Title: **Committed Costs vs. Uncertainty in New Product Development**

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Keywords: operational analysis; product development; marketing; cost-risk

IC^2 Institute Working Paper WP-1993-02-01

(KY)

Committed Costs
vs.
Uncertainty Reduction in New Product

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Working Paper 93-02-01 A

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This paper discusses the nature of committed and determined costs in a new product development project, and quantifies their relationship to project uncertainty. We introduce the concept of "product, process, schedule and market (PPSM) intelligence" and emphasize its use for jointly considering marketing and production factors in project evaluation. Using a discriminant function-based measure of information gain, we compare committed cost, incurred cost and information gain over the life of a development project.

The method leads to a risk profile that may be constructed from the observed behavior of the firm, without the use of hypothetical lotteries. We show, using data from two companies, that this cost-risk construct is meaningful and can provide guidance for operational decisions in the new product development process.

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Introduction

It is often observed that the greatest portion of total product development costs are committed in the design phase. That is, new product design, engineering, production and marketing costs are committed, or "frozen," much faster than they are actually expended. More specifically, several sources (see e.g. Corbett, 1986; Rasmussen, 1990; Port *et al.,* 1990) report a pattern of committed vs. expended monies over the development cycle similar to that of Figure 1.

At each phase of this cycle, the firm attempts to reduce project uncertainty by pursuing increasingly accurate estimates of life cycle cost and the likelihood of success in the marketplace. This is achieved by means of consumer focus groups, production pilot tests, destructive testing, test markets, and so on.

It has been informally observed[1] that a firm should not commit funds at a rate that exceeds the rate of uncertainty reduction. This is apparent from the following argument: A given return on investment (ROI) is projected for a project, and a certain investment has been committed. Given that subsequent information confirms the expected ROI, what incentive would justify committing additional funds? For a risk-averse manager, the answer is, "only a reduction in the uncertainty surrounding the ROI estimate."

The purpose of this paper is to formalize this observation. The paper elucidates the nature of committed costs and clarifies the

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[1] *inter alia,* in remarks by Wolter Fabrycky at the National Science Foundation International Workshop on Concurrent Engineering Design, held at the IC^2 Institute in October, 1990. See also Blanchard and Fabrycky (1990). The authors are grateful to Prof. Fabrycky for additional helpful comments during the research leading to this paper.

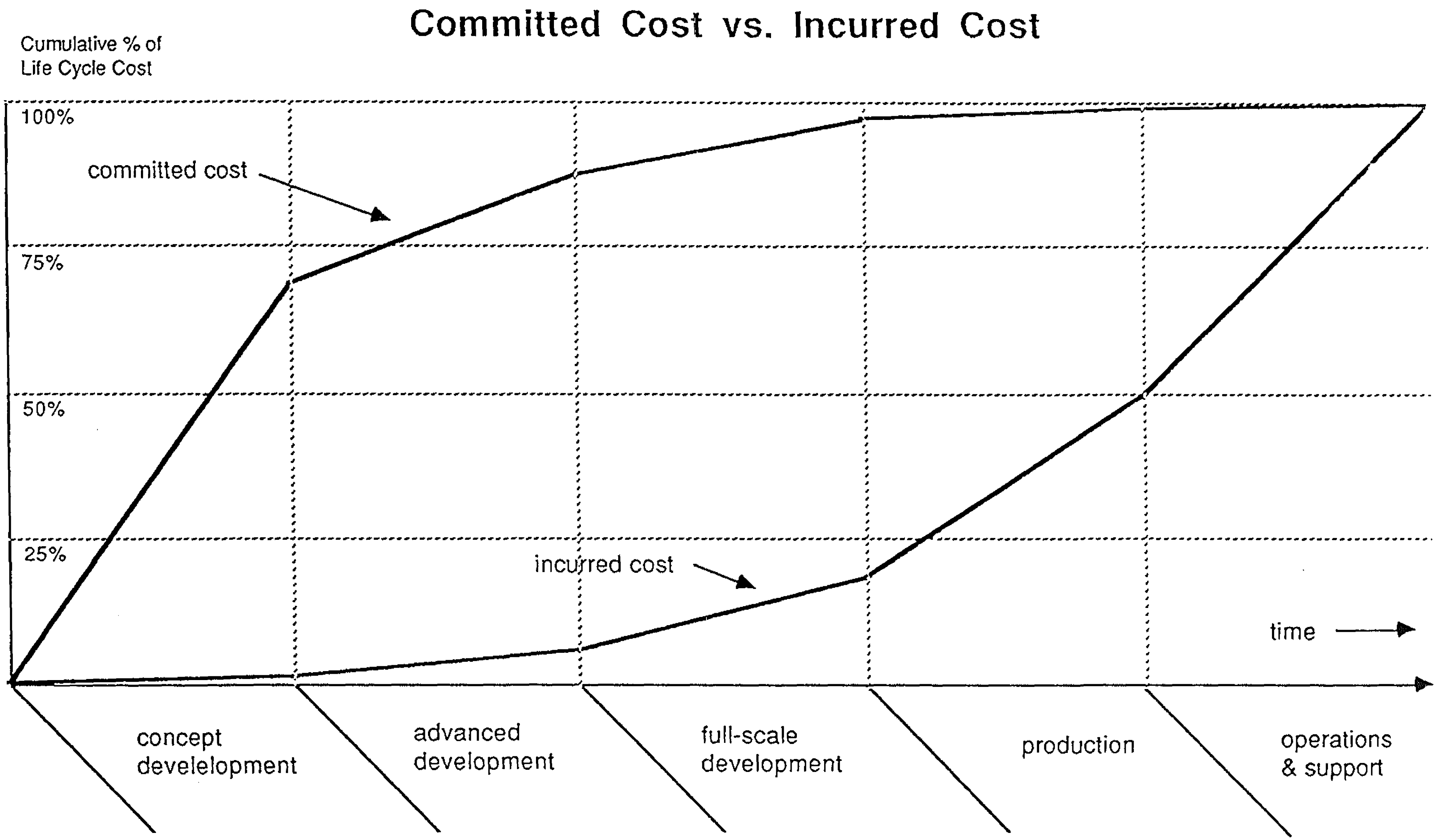
Committed Cost vs. Incurred Cost
Cumulative % of Life Cycle Cost
100%
75%
50%
25%
committed cost
incurred cost
time
concept develelopment
advanced development
full-scale development
production
operations & support

Figure 1

associated terminology. We develop a measure of uncertainty that is pertinent to the Go/NoGo decision for a new product, and, using both published and proprietary data, compare average rates of cost commitment and average rates of uncertainty reduction in project administration. As part of this descriptive effort, we lay the groundwork for operational guidelines for gathering market, product performance and process intelligence when the firm is under pressure to achieve rapid time-to-market.

