from short-term pressures. These mechanisms enable the organization to bet on experienced people who have demonstrated past success. (Note that university tenure fits this model.)

However, some of the best people are hard to evaluate on formal measures. In these cases, usually "a few percent of the staff," they are left pretty much alone, but bound to a research area. They may be asked to coordinate with the business units in the hope that they will be influenced to work on topics that ultimately serve the business units. One interviewee said that, for these people, motivation is 95% self-created and only 5% from salary and bonuses.

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[4]One problem with a measure such as publications is that the organization may not want to share an idea that gives it a strategic advantage. This is particularly acute in the US Army where many projects are classified as secret.

Metrics of Success Depend Upon the Tier

To select the right metrics[5] for R&D, an organization must recognize the tiered structure of R&D. This means recognizing how roles vary among the tiers and recognizing how the tiers are interrelated. For example, tier 1 succeeds if it provides the raw materials (basic ideas) that are later transformed into competitive advantages. It must also provide a conduit to research outside the firm (tier 0) and it must be a source of basic platforms and architecture. Tier 2 succeeds if it matches the firm's technological capability to internal customer needs by selecting and developing a portfolio of projects that define the firm's core technological competency and provide tier 3 with the capabilities to serve its customers. Tier 2 (and other tiers as well) must produce managers with both technological and customer-oriented skills, managers that will serve the rest of the organization, and tier 2 must play its role of federator by enhancing the combined value of the business units. Tier 2 must become a knowledge bank which can be used by the rest of the corporation for intelligent buying, for trouble-shooting, and for rapid response to competitive actions. Tier 3, the largest in terms of research volume, succeeds if it serves its customers -- the business units. Tier 3 can be evaluated on internal customer satisfaction, the fulfillment of customers' needs, and with profit-center-like incentives. Naturally organizations differ on the relative size of the tier 1, 2, and 3 efforts and on the detailed definition of their missions. In addition, many of the roles are blurred and vary continuously from one tier to the next. However, the tiered structure provides a first-cut at matching metrics to mission.

All of our interviewees recognized the interdependencies of the tiers and many of them formalized the interdependencies with a "stage gate" process. A stage gate process provides a serious of formal stages through which a project must pass. The earlier stages require fewer resources per project (or technology), hence allowing a broader portfolio in which each project can be more risky. As the project(s) proceed through the gates greater demands are placed on the projects in terms of meeting the organization's objectives. Formal ROI calculations are made in the later stages. For more on stage gate see Cooper (1990) and Griffin and Hauser

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[5] By "right metrics" we mean those metrics which, if maximized by the R&D organization, lead to the greatest long-term (expected) profit for the firm.

Table 2. R&D Metrics Reported by Interviewees

	Category	Metric
Qualitative Judgment	Strategic Goals	Match to organization's strategic objectives Scope of the technology Effectiveness of a new system
	Quality/Value	Quality of the research Peer review of research Benchmarking comparable research activities Value of top 5 deliverables
	People	Quality of the people Managerial involvement
	Process	Productivity Timely response
	Customer	Relevance
Quantitative Measures	Strategic Goals	Counts of innovations Patents Refereed papers Competitive response
	Quality/Value	Gate success of concepts Percent of goal fulfillment Yield = [(quality*opportunity*relevance*leverage)/overhead]*consistency of focus
	Process	Internal process measures Deliverables delivered Fulfillment of technical specifications Time for completion Speed of getting technology into new products Time to market Time of response to customer problems
	Customer	Customer satisfaction Service quality (customer measure) Number of customers who found faults
	Revenues/Costs	Revenue of new product in 3 years/R&D cost Percent of revenues derived from 3-5 year old products Gross margin on new products Economic value added Break even after release Cost of committing further Overhead cost of research

and use that as the basis for compensation decisions and development activities. ... We usually adjust the job until the person does it reasonably well. This can lead to disconnects between compensation and contribution."

Target Value Concepts

A common approach was a tendency to set targets. Researchers and managers were then given incentives to meet those targets. In some organizations, projects would set milestones which had to be kept. In another organization, researchers were evaluated by comparing the goals at the beginning of the year with the delivery at the end of the year. However, this organization cautioned us that such evaluations could not be done quarterly because of the uncertainty inherent in R&D.

While some bonuses were paid if the goals were achieved or overachieved, other organizations actually gave the highest reward if the research project was right on target rather than too high or too low. We found one very interesting combined target-value metric. In that organization four targets were established based on the product that was developed from an R&D effort. The targets were production cost, labor cost, quality cost, and production investment. Weights were applied to each measure and the project was asked to keep the sum of the weighted deviations on target. In this way, a project could be over on implied production cost if there were a corresponding savings on labor cost[6].

Challenges to Implementation

Ratings inflation. Our interviewees expressed a concern that qualitative metrics are difficult to use for motivation because they are inflated. If the person providing the rating (the manager or the customer) does not incur a perceived cost for providing a high rating, then the

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[6]Let P=actual production cost, L=actual labor cost, Q=actual quality cost, and I=actual production investment. Let A, B, C, and D be the targets established for these costs. Then the project is asked to maintain the following equation were w_p, w_l, w_q, and w_i are weights established by management: $w_p(A - P) + w_l(B - L) + w_q(C - Q) + w_i(D - I) = 0$

ratings tend to be clustered toward the top of the scale. This is particularly true for jobs that are not well-defined such as the role of scientists and engineers in tier 1. The result is that the ratings carry less information about job performance and are less effective at providing incentives. We show in an earlier paper in this research project (Hauser, Simester and Wernerfelt 1995) that such ratings inflation is a natural result of the potential for gainsharing between the rater and the ratee, but that one can design incentive systems to take ratings inflation into account.

