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Diversification and Strategic Management of LLNL's R&D Portfolio

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Executive Summary and Recommendations

The different R&D efforts at LLNL can be equated to *strategic business units* (SBU) in the classical theory of corporate portfolio analysis.¹ Our initial investment is the LDRD and the other internal money used to start the program. Our customers are both governmental and commercial units that give us a return on our investment by funding our future research.

By placing each SBU on a two dimensional space where the axes are attractiveness of the research area and our market position in that area, one can identify the question marks, stars, cows and dogs (see Fig. 1). New research efforts are born as question marks and become stars if they succeed in capturing market share. As the attractiveness of the research area decreases with time the stars become cash cows to be milked to nurture the new question marks, and the old question marks that did not transform into stars become dogs that should be euthenized. As time progresses further and a research area dries up even the cash cows can become useless dogs. It is therefore necessary to create new question marks and to efficiently transform them into stars so that this cycle can be sustained.

The most efficient way to diversify into new research areas depends on the growth factor of the area (growth factor \approx how many times larger the research area will be when the effort will be made to capture the full market share * probability of success). A simple linear optimization shows that if the growth factor is greater than one, the optimal solution is to mount an effort to capture the full market share immediately. Conversely, if the growth factor is less than one, one should conduct several years of small scale research to scope out the area and improve the probability of success.

In the past we have tended to operate in low growth areas where a go slow approach is optimal. We should be aware that a shift in paradigm is necessary in a high growth area such as minimally invasive medical research. It is in another area of parameter space where a crash program to immediately capture full market share is optimal.

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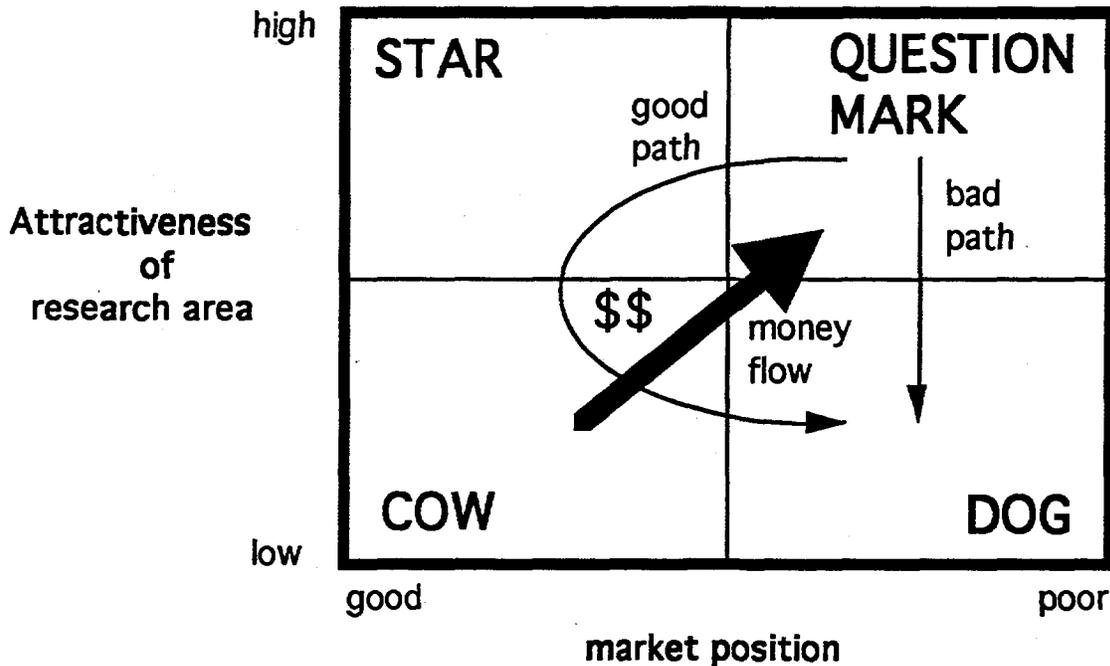


Figure 1. McKinsey/BCG business matrix

Introduction

This memo addresses strategic management of LLNL's research portfolio. A general framework is first established by presenting the McKinsey/BCG Matrix Analysis as it applies to our research portfolio. The framework is used to establish the need for the diversification into new attractive areas of research and for the improvement of the market position of our existing research in those attractive areas.

