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An Empirical Analysis of the Valley of Death: Large-scale R&D Project Performance in a Japanese Diversified Company

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Summary

The purpose of this study is to contribute reference material that provides insight into innovative process management that increases R&D output in commercializing new products. A model of a process from research to commercialization with the cumulative profit and loss curve is put forward and hypotheses related to success and failure are developed at the stages up to product launch. Seventeen large projects that have resulted in successful product launches have been examined from the initial research stage to commercialization. Project duration, standardized cumulative R&D expenditures and research resource concentration are analyzed in terms of statistical method and patterns in cumulative profit and loss curves after product sales, as well as the reasons for and other aspects of success/failure are investigated and analyzed.

Consequently, valuable information on future management tasks has been obtained such as: (1) project duration differs depending on market sectors, product types and presence/absenceof materials research (2) cumulative profit and loss curves can be categorized into four patterns (3) reasons for failure can be divided into technological and market problem categories and (4) these factors have an impact on product sales.

Key Words: R&D management, innovation process, project management, commercialization, valley of death

1. Introduction

In recent years, reduced efficiency has been identified in R&D by Japanese firms (Murakami, 2000). It is obvious that one can increase R&D efficiency by decreasing inputs or by increasing outputs. In decreasing inputs, R&D project selection and focus strategies were adopted by many

Japanese firms,especially in the ten years that were considered to be the lost years during the 1990s and a corresponding methodology emerged (Osawa and Murakami, 2002) (Osawa, 2003). Continuous success in the innovation process - from R&D to the creation of a new product and commercialization of that product - could be a potent means by which a firm can achieve continued growth.

Accordingly, this paper intends to provide insight and reference material to firms that are intent upon increasing R&D output with innovative process management. For example, one may wish to assess approximately how much time is required for any given R&D project, from inception to product launch or, how much R&D expenditure is required during that time. What steps should be followed in commercializing a product after its launch? Are there any trends to be found in this process? In the case of diversified firms, these variables may fluctuate in value due to the wide array of market sectors and product types. However, if any trends can be confirmed, they could provide valuable guidelines for future activities on R&D management.

2. Framework

2.1. Overall Process from Research to Commercialization

The cumulative investment required in a project up to the breakeven point was shown in the "cumulative cash flow curve" (Twiss, 1980). Cooper (1993) described innovation process from idea to commercialization as "ideation, preliminary investigation, detailed investigation, development, testing & validation, full production & market launch". Sensenbrenner (1998) pointed out that there was a gap between federally-funded basic research and industry-funded applied research and development as the "valley of death". Evans (2002) showed that valley of death existed in the availability of capital from "basic research" to "commercial operation" in the phase of development & scale up.

The stage from original idea to research commencement was described by Cooper (1993) as the "pre-R&D project stage", usually carried out over one to six months with little expenditure. Therefore, the R&D project in this case study is considered from the research stage onwards, omitting the initial low-expenditure stage.

Our investigations show that each project started with research, then moved through a process chain from development to commercialization. From an R&D results perspective, we were able to classify four situations, namely: (1) technology transfer (success in R&D); (2) success in the product launch (placement in the market); (3) success as a new product, and (4) success as a business. There are many projects that have ended in failure with wasted effort in the middle stages of the process. Processes can also be tracked by cash flow or cumulative profit and loss: initially invested resources grow over time creating a negative cash flow or cumulative loss and at some point the cash flow or cumulative loss is improved by profits from product sales, finally becoming positive, as shown by Twiss (1980).

When these processes were combined with the cumulative profit and loss curve, a pattern like the one in Figure 1 is suggested. In this study, we consider the "valley of death" as the gap between product launch and when the business becomes success. This diagram illustrates the framework of this overall study, in which large-scale projects are divided into two parts for the analysis. These parts correspond to the periods: (1) from R&D to technology transfer, to product launch, and (2) commercialization after product launch, through to success as a new product and success as a business. Given these processes, two broad categories of investigation and analysis have been conducted. Our reason for focusing on large projects is because vast resources are introduced and if they succeed, they could account for a significant percentage of the firm's future sales and profitability. In other words, the effect on the firm could be significant.