The following sections clarify the nature of committed costs, develop the needed uncertainty measure, assess the risk behavior of the firms on which the data were based, and interpret the implications of the work.

Committed Costs

Committed costs are fixed future streams of expenditures. Within this definition are leases and other contracts (with suppliers, customers and employees), warranties, mortgages, and capital amortizations. Such commitments can reduce uncertainties of supply, eliminate some search costs, increase demand, deny opportunities to competitors, and lock in lower costs over the life of the commitment.

Designs, tooling, and other hardware are also frozen at the time a decision is made to commit funds. Another relevant category of costs, then, are those that flow consequentially from a design decision. If, for example, a design calls for aluminum rather than plastic, aluminum must be purchased and machines for forming aluminum must be acquired. "These detail design decisions... in large measure determine how big the factory will be, how many assembly operations will be required, and what the component purchase costs will be (Chryssolouris, Graves and Ulrich, 1991)." Some of these costs, e.g. the incremental cost of acquiring aluminum processing equipment rather than plastic molding machines, are known. Others, such as the future relative prices of aluminum and its alternatives, are subject to uncertainty.

The first category, *committed* costs (including leases etc.), are nonrecoverable if the project fails. The second category (materials etc.), although possibly recoverable, are irreducible if the project proceeds. The collection of both categories might be called *determined* costs. In the next section, we examine the foundations of Figure 1 and find that this distinction is meaningful. Appendix 1 traces the history of Figure 1 in the literature.

Freezing designs and costs makes "downstream" tasks more efficient, because engineers and managers know what it is that must be manufactured, advertised and distributed, and under what conditions these tasks must be executed. Contingency plans dealing with other design alternatives can be discarded. On the other hand, of course, committed costs reduce flexibility. They make less cash available for alternative investments that may come to light. If market estimates or consumer requirements change, costs sunk into the wrong design are not recoverable. Managers ask, "What would it cost to shut down this project?" The answer to this question is, "the present value of all nonrecoverable costs." This quantity, together with speed of response, are components of the firm's flexibility.

Under sequential engineering, a prototype could be built and tested before beginning the search for the best production method. The costs of prototyping included only the cost of building and testing the prototype. Under concurrent engineering - and pressure toward rapid time-to-market - the prototyping activity includes looking ahead to manufacturability. The cost of investigating and deciding the mode of production is now part of the cost of prototyping. This cost is now committed - and possibly expended - earlier. And, if the project is killed, these costs are not recovered. At any stage of the development process, then, bailout costs are *increased* under concurrent engineering. These increases must be offset by extra revenues from early market launch of successful alternative products, if concurrent engineering is to add flexibility to the enterprise.

Clearly, maximum flexibility would result from holding design alternatives open as long as possible, and operating on a cash-and-carry basis, making the two curves of Figure 1 converge. But this strategy would eliminate the benefits of cost commitment that were noted above, and is certainly unrealistic in almost all cases of interest to industry.

Postponing cost commitments

What is the relation of cost commitment to uncertainty reduction? We shall argue that the prospect of reduced uncertainty is the only justification for postponing cost commitments. In other words, if no further uncertainty reduction is expected, all project costs may be committed at the earliest possible moment.

At many stages in the new product development process, data are collected and estimates made regarding product performance, manufacturing process costs and alternatives, project schedule, alternative investments, and market response. We refer to these collectively as product, process, schedule, and market (PPSM) intelligence. These intelligence gathering activities ("tests") are scheduled, and precede decision points (also scheduled). At each decision point, we assume, management may specify a value for "fraction of remaining project costs to be committed at this point."[2] Four additional choices are made at each decision point: (i) "Go," i.e. proceed directly to rollout of the product with no further testing; (ii) "On" to the next test; (iii) "Skip" the next test and proceed directly to the next test but one[3]; or (iv) "No Go," i.e., kill the project. (See Charnes, Cooper, DeVoe and Learner 1966, 1968.) The first, second and third alternatives imply continuing with all scheduled production, advertising, and other "non-test" activities. Of course, for the fourth alternative, no further costs should be committed. For purposes of analysis, we assume no unscheduled tests or decisions are made.

These conditions, plausibly reflecting management practice, justify the assertion that all remaining project costs may be committed immediately if no further PPSM intelligence is anticipated. Moreover, if the aforementioned benefits of cost commitment are material, all remaining costs *should* be committed immediately under

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[2] Committed costs as defined above are a different quantity from the expenditures management *authorizes* at each decision juncture. In the event of a subsequent project shutdown, some authorized monies that have not been committed or expended may be recoverable.

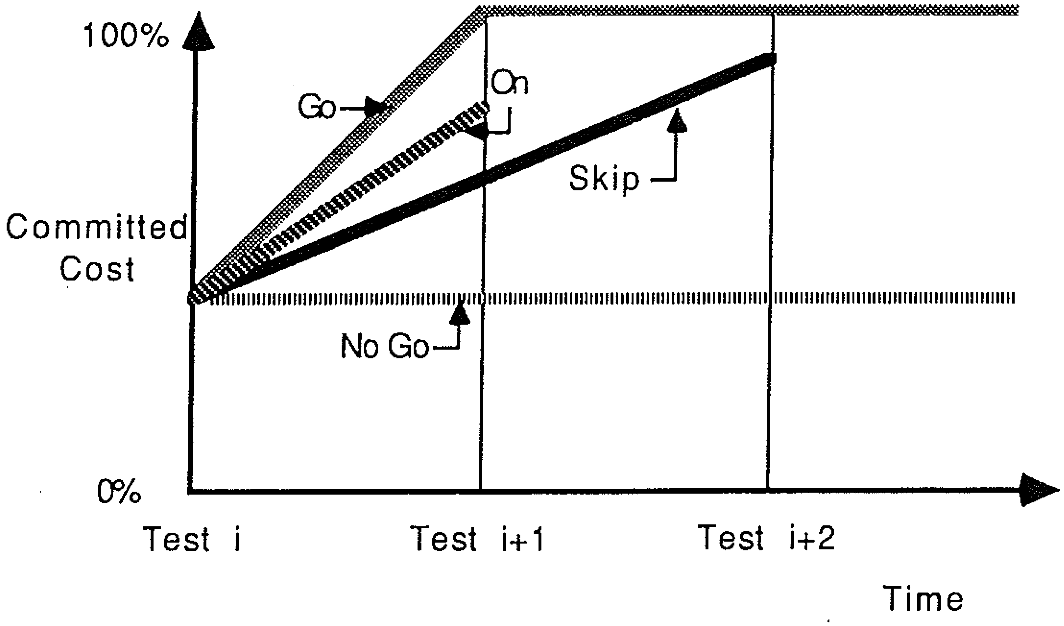
[3] For example in Urban and Katz (1983) "...some conditions are identified under which a test may be bypassed."