Once the need for such diversification into attractive areas is established, we turn our attention to optimizing our diversification. As with any corporate activity there are limited resources available for this diversification. One is faced with the dilemma of either planting many seeds of new research, watering them all, then allowing the strongest to grow to full maturity; or planting only the largest seeds. This dilemma can be resolved by a simple decision analysis and a linear optimization. The conclusion is that in the attractive high growth areas one should only plant the large seeds – diversify into only a few areas and try to obtain full market share as soon as possible.

McKinsey/BCG Matrix Analysis of the R&D Portfolio

The Boston Consulting Group developed the first matrix for corporate business portfolio analysis. They located each *strategic business unit* (SBU) of a corporation on a matrix where the two axes are market share and market growth rate. The matrix is divided into four quadrants: the stars, those businesses with a large market share in a market with a high growth rate; the dogs, those with a small market share in a low growth market; the cows, those with a large market share in a low growth market; and the question marks, those with a small market share in a high growth market.

A large market share can be related to *return on investment* (ROI) of the SBU as was shown in a Harvard Business Review study.² The results of this study are shown in Fig. 2. It shows a linear relationship between ROI and market share. Obviously a business wants to be as profitable as possible so a large ROI is desirable.

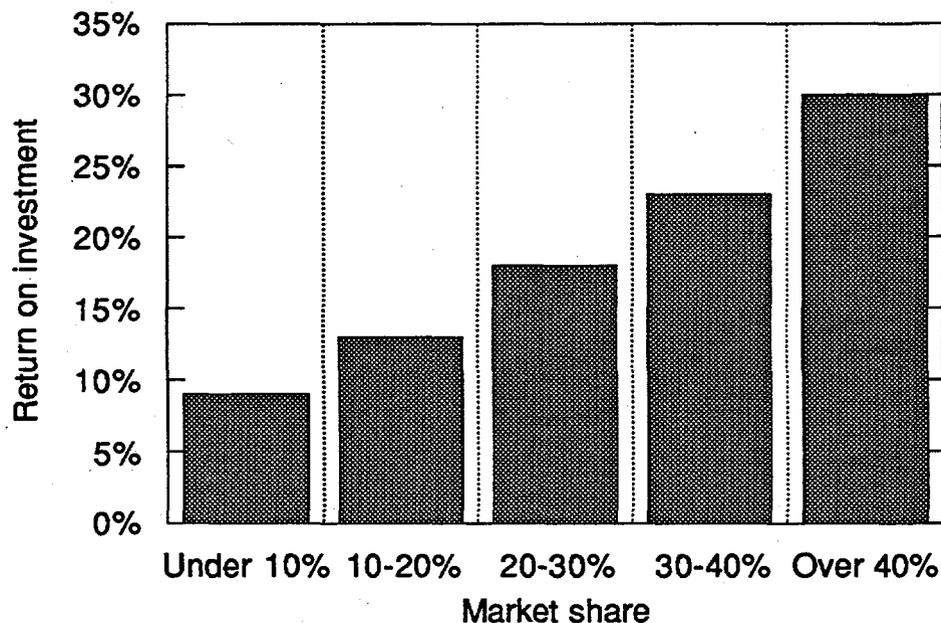


Figure 2. Relationship between ROI and market share.

The relationship between market position and profitability shown in the HBR study should also apply to our R&D. Let us look at the reasons this study gives for a large market share leading to a high ROI. The first is being ahead on the *learning curve*. More experience can lead to more knowledge which leads to more efficient technology and lower costs. This gives a business a competitive advantage that they can convert into higher profits. In our case, expertise and experience in glass laser construction gives us a competitive advantage that we have used to obtain funding from the French and to

position ourselves to lead the NIF project. The second reason is *market power*. Being the market leader allows a business to influence the competitive environment. They can bargain more effectively, "administer" prices, and realize a higher profit. We have the same ability to bargain effectively and to influence national policy in a way which will benefit us. The third reason is the *guarantee of quality*. When a consumer purchases an expensive product infrequently, he desires an assurance of quality. A market leader that has delivered in the past provides such assurance. If DOE wants to construct a billion dollar super laser or the Air Force wants a compact high power laser they turn to someone who has previously delivered. The final reason is *economies of scale*. A larger organization can distribute fixed costs over more production and take advantage of synergies between their products. We can do this by utilizing resources such as the x-ray optics fabrication facility, the laser matter simulation codes, and the high power diode facility for many different projects.