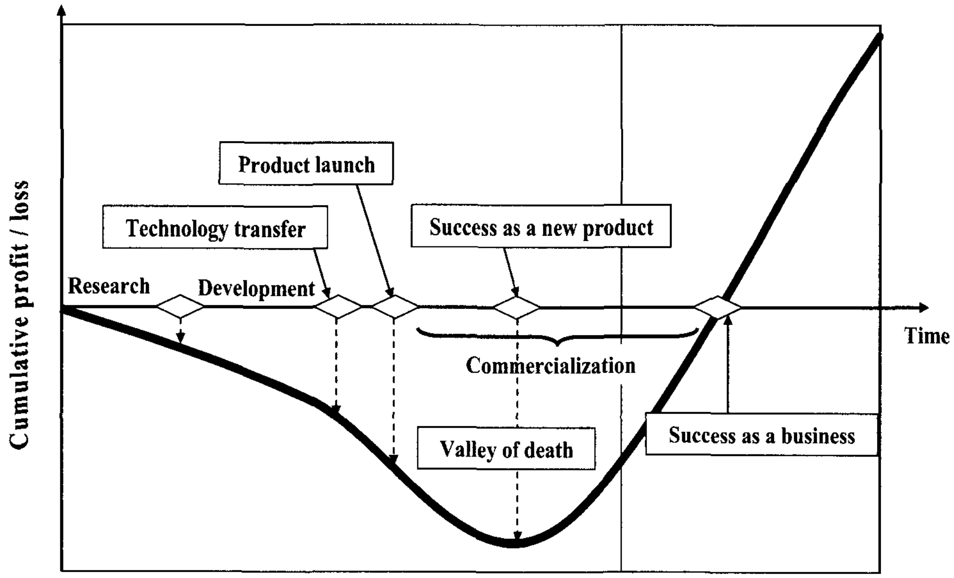

Figure 1: Overall Process from Research to Commercialization

2.2. Process of the Stages up to Product Launch

2.2.1. Top Management or CTOs Interest in R&D Projects up to Product Launch

One major concern for top management or CTOs with overall responsibility for R&D is to decide how much time and expenditure to devote to an R&D project in order to at least achieve success with the product launch. This is especially true for large-scale R&D projects that may have a significant impact on the future performance of the company (in this section "time", "duration", "expenditure" and "success" all refer to the period from R&D to product launch). Project leaders naturally want large-scale R&D projects to succeed, and this frequently creates a tendency for the duration and expenditure of projects to exceed initial estimates. This is acceptable for top management or CTOs if the project is a success, but if it is not, losses can be extreme, not only because of the failure of the project itself, but also because of missed opportunities for investment in other projects.

If there were some basis that enabled top management or CTOs to fix a maximum duration and expenditure for the success of large-scale R&D projects, this would be of tremendous assistance, allowing them to take action more confidently and expediently. For example, from the perspective of individual project management, this could permit investigation of countermeasures for R&D projects that exceed upper limits without success and from the perspective of R&D management in general, this could mean reviewing the resource allocation plan between large-scale and other R&D projects.

However, in reality we expect difficulties in setting uniform upper duration and expenditure limits for large-scale R&D projects because firms－especially diversified firms as in this case study－work with diverse target markets and product types. Therefore, we attempt to analyze the nature of the relationship between duration, expenditure, and target markets and product types respectively. From this understanding it may be possible to set different maximum durations and expenditures by, for example, target markets and product types. The results obtained could be useful for top management or CTOs in making the confident and quick decisions mentioned above.

2.2.2. Hypothesis Development of the Stages up to Product Launch

For the diversified firm in this case study, the target markets were information and communication, electronics, automobiles, energy, and industrial materials, and the product types were materials, parts, and equipment.

Concerning target markets, as a general rule, there are many products from R&D projects targeting the energy and industrial material markets that have long life spans. For example, the lifespan of power cables, one of the products in the energy sector, is estimated to be thirty years (The Kansai Electric Power Co., Inc., 1999) and pre-stressed concrete, one of the products in the industrial materials sector that is used in bridges and other large structures, has an estimated lifespan of forty-five years or longer[1]. This suggests that because of the demand for long-term reliability in R&D, a significant amount of time is required for R&D that includes product evaluation.

On the other hand, in the case of R&D projects on information and communication sector, there are many products with short life cycles and the requirement of reliability may not be as high as in the energy and industrial material sectors. For example, the results of one study (Fujitsu Research Institute, 2005) showed that more than eighty percent of cell phone users purchased their phones within the last two years. This suggests that, from the perspectives of pay-back time and of development keeping pace with the competition, R&D must be carried out quickly. In the case of R&D projects for electronics and automobiles, because product life cycles are shorter than those for energy and industrial materials, but longer than those for information and communication, the project durations are likely to lie somewhere in between these.

From the above, the following hypothesis (1) was proposed, with energy and industrial materials in one group, electronics and automobiles in another and information and communication on its own.