such circumstances. The following example, though unrealistic, will make the point: Suppose no further intelligence is to be gathered. The project schedule does not call for a factory to be leased until the product prototype is complete, and that activity is just beginning. Why should a lease be signed now rather than at the later, scheduled time? If a lease decision is to be made after a search for the best location and lease terms, then the search and decision should be in the project schedule, and the lease signed at the scheduled time. (We hold open the possibility that available lease terms may be so prohibitive as to merit a "NoGo" decision at that time.) If such a search-and-decision is *not* scheduled, then the lease *may* be signed immediately; there is not, nor will there be, any information to indicate the contrary. There is no incremental cost attached to making this commitment now rather than later; the cost of capital pertains only to the time of expenditure, not the time of commitment.

Figure 2 summarizes the possible trajectories of committed costs from a decision point "i." In the case of the "On" decision, an additional decision on committed costs must be made at stage i+1. Other decision options determine the path of committed costs for longer time spans.

Having established that all costs may be committed at the moment when no further PPSM intelligence is expected, we move to the question, "How much cost may be committed when such intelligence *is* anticipated?"

Figure 2. Impact of GO - ON - SKIP - NO GO decision on committed costs



Uncertainty in the new product development process

Rigorous and unambiguous measures of information and uncertainty have been available since the 1940s for dealing with events that are characterized by one or more probability distributions. What may be at issue in the analysis of a particular problem is the definition of the appropriate random variables and their distribution functions.

The problem addressed in this paper is that of describing the rate at which a firm commits funds, relative to the rate at which it reduces uncertainty. The preceding section informally established that these two rates should be somehow linked.[4]

Appendix 2 examines a number of uncertainty measures and concludes that the discriminant function is best suited to dealing with

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[4] We note, again informally, that the proposition is implicit in Akaike's (1973) construction of a decision-theoretic loss function from Kullback's (1959) information measure.

data like those of Table 1. Table 1 shows Booz-Allen data (cited in Cunningham and Cunningham, 1981) on new product project attrition.

Table 1

development stage	number of surviving projects	q=Prob {market success | survived this stage}	-q ln q -(1-q)ln(1-q)
start	116	0.009	0.050
product evaluation	24	0.042	0.173
economic analysis	14	0.071	0.257
product development	6	0.167	0.451
test market	2	0.500	0.693

According to Morrison (1976), the log likelihood ratio

$$\lambda = \ln [\, g(.) / h(.) \,] \qquad (1)$$

is a sufficient function for discriminating between two distributions g and h, based on an observation vector **x** of what we have called PPSM test results. In the Kullback (1959) theory, λ is equal to the information provided by **x** favoring the hypothesis $H_1: \mathbf{x} \sim g(\mathbf{x})$ over the hypothesis $H_2: \mathbf{x} \sim h(\mathbf{x})$. That is, the discriminant function (4) is the optimal way of classifying a project either as a member of the population "products that will succeed" or as a member of the population "products that will fail." The decision rule is, "**x** was generated by a member of the successful population g if $\lambda > 1$, and by a member of the unsuccessful population h if $\lambda \leq 1$."

A sequence of PPSM intelligence gathering activities i = 1,2, ..., n occur throughout the duration of the development project, resulting in the data vector $\mathbf{x} = (x_i)$. Each x_i is a random variable with density $g_i(x_i)$. We build a stepwise discriminant function using the cumulative PPSM data:

$$
\begin{aligned}
&\lambda_1 = \lambda_1(x_1); \\
&\lambda_2 = \lambda_2(x_1, x_2); \quad \ldots \qquad\qquad (2) \\
&\lambda_n = \lambda_n(x_1, x_2, \ldots, x_n).
\end{aligned}
$$

If the PPSM results x_i are not collinear, each successive λ_i will be a better discriminator in that the probabilities of misclassification will be reduced.

The i^{th} PPSM test yields discrimination information λ_i. Following this test, if the project is not terminated, a decision must be made concerning the amount of further cost commitment. We desire to commit costs at a rate less than or equal to the rate of change of information increase (uncertainty decrease). The value of λ_{i+1} is not yet known, so we must estimate it using its expected value under H_1

$$\hat{I}_{i+1} = \int g_{i+1}(x_{i+1})\, \lambda_{i+1}(x_1, x_2, \ldots, x_{i+1})\, dx_{i+1} \quad . \qquad (3)$$

The additive property of the logarithmic information measure (see Kullback, 1959) allows us to propose the operational rule

At phase i (following test #i), commit the additional fraction of total project costs equal to $(\hat{I}_{i+1} - \lambda_i)/(\hat{I}_n - I_1)$.

However, as we are in this initial development primarily concerned with descriptive rather than normative measures, we now return to the attrition probabilities of Table 1, reinterpreting them in Table 2 as the (average) odds of correctly classifying a successful product[5]. The rightmost column of Table 2 may be identified with equation (3). It is the expected value of the discriminant function at each stage.