A business does not only want to be profitable it also wants to grow. This is the reason for the second axis of the matrix. A low growth market is unattractive for several other reasons. It is hard to enter since it is usually a mature market with many well established competitors, and it is not very profitable since competition is based on cost and quality.

The animal designations lead to some well known metaphors in the business world. The cows are looked upon as revenue producers who should be milked to feed the development needs of the question marks and stars. The dogs pull down corporate profitability with little hope for improvement. One should divest himself of them.

As markets mature the stars will become cows and the question marks will become dogs. A cow can also become a dog if its market share diminishes. Obviously it is preferred that question marks become stars rather than dogs so that corporate profitability can be maintained. As one gets rid of the cows that turn into dogs, one also should create new question marks that can be nurtured into stars for continued corporate existence.

There is another way to express this cycle. Businesses need to renew their product lines as their older products mature and eventually become antiquated. For instance, IBM needed to diversify into computers in the 60's to compensate for the antiquation of the traditional business machines like manual typewriters. A national laboratory needs to renew its research lines to prevent its research from becoming disconnected from the national long range needs. As the demand for new nuclear weapons wanes, we must address the developing need for things such as low-cost health care and nuclear non-proliferation.

A business diversifies by redirecting the profits from its cash cows in mature markets to start up and nurture business units selling products in emerging markets. If a business redirects a fraction r_{inv} of its income and if it receives a return on its investment [i.e., $ROI = \text{total return} / \text{total investment} - 1$], then it will grow as a function of time if

$$\frac{(ROI)(r_{inv})}{1 - (ROI)(r_{inv})} \geq \frac{1}{N}$$

where N is the number of years in the product life cycle. The denominator in this formula comes from the compounding of business growth since a fraction of the total return is reinvested. We can diversify into new research lines by redirecting some of the funding from our mature projects such as NOVA and nuclear weapons design, to support new research lines such as NIF, health care, and non-proliferation. LDRD should, if it is being allocated correctly, accomplish this goal. Our ROI is calculated by using the new research dollars brought into the laboratory (total return) and the dollars diverted from mature research projects to attract the new funding (total investment). The condition for growth applies as well to us with r_{inv} being the fraction of our research dollars that we reinvest and N being the average number of years that a research project lasts.

A further refinement of the matrix was done by McKinsey & Company for General Electric. GE was dissatisfied with the narrow focus of the BCG matrix. They felt that market position and industry attractiveness were determined by more than market share and market size. This prompted McKinsey to generalize the variables on the two axes to be linear combinations of various quantities q_i with variable weights w_i assigned to each quantity. The sum of these weights equals one,

$$\sum_i w_i = 1,$$

and each quality is ranked between 0 and 5 then divided by five before the weighted average is formed,

$$Q = \sum w_i q_i / 5$$

where

$$q_i \in \{0, 1, 2, 3, 4, 5\}.$$

The value of each axis therefore goes between 0 to 1.

An example of such a ranking applied to research areas (SBUs, designated as research programs A thru G) is shown in Table I. The market position is calculated as a combination of market share, total revenue, technology base cost efficiency, marketing, and investment needs. The attractiveness of the research area has been determined by: size, growth, competitive environment, cyclicity, and capital intensity. The position of the research areas on the matrix is shown in Fig 3. This is meant to be only an illustrative example. The list of qualities is by no means complete or the weightings definitive. The determination of these and the assignment of rankings is the core of a strategic planning exercise by senior management.