Team issues. Much research is done in teams. Indeed we have found that some incentive systems combine rewards to individual performance with rewards to teams. However, we also found concerns that incentives not be based on teams that are too large. For example, laboratory-wide measures and incentives were believed to affect behavior less than measures based on individual projects.

Research culture. Two organizations expressed the view that a business orientation would violate the mindsets of the researchers. Presumably researchers see themselves as scientists first and profit-maximizing employees second. This cultural issue may not be at odds with some of the goals of tier 1, but it clearly conflicts with the goals of tier 3.

Other motivations. Our interviewees suggested that researchers have a variety of personal motivations including: Researchers tend to want to work in appreciated and/or popular fields. Scientists and engineers value highly the ability and the opportunity to conduct hands-on research. Researchers become enamored with the project rather than with their customers' needs. Researchers are more interested in technological solutions than in commercialization. While some of these issues may be facility specific, they are deeply held beliefs that must be addressed in any incentive system.

Examples

Table 3 lists examples of the incentive schemes that we observed. Bonus systems were fairly common, but they varied in their perceived effectiveness. We observed some examples of royalties and stock options, but our interviewees did not believe that royalties and stock options were particularly effective. It is an interesting comment on the R&D culture that keeping one's funding or obtaining discretionary funding was perceived as a strong motivator.

Table 3. Incentives

Bonuses	Based on how corporation did how customer did customer satisfaction	**Other**	Royalties on patents
			Stock options
	Based on operational performance contribution to vision		License and support to start company
			Discretionary funds
	Based on managers' judgment		Get to keep funding
	Based on management review peer review visiting committee small group level review		Promotion up the technical ladder if a company has a dual ladder system
	Based on level in the hierarchy (assumes good people rise)		

Suggested Research

Our initial interviews suggest a number of important research topics that are relevant to both managerial and academic audiences.

Corporate Funding vs. Profit-Center-Like Mechanisms

Every firm allocated some percent of R&D funding from corporate sources, although this percent varied widely. Earlier we proposed two explanations: (1) corporate funding as a means to coordinate business units that would otherwise free-ride and (2) corporate funding as a means to overcome the short-term orientation by the business units. Both explanations suggest that corporate funding should be greater in tier 1 than in tiers 2 and 3.

We plan to explore this issue further with formal mathematical models in order to identify which measurable conditions determine the percent of corporate funding that should be allocated to each of the tiers. We also hope to identify the conditions that indicate which projects should be funded corporately and which should be funded with profit-center-like mechanisms. Once we identify these conditions, we will be able to use them to determine which of the proposed explanations, if any, is more likely to be the correct explanation.

Managers as an Output of R&D

Our interviewees suggest a Darwinian mechanism by which the corporation uses R&D as a filtering device to identify and train those rare individuals with expertise and interest in both the technical and the customer-oriented aspects of managing the business. When such managers are identified effectively and consistently, they become a renewable asset of the organization. This phenomenon suggests a value for R&D above and beyond its technical output; this value should be reflected both in R&D metrics and in R&D funding.

We plan to explore this phenomenon further to determine if it is generalizable beyond our sample and whether we can learn how to manage the process better and to measure its outputs.

Incentives to Select and/or Build Core Technological Competency

It is clear from our interviewees that the decisions made by R&D, especially tier 2, are directed by the organization's strategic plan and, implicitly, determine the organization's strategic core technological competency. However, such decisions have far ranging implications that are difficult to tie back to the person or group making those decisions. Any benefits from these decisions usually accrue to other parts of the organization at a much later date.

We plan to explore how to measure the success of the technological competency that is created. We hope to develop incentive systems for R&D managers, scientists, and engineers such that, acting in their own best interests, they make the technology decisions that are in the best long-term interests of the organization. In order to make progress on this issue we will have to define carefully what we mean by "core technological competency."

Research Directed vs. Customer Directed R&D

The evidence is persuasive that those products which meet customer needs are more likely to succeed. (See review in Griffin and Hauser 1994, table 1.) However, this does not mean that all R&D should be directed by customers. Customers are very good at expressing their needs, but R&D has the technological expertise to determine how best to fulfill those needs profitably. In addition there are often synergies across projects that must be considered. For example, R&D might want to adopt a common architecture across projects rather than re-invent an architecture for each project. This common architecture enables the firm to gain experience and, in the long run, become more profitable. Such goals might suggest that an organization invest more heavily in front-end R&D design than can be justified with an ROI calculation for a single project. These goals also suggest that priority be given to those architectures that are flexible and that can be used across a variety of projects. This concept might extend to basic technological expertise. For example, a firm might explore a multimedia application, even if there were no immediate customer demand, in order to develop the "know-how" to be a player in this fast-moving market.

We plan to explore the tradeoffs between a research-directed and a customer-directed

R&D center. Our exploration of this issue will provide insight on how to allocate effort among the three tiers of the R&D mission and how to allocate effort among projects. Our research should also suggest metrics and incentives with which to measure and reward success.

The Best Set of R&D Metrics

Table 2 provides a list of metrics. The tiered structure of the R&D mission suggests which metrics should be used when. We hope to improve on these qualitative insights with a more formal model. If we succeed in the above research challenges we will be better able to suggest which metrics should be used under which conditions and in which tiers of the R&D mission.

If we succeed in our research goals we will understand (1) which metrics and incentives lead to the best decisions and efforts by R&D and (2) how one can measure the success of R&D. We will then be in a position to undertake a large-scale survey of R&D organizations to test our theories and to suggest ways to improve the theories.

Summary

This report has summarized many of the issues identified by in-depth exploratory research with ten research organizations. We are now beginning the next phase of our research which will include (1) a formal theory based on these issues, (2) the development of large-scale data collection to test the theory, and (3) the design and implementation of prescriptive models based on the theory.

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