The rightmost column of Table 2 is graphed in Figure 3. It is, as desired, monotonically increasing, implying that uncertainty is monotonically decreasing. If the rate of cost commitment and

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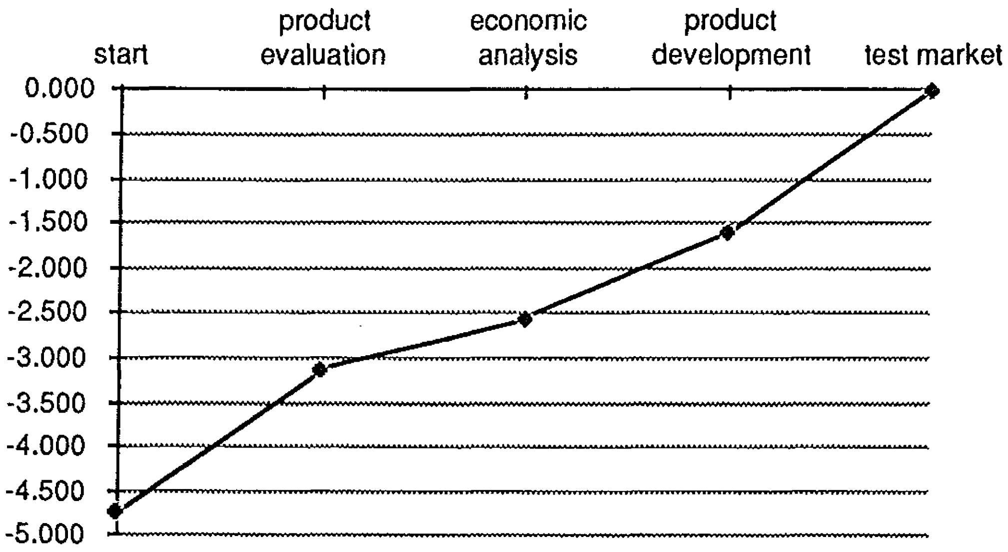
[5] Perfect information is obtained when x_n, the actual market performance, is observed. At that time, λ will have an infinite value. However at that time all project costs will have been committed, so the relevant span of time for this analysis of cost and uncertainty ends at the moment of the product rollout decision.

uncertainty reduction were parallel, however, and if Figure 1 is accurate, the graph of Figure 3 would have the concave shape of the upper curve in Figure 1. In the next section, we attempt to reconcile Figure 1 and Figure 3.

Table 2: Average log odds of correctly identifying a successful product. (From the data of Table 1.)

development stage	q=Prob {market success | survived this stage}	odds of success = q/(1-q)	log odds success
start	0.009	0.009	-4.745
product evaluation	0.042	0.043	-3.135
economic analysis	0.071	0.077	-2.565
product development	0.167	0.200	-1.609
test market	0.500	1.000	0.000

Figure 3. Average log odds of correctly identifying a successful product, by development stage.



Product development risk: Empirical results

Company A

The Shields data on committed costs (see Figure 1 and Appendix 1) probably heavily represent avionics and aircraft parts manufactured by aerospace firms. The Booz-Allen data of Table 1 cover a variety of industries, but list toward consumer goods. Inferences drawn by comparing the costs of the former with the risks of the latter would be suspect. Instead, in this section we present and compare results drawn from two individual firms, one on the basis of secondary data and one on the basis of primary (original) data.

McGrath, Anthony and Shapiro (1992, page 49) offer the needed cost and risk data drawn from a single firm ("Company A") and from "other companies considered to be the best" product developers in Company A's industry. (The consulting firm with which these authors are affiliated works largely with firms in electronics-related industries.) McGrath *et al.* refer to the committed costs associated with cancelled projects as "lost investment." The attrition and cost data for Company A appear in Table 3.

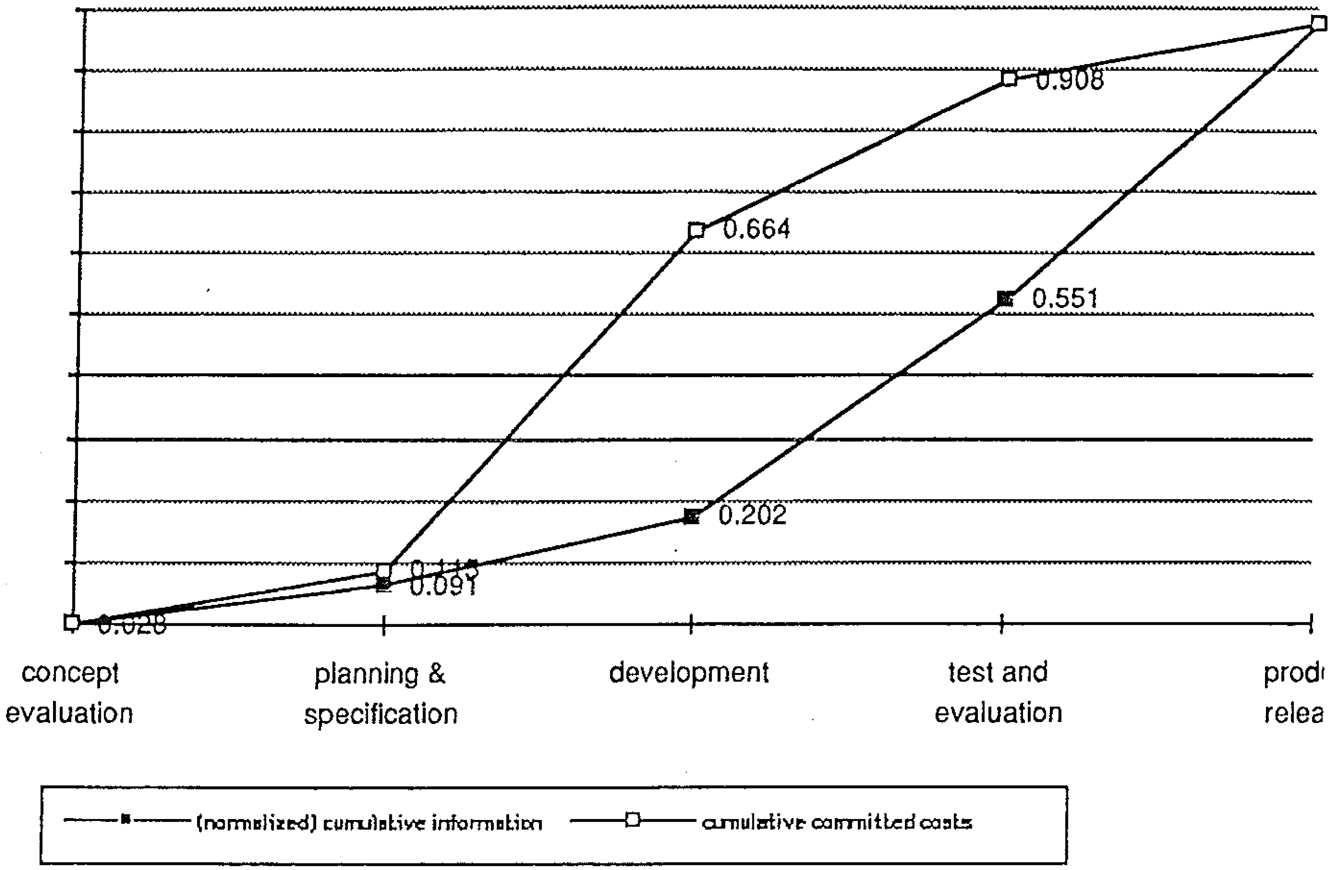
Table 3. Attrition and Committed Cost Data for Company A's failed new product development projects.