		research program (SBU)						
weight		A	B	C	D	E	F	G
market share	0.4	5	1	2	1	3	4	1
total revenue	0.1	3	1	3	2	3	3	2
technology base	0.1	5	2	3	2	5	4	3
cost efficiency	0.05	3	3	3	2	2	2	3
marketing	0.05	3	3	4	4	4	2	2
investment needs	0.3	4	3	3	0	4	4	2
size	0.1	2	3	4	4	4	3	4
growth	0.5	0	0	5	5	5	1	1
competition	0.2	5	4	2	3	3	4	2
cyclicality	0.1	2	3	3	4	4	3	3
capital investment	0.1	2	2	4	3	4	4	3
market position		0.86	0.38	0.53	0.22	0.70	0.74	0.35
attractiveness		0.32	0.32	0.80	0.84	0.86	0.46	0.38

Table I. Examples of rankings for McKinsey/BCG matrix.

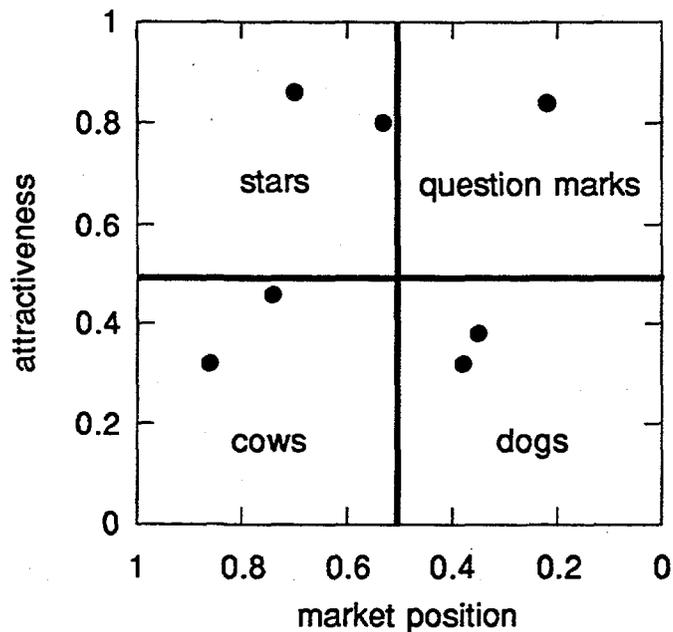


Figure 3. Location of rankings on the matrix.

Linear Optimization Model to Determine Entry Scale

With the need for new research in attractive areas now established within the framework of the McKinsey/BCG matrix, we turn our attention to the most optimal way of developing this research. This development can be done by either starting from scratch (diversification into a new research area, creating a question mark) then expanding the question mark into a star or by expanding an existing program in an attractive area (transforming an existing question mark into a star).

All of these activities consume laboratory assets and our resources are limited. We need to optimize our long term return on investment constrained by the available financial resources (e.g., LDRD and CRADA funding). We are immediately faced with the dilemma of either starting many small research programs, allowing them to develop for several years then pursuing the most successful on a large scale; or only pursuing the most promising on a large scale. The question can also be posed in a more continuous way – how many years of investigative research should we do. These questions can be answered by a straightforward decision analysis using a constrained linear optimization.

The model that we use consists of two functions. The first is the total return

$$R = N_b p_{sb} R_b + N_s p_s p_{su} R_b + N_s (p_{ss} - p_s) R_s, \quad (1)$$

where

- $R \equiv$ total \$ return,
- $N_b \equiv$ initial number of large research programs,
- $N_s \equiv$ initial number of small research programs,
- $R_b \equiv$ \$ return on large programs,
- $R_s \equiv$ \$ return on small programs,
- $p_s \equiv$ fraction of small efforts upgraded to full scale programs,
- $p_{sb} \equiv$ success rate of initial large program,
- $p_{ss} \equiv$ success rate of initial small program,
- $p_{su} \equiv$ success rate of large program after preliminary research.

The first term on the right hand side of Eq. (1) is the return from the programs that are initially started at a large scale and are successful. The second term is the return from the small programs that are upgraded to successful large programs. The return that is missed while the research is being done on the small programs is neglected. The last term is the return from the successful small programs that are never upgraded to large programs.