[Hypothesis 1] *The period from commencement of research to product launch of an R&D project, (hereinafter defined as the "project duration") varies according to the type of target market sector*

It was also hypothesized that expenditures from commencement of research to product launch are proportional to project duration, and if hypothesis 1 is supported, then the following hypothesis (2) could also be supported.

[Hypothesis 2] *The expenditures of R&D projects from commencement of research to product launch vary depending on the market sector*

Regarding product type, as a general rule, R&D on materials usually starts as small "beaker

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1) Ministry of Land, Infrastructure, and Transport, http://www.mlit.go.jp/road///ir/sisan/9pdf/26.pdf

and scale" projects that undergo multiple cycles of: (1) creation of samples by changing parameters; (2) evaluation, and (3) analysis. Since there are numerous parameters in this chain such as temperature, pressure, time, etc., one cycle of sample creation, evaluation, and analysis requires a long time, and the number of cycles can also be quite large. There are cases when time is required for the development of complementary technologies that are critical to product development. Furthermore, there are many cases in which dedicated equipment is required in order to scale up the research effort and after design and manufacturing of the equipment, multiple cycles of the "beaker and scale" level processes are carried out. From the above, the duration of materials-related R&D projects is expected to be relatively long. For example, the development of blue LEDs took twenty years from initial development in the 1970s to completion in 1989[2].

By contrast, the duration of R&D projects for equipment is not expected to take as long as that for materials because they often involve a combination of existing materials with existing products. For example, with cell phones, new products can emerge serially, facilitating short periods between replacement purchases. R&D projects involving parts do not contain as many parameters as those involving materials but, because it is necessary to perform a similar number of cycles as for materials, project duration is expected to fall somewhere between that of materials and equipment.

From the above, the following hypothesis (3) was established.

[Hypothesis 3] *R&D project duration varies depending on the product type*

It was also hypothesized that cumulative R&D expenditures are proportional to project duration, and if hypothesis 3 is supported, then the following hypothesis 4 can also be supported.

[Hypothesis 4] *Cumulative expenditures of R&D projects vary depending on the product type*

Furthermore, there are cases where R&D projects on parts or equipment product types also incorporate R&D on materials. This suggests that project duration depends more on whether or not any R&D is performed on materials, rather than the product type itself. For example, the development of LCD color TV equipment took eighteen years, starting with development of liquid crystal materials in the 1970s, through to the final stage of development in 1987[3]. Also, research carried out by Miyazaki (1995) showed that optoelectronics-related competence

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[2] Foundation for C&C Promotion, http://www.nec.co.jp/press/ja/9809/1801.html

[3] Sharp, http://www.sharp.co.jp/corporate/info/history/h_company/index.html

building in Japanese & European firms took a very long time, often spanning one or two decades, involving trial and error.

From the above, the following hypothesis (5) was established.

[Hypothesis 5] *The duration of R&D projects varies depending on whether or not R&D on materials is conducted*

As mentioned above, long-term reliability testing is required for R&D in the energy and industrial materials market sectors, but it is assumed that the R&D expenditure, relative to duration, is not necessarily large. As for materials-related R&D projects, there is a tendency for other factors to be involved, such as the necessity of supplementary technologies keeping pace with product development and—based on the authors' observations of R&D projects to date—the tendency to perform long-term R&D with fewer researchers than in other projects.

If these assumptions or tendencies are correct, the assumption of proportionality of standardized cumulative R&D expenditures to project duration is false. Put differently, it is necessary to analyze the relationship of standardized cumulative R&D expenditures divided by project duration (hereinafter called the "research resource concentration")—rather than the standardized cumulative R&D expenditures alone—with market sector, product type, or inclusion of materials research. From the above, hypotheses 6, 7, and 8 were established.

[Hypothesis 6] *The research resource concentration of R&D projects varies depending on the market sector*

[Hypothesis 7] *The research resource concentration of R&D projects varies depending on the product type*

[Hypothesis 8] *The research resource concentration of R&D projects varies depending on whether or not R&D on materials is conducted*

2.3. Investigation and Analysis of the Stages up to Commercialization after Product Launch

Following a successful product launch, a project becomes successful as a business, when it yields an annual profit after several years and is able to generate cumulative profits thereafter. Normally, after a product launch, sales are made and profits are generated from those sales, but profits do not necessarily arise immediately upon launch. Additional research investment may be required to improve performance, reduce costs, stabilize quality, or for other purposes, and there also appears to be cases where projects suffer further cumulative losses due to unexpectedly large investments in plant and equipment for mass production. There are also projects that do not generate profits in the first year or even cumulative profits after many years. Therefore, cumulative profit and loss curves are expected to differ from project to project.