development stage	% of cancelled projects failing in this stage	Lost investment due to cancelled projects*
concept evaluation	19%	3%
planning & specification	26%	9%
development	37%	55%
test and evaluation	14%	24%
product release	5%	9%

* expressed as percent of all lost investment on cancelled projects

Figure 4a displays the cumulative information gain and cumulative committed costs for this firm, normalized to the same scale. The names used on the x-axis for the development stages are those used by the consulting firm. Note that Figure 4a differs from Figure 1 in that the lower line is information gain, *not* cash expenditures.

Figure 4a. Average uncertainty reduction vs. average cumulative committed cost, by development stage: From published data on a single firm.

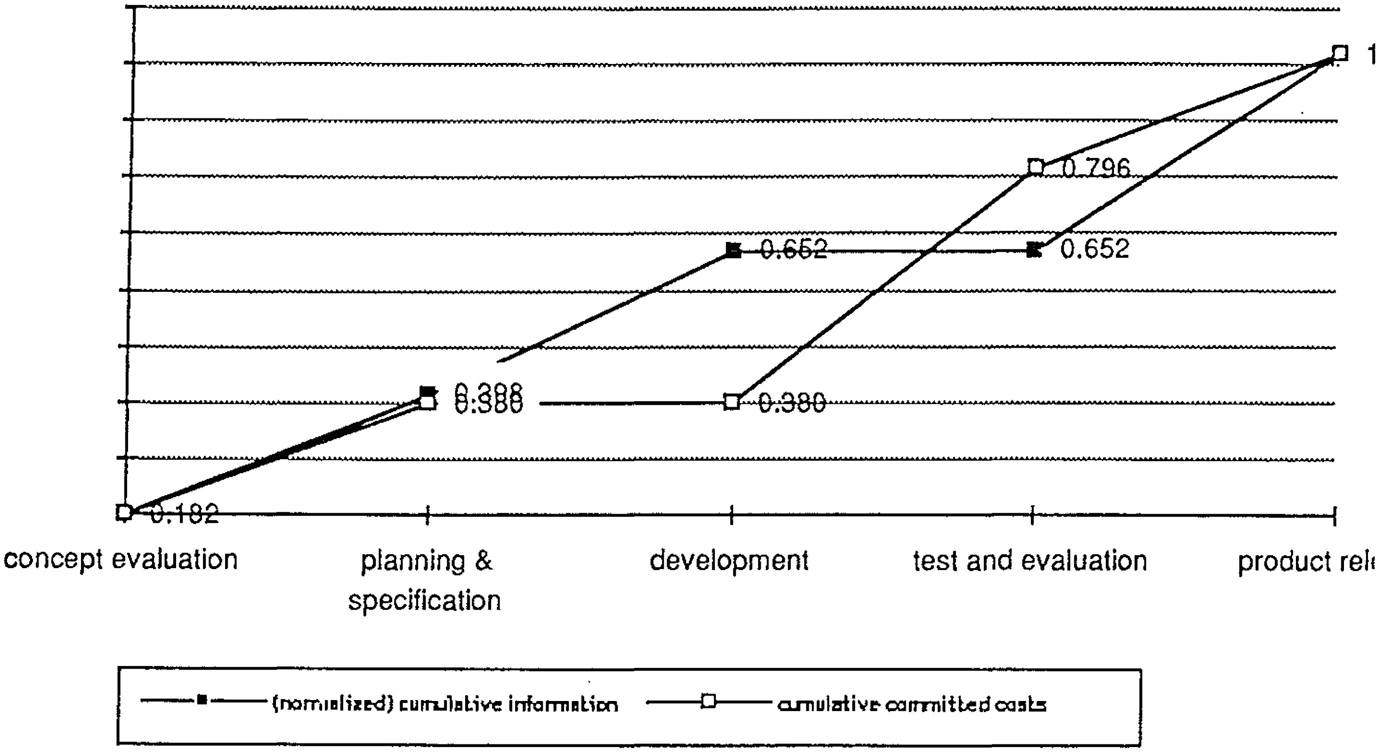


This firm's committed cost (the upper curve) shows the same concave shape as the Shields data. The fact that this curve lies consistently above the risk-reduction curve shows that the firm is, intentionally or not, risk-inclined.

Figure 4a's comparison of rates of cost commitment and uncertainty reduction lends itself to a very simple index of risk behavior. To construct the index, simply sum the differences between the latter two rates at each development stage, then divide by the number of free points of comparison. For the company represented by the McGrath *et al.* data, the risk index is (.024+.462+.357)/3=.281. The completely risk-neutral firm would of course have an index of zero, and risk-averse firms would have a negative index.

Figure 4b displays the same analysis for the McGrath *et al.* data on the industry leaders. McGrath *et al.* do not reveal how many companies are summarized in this aggregate. The closer convergence of the two curves in Figure 4b, and the risk index value of -0.049, show that the industry leaders in Company A's industry were slightly risk-averse but generally matched risk reduction and cost commitment more skillfully than did Company A. This analysis supports McGrath *et al.*'s contention that the leaders in Company A's industry are superior managers of the product development process, at least relative to Company A itself.

Figure 4b. Average uncertainty reduction vs. average cumulative committed cost, by development stage: From published data on an aggregate of industry leaders.