The total return needs to be optimized while constrained by the second function

$$I = N_b C_b + N_s p_s (1+r)^N C_b + N_s C_s \quad (2)$$

which is a constant. Here,

- $I \equiv$ total \$ available to invest,
- $C_b \equiv$ \$ to set up large research program,
- $C_s \equiv$ \$ to set up small research program,
- $r \equiv$ market growth rate,
- $N \equiv$ number of years before small programs upgraded to large programs.

The cost of setting up a large research program is assumed to be proportional to the size of the market when the program is established.* Therefore, the three terms on the right hand side of Eq. (2) are: the cost of setting up the initial large programs, the cost of upgrading the small programs to large programs after N years, and the cost of setting up the initial small programs, respectively.

There are three independent variables, N_b , N_s , and p_s in the above equations. Eq. (2) allows one to eliminate N_b in Eq. (1). One is left with a linear function of two variables that is constrained to the domain $0 < p_s < p_{ss}$ and $0 < N_s < N_{\max}(p_s)$. The maximum on N_s is forced by the inequality $N_b > 0$ and Eq. (2). When the optimization of the function $R(N_s, p_s)$ is done, we find that the optimal solution is determined by two factors. The first is the ratio of the expected value of the return on investment for small investments, $EVROI_s \equiv R_s p_{ss} / C_s$, to the expected value for large investments, $EVROI_b \equiv R_b p_{sb} / C_b$. The second is the corrected growth factor, $G \equiv (1+r)^N p_{sb} + (1-p_{ss}) + R_s / R_b$.

There are three areas in this two dimensional space with different optimal solutions (see Fig. 4). In region I, one should start many small programs then upgrade the successful ones after N years to large programs (i.e., $N_b = 0$ and $p_s = p_{ss}$). In region II, one wants to start only large programs in the research areas that have the highest probability of success (i.e., $N_s = 0$). The final area in parameter space, region III, is not physically realizable since the rate of return for small projects is not usually greater than that for large programs. For the sake of completeness, the solution in this region is to start only small projects and never upgrade them to large projects (i.e., $N_b = 0$, and $p_s = 0$).

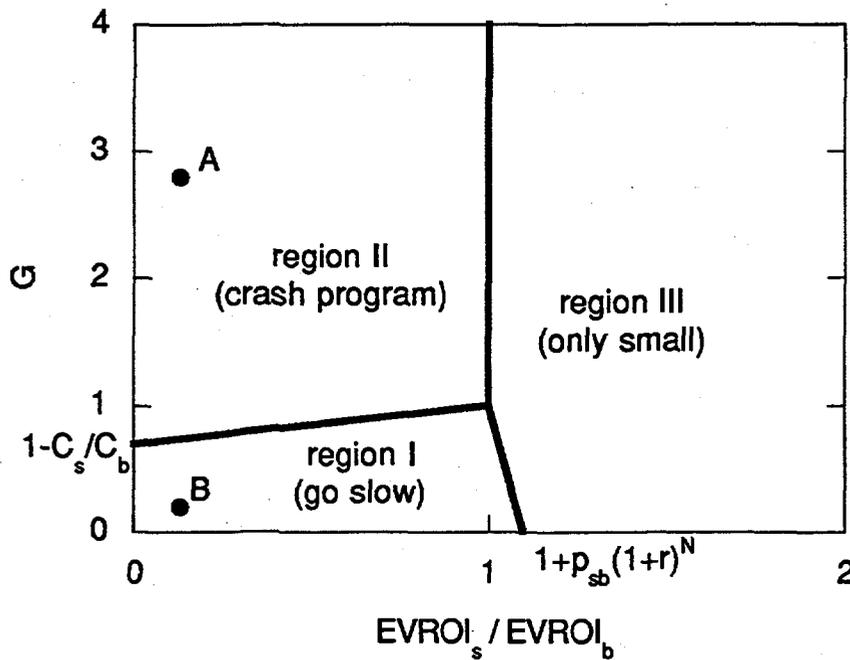


Figure 4. Areas in parameter space for optimal solutions.