To provide insight, not only for managers of large-scale projects in the future, but also for top management, investigation and analysis was conducted firstly to verify what sort of patterns in cumulative profit and loss curves could be found and secondly, what differences could be found between successful and failed projects. The reason for investigating in the post-product launch successes and failures is that significant resources are injected up until the product launch stage and the authors propose that the analysis of success/failure of these projects, as new products or as businesses, would be useful for making future R&D more efficient.

As markets and technologies differ for each R&D project, quantitative profiles of these processes vary infinitely. Also, previous research has been conducted on the causes of project failure and success rates. For example, inadequate market analysis and product problems or defects, etc. were pointed out for failed reasons (Hopkins, 1971). Understanding of user needs, attention to marketing, efficiency of development, effective use of outside technology and so on were important as characteristics differentiating between success and failure (Rothwell, 1972; Rothwell et al., 1974).

Furthermore, 18 important variables were captured for differentiating between success and failure such as technical/production synergy and proficiency, market knowledge and marketing proficiency (Cooper, 1979, 1980). Key factors affecting product outcome, such as the quality of the R&D organization, the technical performance of the product were found (Maidique and Zirger, 1984; Zirger and Maidique, 1990). As for success rate, for example, one survey showed that 80% of the products that were introduced to the market based on promising expectations did not succeed (Barrett, 1996) and another survey demonstrated the typical success rate of R&D projects was approximately 9% (Albala, 1977). Additionally, the success rate was reported as only 0.2% (one out of 500 was successful) (Stevens, 1997), or the rate of technology transfer or commercialization of technology developed had reached 61% in 2002 from 18% in 1997 (Gil and Park, 2004).

However, in diversified firms with a broad array of product sectors and types, though systematic research has been conducted at the macro-level by the authors (Osawa and Miyazaki, 2005), there has been little work done, based on micro-level studies, that focus on individual projects.

Investigating why individual R&D projects in a diversified firm end in failure, and tracking the processes from inception to commercialization by examining the cash flow or cumulative profit and loss, could provide valuable insights for R&D management of projects that are currently underway or have yet to be started.

3. Methodology

3.1. Investigation and Analysis of the Stages up to Product Launch

Seventeen large-scale projects of a diversified firm in the nonferrous metal industries that were successful, from product launch to the technology transfer stage, (R&D) were investigated and analyzed based on the overall process shown in Figure 1. These projects were categorized by market sector, product type, and whether research on materials was carried out as shown in Table 1.

Table 1: Classification of 17 Projects

No.	Market sector	Product type	R&D on materials
1	Information and Communications	Materials	Present
2		Parts	
3-6		Equipment	Absent
7	Electronics	Parts	Present
8			Absent
9		Materials	Present
10	Automobile	Equipment	Absent
11		Parts	Present
12			Absent
13-15	Industrial materials	Materials	Present
16	Energy	Equipment	
17		Materials	

A study was made on project durations and R&D expenditures accumulated during that time. Since the ratio of successful product launches in a single firm is low, the project duration was distributed broadly from the 1960s to the 2000s. Therefore, it was considered necessary to adjust cumulative R&D expenditures for inflation using a GDP deflator4).

Furthermore, recently there seems to be an argument in favor of shortening the project duration, but there was no concrete evidence and no particular corrections were made for this. Additionally, as the research cost figures used in these analyses and other activities are corporate confidential data, the values used were modified by dividing the GDP deflator-adjusted cumulative R&D expenditures by the smallest of those expenditures in the seventeen projects (hereinafter called the "standardized cumulative R&D expenditure").

Finally, the results were analyzed with the statistical methods of a histogram, correlation diagram, Mann-Whitney U test, Kruskal Wallis test and multiple regression analysis. Multiple regression analysis was conducted through the Theory of a quantification method 1[5] using dummy variables, by market sector, product type and research materials.

3.2. Investigation and Analysis of the Stages up to Commercialization after Product Launch

Cumulative profit and loss curves of R&D projects thus obtained were categorized by patterns. Next, these patterns were grouped into: (1) profit in a year equates to success/failure as a new product, or (2) cumulative profit equates to success/failure as a business. Furthermore, respective reasons for success/failure of projects were studied by conducting interviews and other means and then analyzed.

3.3. Methodological Limitations

There are three main methodological limitations.

1) The size of the sample (17) was small since there were not many large-scale R&D projects being conducted by a single firm. Therefore, the Mann-Whitney U test, Kruskal Wallis test and multiple regression analysis were carried out instead of multiple comparisons on project durations, standardized cumulative R&D expenditures and research resource concentrations among market sectors or product types.
2) This case study was performed in only one firm and there were not any published, comparable data in other firms. Therefore the results of this case study may be considered as a specific example.
3) The influence of a project leader's qualities or management skills was not considered in this analysis since these large-scale projects achieved strong support of top management

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4) Cabinet office," http://www.esri.cao.go.jp/jp/sna/qe011-68/def-cy01168.csv,
http://www.esri.cao.go.jp/jp/sna/qe053-2/def-cy0532.csv.