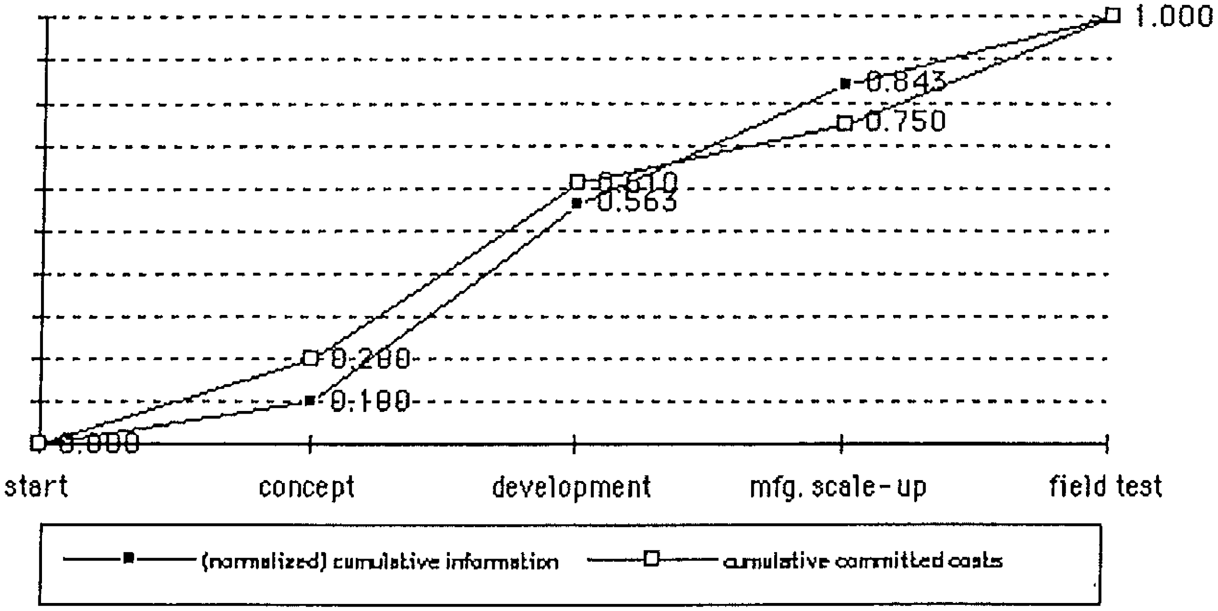


McGrath *et al.* note that the development stage is usually where most of the development investment is made. This is the stage where their industry leaders are most risk-averse. (The leaders become risk-inclined in the test and evaluation stage.) It is also where Company A itself is most inclined to take risk. They note further that "the best practice companies [shown in Figure 5] developed 48 products at a cost of $60 million, while it cost the case-example company $75 million - 25% more [to develop the same number of products]." McGrath *et al.* fault Company A for scuttling an insufficient number of unworthy projects in their early stages. With equal justice, one might fault Company A for having too many bad product ideas in the first place, or for committing too much investment too early. The new product development battle can be fought on any of these arenas, and the risk profile developed in this paper does not unduly emphasize any of the arenas.

Company B

From a large, diversified manufacturer of industrial and office products, we obtained data on twenty new product development projects randomly chosen from a file representing all the firm's business units. For project planning and evaluation purposes, this firm (Company B) divides such projects into four stages: Concept, Development, Manufacturing Scale-up, and Field Test. In each stage, a project manager must estimate the updated internal rate of return, market risk, and technology risk. This firm uses only owned factories, and prefers line extensions to new businesses; by avoiding leases and unfamiliar new equipment, committed costs are minimized. Nonetheless, it is remarkable that the two curves of Figure 5 match so closely. Indeed in the manufacturing scale-up phase, the curve representing rate of cost committment falls below the rate of information increase.

Figure 5. Average uncertainty reduction vs. average cumulative committed cost, by development stage: Data from an innovative diversified company.



The raw data show that a few of the failed projects incurred expenditures in excess of the forecasted life cycle cost. Indeed, the overrun may have contributed to the NoGo decision. The upper curve of Figure 5 was derived using only the failed projects, for which the shutdown costs were known with certainty. The shutdown decision may have been based on cost overruns or on the perception of relatively low shutdown costs, so the extent and direction of bias in the placement of the upper curve is a matter for conjecture. (These comments apply also to Figures 4a and 4b.) Also, the location of the left end of the line at zero is arbitrary, as the data contained no projects that failed at the "start" stage. However, the fact that the lines nearly coincide does not depend on this arbitrary choice. The 50% rate of conversion of concepts into market successes, and the close convergence of the two curves in Figure 5, demonstrate that Company B's reputation as a superior developer of new products is well-deserved.

For Company B, the risk index takes a value of (.10+.05-.09)/3=.02. This index, although a useful summary, obscures interesting diagnostic features like the crossover in Figure 5. There, the firm in question becomes more risk-averse in the scale-up stage than it was in earlier stages.

Are the development stages named by the different sources truly comparable, and is terminology consistent? What were the time periods spanned by the studies? As "committed costs" and "determined costs" are not conventional cost categories in corporate reporting, how were these quantities defined and how were they culled from financial records? These uncertainties suggest a preliminary investigation of the robustness of the discriminant function-based risk profile is in order.

Sensitivity analysis

A 1990 SAMI report (*Wall Street Journal,* 1990) revealed that of 6,960 new brands introduced in the two previous years, only 240 reached the $1 million annual sales mark. This is slightly less than 3.5%, quite a different number from the 50% post-introduction "success rate" actually achieved by Company B. The low 3.5% figure may be peculiar to the consumer package goods industry. But how sensitive are the results of analyses like those of Figures 4 and 5 to the post-launch success rate? Table 4 suggests they are quite insensitive. Table 4 gives the data for the "information curve" of Table 1 for each of several product success rates. (The numbers for "start" and "test market" remain the same, of course, due to the normalization.)

Table 4. Normalized information at each development stage as a function of product success rate

post-launch success rate	start	product evaluation	economic analysis	product development	test market
3%	.65	.79	.83	.90	1
10%	.65	.78	.83	.90	1
17%	.65	.78	.83	.90	1
50%	.65	.77	.81	.88	1
90%	.65	.74	.77	.83	1

Conclusions, qualifications, and directions for research

Joint consideration of the three curves "committed cost," "incurred cost" and "information gain" can illuminate the relationship between flexibility and risk. The relationships drawn in this paper can elucidate the risk behavior of firms and industries, aid the comparison of new product development procedures between nations, and provide operational (normative) guidelines on how managers should commit project costs.