The optimal value of the ROI in the three regions is most easily expressed as a value

$$Z \equiv \frac{R/I}{p_{sb} R_b/C_b} \tag{3}$$

scaled by the expected ROI if one started only large projects, $EVROI_b$. The maximum values are:

$$Z_{\max} = \begin{cases} 1 & \text{in region I} \\ \frac{\frac{R_s p_{ss}}{R_b p_{sb}} + \frac{p_{ss}}{p_{sb}} \left(p_{su} - \frac{R_s}{R_b} \right)}{\frac{C_s}{C_b} + (1+r)^N p_{ss}} & \text{in region II} \\ \frac{EVROI_s}{EVROI_b} & \text{in region III} \end{cases} \tag{4}$$

We now consider two different situations. For both situations, we assume that $p_{su} = 1$, $N = 3$, $C_s / C_b = 0.3$, and $R_s / R_b = 0.1$. The first scenario is that of starting research in a large growth area, $r = 50\%$, with a small probability of failure ($p_{sb} = 0.8$ and $p_{ss} = 0.3$). For this scenario, one is in the middle of region II as shown by point A in Fig. 4. For the

second scenario, starting research in a low growth area, $r = 5\%$, with a large probability of failure ($p_{sb} = 0.1$ and $p_{ss} = 0.03$), one is in region I (point B). The general conclusion that one should take away from these two scenarios is that one should start full scale programs when there is a large expected growth in the market after being discounted for failure, $(1+r)^N p_{sb}$. Here, we have neglected the last two terms in the expression for G since they are not significant in most cases.

The above two scenarios did not allow flexibility in choosing the number of years of research that one will conduct. A modification of the previous scenarios which has the same optimal solution, Eq. (4), will allow us to answer the question of how many years of research to conduct. We assume that $p_{sb} = 0.1$, $p_{ss} = 0.01$, $C_s / C_b = 0.01$, and $R_s / R_b = 0$ in all cases. The assumed probability of success of the programs upgraded in size after N years of research is shown in Table II. Also shown is the optimum value of the scaled return on investment, Z_{max} , for three different market growth rates. For a market with only a 5% growth rate, one should conduct all six years of research. The rate of return on investment will be 330% higher than if no preliminary research was conducted. Only 4 years of research should be done if the growth rate is 50% (15% increase in return on investment) and no preliminary research should be done if the growth rate is 100%. These results are the consequence of a competition between the rate of growth of our knowledge as the preliminary research is done versus the rate of growth in the market for that research.

N	p_{su}	Z_{max} ($r = 5\%$)	Z_{max} ($r = 50\%$)	Z_{max} ($r = 100\%$)
1	0.1	1	1	1
2	0.3	1.43	1	1
3	0.5	2.32	1.14	1
4	0.7	3.16	1.15	1
5	0.9	3.95	1.05	1
6	1.0	4.27	1	1

Table II. ROI for different number of years of preliminary research.

Some Final Thoughts

Scientific analyses of business situations need to be viewed for what they are: a framework on which to make decisions. The analyses serve to organize ones thinking. Many subjective judgments and simplifications are incorporated in them. They provide a first cut at the formulation of a decision. They are not the final word. Managers should apply their past experiences and subjective judgments to fine tune their decisions. For instance, the analysis shown in Table II for a growth rate of 50% concludes that one should do four years of preliminary research. If a manager's experience leads him to believe that the growth rate might be more than 50% but not less than that and if he also believes that the growth in knowledge indicated by p_{su} is the best case scenario, then he

might decide not to conduct any preliminary research. In contrast, if he believes that the largest possible growth rate is 5% then he would decide to do enough preliminary research to be sure of the best new project. That is, no reasonable combination of variables would lead him to start the projects at full scale. The first case was a borderline call, the second a "no brainer".

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1. C. W. L. Hill and G. R. Jones, *Strategic Management* (Houghton Mifflin, Boston, 1992), pp. 273-307.
 2. R. D. Buzzell, B. T. Gale and R. G. M. Sultan, HBR Jan-Feb 1979, p. 97.
- * The assumption that the cost of setting up a business is proportional to the size of the market can be justified by the following argument. Take the biomedical laser research market. Sandia was able to enter this market (\$6 million burn debridement CRADA) with very little investment because there was little high tech computer simulation and instrumentation applied to biomedical lasers. Now, in order to compete with them, we must invest much more to demonstrate the same capability that they are being paid to develop.