The above mathematical formulation addresses committed costs, and does not deal explicitly with the wider category of determined costs. Costs are "determined" in this wider sense when design decisions lock in materials and product/process technologies. The issue associated with "determined costs" is that changing materials costs, customer tastes, competitor capabilities, and product/process technologies may reduce the market viability of the current design. By including technological scanning within the scope of PPSM intelligence, and by including technology assessment in the ROI estimate for the current design, the mathematical model offered by this paper can address technological risk without modification.

The overt problem in new product development is to increase the "hit rate," i.e. the proportion of concepts that become market successes. A collateral problem, no less important, is reducing the cost of failures. It is the latter problem to which the present research is most applicable. This paper has discussed the nature of committed and determined costs, and quantified their relationship to the reduction of project uncertainty. We have introduced the concept of "product, process, schedule and market (PPSM) intelligence" and emphasized its use for jointly considering marketing and production factors in project evaluation. We have shown that the ideas developed can show the relationship between cost commitment and risk behavior of the firm, and provide guidance for operational decisions within a firm. We close with a call for careful collection of industry-specific data for further tests of these ideas.

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APPENDIX 1: Committed costs vs. expended costs

It is the rare conference or publication on new product development in which a variant of Figure 1 (in the text of this paper) is not displayed. In this appendix, we trace the genealogy of the several versions of this graph that have been circulated throughout the research community.

In each portion of Table A1.1, the data series (columns) are given the names used by the original source. All numbers are cumulative.

Table A1.1. Patterns of Committed/Determined Costs

I. Rasmussen (Kodak)

stage	"committed"	"spent"
concept	65%	5%
validation	85	8
development	95	20
production	100	80
operation	- -	100

II. Shields

stage	"committed"	"cash flow"
conception	65%	8%
design	85	13
testing	92	15
process planning	97	25
production	100	100

III. Riddell

stage	"determined"	"incurred"
concept development	70%	1%
advanced development	85	7
full-scale development	95	18
production	100	50
operations & support	- -	100

IV. CAM-I (MECM)

stage	"impact on cost"	"cost"
concept	70%	3%
full development	85	15
production	95	50
operations & support	100	100

V. CAM-I (ME)

stage	"committed"
system planning and conceptual design	55%
preliminary system design	85
detail design and development	97
production, construction and evaluation	100
system/product use and logistics support	--

Jakeila (1989) cites Rasmussen's 1989 presentation to CAM-I as the source of his figures, and Rasmussen in turn (1990) cites the Kodak Corporation. Shields (1989) does not cite a source. Port, Schiller and King (1990) cite CAM-I as the source of the graphic in their *Business Week* article; the figures therein seem to be an amalgam of those presented by Riddell (1989) and Lewis (1989) at various CAM-I symposia. Riddell's original slide cites the Boeing Corporation as the source of data. Lewis's slides cite the January, 1987 issue of *Mechanical Engineering* (denoted in Table 1 above as "ME") and the August, 1980 issue of *Military Electronics/Countermeasures* ("MECM" in Table 1 above) respectively.

In addition, Whitney (1989) notes that 70% of General Motors' cost of manufacturing truck transmissions is determined in the design stage. Whitney also cites a study at Rolls Royce (Corbett, 1986) showing that 80% of the final production cost of various components is determined in design.

Whitney, and Riddell and MECM, use the terms "determined cost" and "impact on cost," respectively. That their numbers are slightly higher than the corresponding numbers in the "committed cost" columns lends support to the distinction between "committed" and "determined" that we advanced in the text of this paper. Of course, there is no assurance that the product development stages named by these several sources are strictly or even approximately comparable.

APPENDIX 2: Developing a PPSM uncertainty measure

Below, we discuss a number of random processes and uncertainty measures in the context of the new product development process, in order to clarify issues and terminology, and to lead to a measure that will be useful in guiding expenditure decisions.

Entropy Measure

"Committed cost" as portrayed in Figure 1 of the text means money that must be expended at the scheduled (future) time even if the project is cancelled today. In the language of project management or decision analysis, the level of committed cost at time t or phase n is the "cancellation penalty" or "bailout cost" at time t or phase n.

Most firms and industries maintain project histories from which the probability of bailout at phase n can be computed, namely, as the proportion of projects that survive the phase n review. Table 1 in the text of this paper displays an attrition pattern for a set of 116 ideas for new products. It may be read, e.g., "After economic analysis, 14 of the original 116 projects will have survived." In the third column, the quantity q represents the updated probability of success for the product. 1-q then is the updated probability of failure. The rightmost column of the table gives the entropy of the probability law (q, 1-q), as defined in equation (A2.1).

$$H(q) = -q \ln q - (1-q)\ln(1-q) \qquad \text{(A2.1)}$$

The entropy is often taken as a measure of the uncertainty inherent in such a probability law (see Shannon, 1948). A thought experiment will illustrate this use of H(q). Suppose a completely prescient and truthful being tells us, at the prototyping phase, whether each given product will succeed or fail in the marketplace. The average information content of this message is $H(q) = .117$. This small number means the message (which will almost always be, "The product will fail") is usually unsurprising and hence relatively uninformative. Contrast this to the higher information content of a perfect forecast delivered at the time of product rollout, when prior success and failure probabilities are more equal.

Although we might intuitively regard the development process as decreasing uncertainty at each stage, Table 1 shows that, on the contrary, uncertainty increases. Prior experience tells us 114 of every 116 product concepts will fail or will be rejected prior to launch. Therefore for an arbitrary concept, we are almost certain that "this won't work." As we work to increase the odds of success for the particular concept, uncertainty necessarily increases.

The above is a consequence of the fact that the graph of $H= p \ln p$ is concave over the range $0 \leq p \leq 1$, reaching a maximum when $p=0.5$. We must look further for an information function that increases monotonically as the odds of product success progress from very small to very high.

ROI Variance Measure

PPSM intelligence will be gathered at each phase shown in Table 1, making the product development process a multistage decision problem under uncertainty with recourse. That is, the Go/NoGo decision is made repeatedly, using the latest updated PPSM data. Where the historical data of Table 1 refer to the aggregate of past projects, these updated PPSM data pertain to a particular concept/product. It is important to note that whereas the (q, 1-q) law describes the binomial random variable "success/failure," the project-specific PPSM intelligence refers to a different random variable, a measure of success that for the purposes of this paper we will assume is return on investment (ROI).[6]

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[6] The criterion could as well be payback or other traditional measures. Although advances in measurement such as data envelopment analysis (Charnes, Cooper and Rhodes, 1978) are now available for the multicriterion evaluation of projects, here we stay with single-criterion measures for simplicity of exposition and to clarify the relationship between cost commitment and uncertainty reduction.

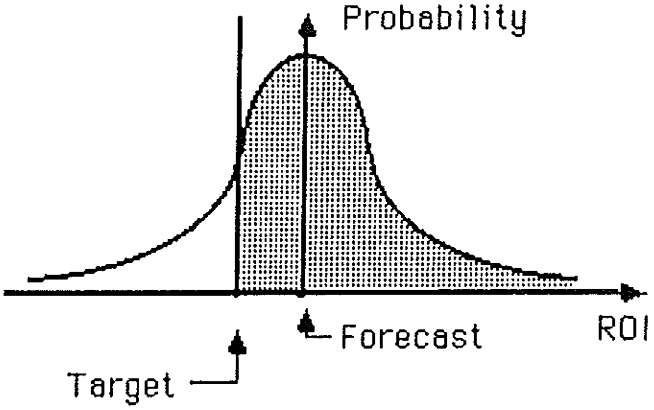

Figure A2.1: Market or ROI Forecast

The Go/NoGo decision is made according to whether the ROI forecast exceeds a target value, possibly with a confidence margin. Each forecast may be stated as a point estimate with a variance, so that the Go/NoGo decision can be conceptualized as in Figure A2.1, under a suitable assumption on the distribution of the ROI estimate. The probability of project survival, immediately prior to a test producing data like that of Figure A2.1, is the expected area of the shaded portion. Following the test, the quantile of the Figure A2.1 distribution representing the shaded portion is taken as the updated probability of marketplace success.

Each successive item of PPSM intelligence should reduce the variance of the expected ROI distribution. If this distribution is normal (Gaussian), its entropy is uniquely determined by its variance (Hastings and Peacock, 1975):

$$H(ROI) = - \ln \sqrt{(2\sigma^2\pi e)} \qquad \text{(A2.2)}$$

As σ^2 decreases, H decreases, indicating a reduction in uncertainty. However, this uncertainty is uncertainty about ROI, not about the product success/failure question *per se.* Measure (A2.2) therefore is not suitable as a guide for scheduling the commitment of costs. To continue the thought experiment, suppose the ROI variance collapses to zero around a mean that is less than the target ROI. Uncertainty has been reduced maximally, yet it is clear no further funds should be committed.

Directed Divergence of p against q

Using the q from Table 1 as a prior distribution, and p as the updated probability of product success, the reduction in uncertainty provided by PPSM intelligence at phase n may be written as

$$I(p:q) = p \ln(p/q) + (1-p) \ln [(1-p)/(1-q)] \qquad (A2.3)$$

where p and q refer to phase n. This measure, due to Kullback (1959), is a generalization of the entropy measure (A2.1).

Expression (A2.3) may represent information gain from an updated sample relative to a baseline sample. Akaike's principle, however, holds that the loss function should equal the directed divergence of the sample against the true distribution. For a single development project, there is no "true" distribution; or, we might say, the distribution collapses to Prob{success}=0 or Prob{success}=1 when the decision or market response is known. This state of affairs violates the "absolute continuity" assumption of the directed divergence measure (see Kullback, 1959). More plainly, for a discrete distribution, this means there will be zeros in the denominator.

Measure (A2.3) highlights the fact that uncertainty is not reduced in an absolute way; it is reduced *relative to some prior state of knowledge.* Without bringing in additional considerations, we have no guidance as to how to specify the prior state of knowledge. For example, to measure reduction in total project uncertainty, must we use as baseline only the 1-in-100 odds given at the top of Table 1 of the text, or is there a way to use all the information given in Table 1 as the baseline state of knowledge? In any case, information to the effect that "the odds of product success are *not* 1-in-100" does not relate directly to what the odds of success *are.* Thus, measure (A2.3) alone cannot be used to guide cost commitment.

Discriminant Functions

Balachandra (1984) uses discriminant analysis in a retrospective study of 100 new product development projects, and translates the results of the analysis into qualitative guidelines ("red light, yellow light, and green light" signals) for the Go/NoGo decision. Zirger and Modique (1990) also use discriminant analysis to find the organizational factors conducive to success of the development process. In this section we use the discriminant technique, with PPSM intelligence as independent variables, for a different purpose. This purpose is to arrive at an information function that will yield quantitative guidelines for the commitment of project costs.

Let us suppose that successful products, in the past, have returned ROIs distributed as the density function g(.), and failed concepts or products have had a distribution of ROI h(.). The latter distribution is constructed using the best estimated ROIs of projects that have been terminated prior to product launch, and the actual ROI performance of products that have failed after launch. The specific functional forms of these distributions are immaterial at present.

According to Morrison (1976), the log likelihood ratio

$$\lambda = \ln [\, g(.) \,/\, h(.) \,] \qquad \text{(A2.4)}$$

is a sufficient function for discriminating between the two distributions, based on an observation vector **x** of PPSM test results. In the Kullback (1959) theory, λ is equal to the information provided by **x** favoring the hypothesis $H_1 : \mathbf{x} \sim g(\mathbf{x})$ over the hypothesis $H_2 : \mathbf{x} \sim h(\mathbf{x})$. That is, the discriminant function (4) is the optimal way of classifying a project either as a member of the population "products that will succeed" or as a member of the population "products that will fail." The decision rule is, "**x** was generated by a member of the successful population if $\lambda > 1$, and by a member of the unsuccessful population if $\lambda \leq 1$."

The usual assumption that g and h are continuous density functions over the interval $(-\infty,\infty)$ implies that, e.g., a member of the "successful" population may have an ROI less than the target value. Indeed, this situation is pictured in Zirger and Maidique's (1990) Figure 2. In reality, projects may succeed or fail for reasons other than ROI performance. Thus this representation is not unreasonable, and we use it in the developments of the present paper.