5) Quantification Theory developed by Hayashi, C.

and as a result, all the project leaders were considered to have higher qualities or management skills than other project leaders. However, this factor can not be denied completely.

4. Results and Discussion of the Analyses

4.1. Investigation and Analysis of the Stages up to Product Launch

4.1.1. Overall Project Durations and Standardized Cumulative R&D Expenditure

From commencement of research to product launch, the shortest and longest project durations were 3 years and 20 years respectively, and the overall mean was 9.5 years. This is shown in the histogram in Figure 2. Most project duration was between 8 and 12 years, with periods of less than 12 years comprising approximately 80% of the total. It seems that if current or future projects cannot launch products within 12 years of commencing research, then changes in the external environment, technological progress and other factors should be rigorously checked before deciding to continue or not.

From commencement of research to product launch, the maximum standardized cumulative R&D expenditure was 7.6, and the overall mean was 3.1. This is shown in the histogram in Figure 3. Projects with a standardized cumulative R&D expenditure of less than 4 comprised approximately 80% of the total. For projects currently underway or planned for the future, it is suggested that the same checks for project duration be made for projects that use a standardized cumulative R&D expenditure of more than 4.

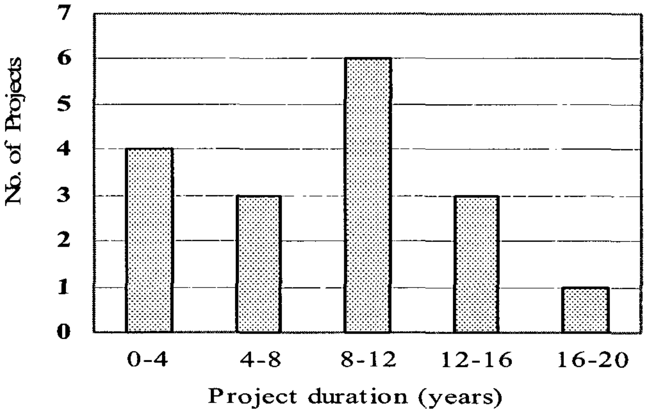


Figure 2: Histogram of Project Duration

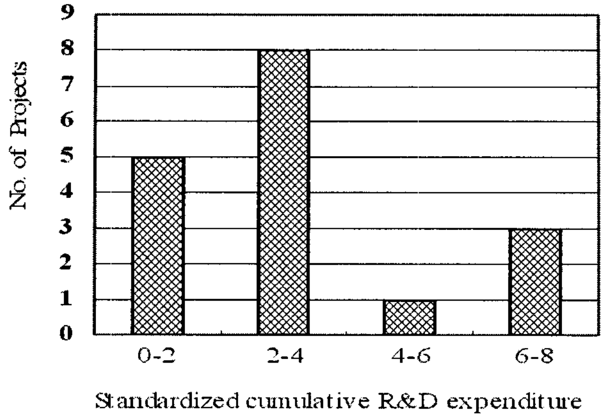


Figure 3: Histogram of Cumulative R&D Expenditures

4.1.2. Project Durations and Standardized Cumulative R&D Expenditure by Market Sector, Product Type and Material Research

Results of the Kruskal Wallis test are given in Table 2. Regarding hypotheses 1 and 3, a significant difference in project duration was found in both market sector and product type at the 5% level of significance. That is to say, hypotheses 1 and 3 are supported in this form. Concerning hypotheses 2 and 4, a significant difference on standardized cumulative R&D expenditures by market sector or product type could not be found. In other words, hypotheses 2 and 4 were evidently not supported. This could be due to the fact that the assumption of the static ratio of standardized cumulative R&D expenditures to project duration is false.

Figure 4 shows the correlation between project duration and standardized cumulative R&D expenditures as evidence of this false assumption. The correlation coefficient for the seventeen projects overall was 0.23, indicating a weak correlation.

Table 2: Results of Tests on Hypotheses 1, 2, 3 and 4

	Project duration		**Standardized cumulative R&D expenditure**	
	Market sector [1]	Product type [2]	Market sector [1]	Product type [2]
Chi-squared	6.687**	7.093**	1.131	3.960
Significance probability	0.035	0.029	0.568	0.138

Note 1) Among information & communication, electronics & automobiles and energy & industrial materials, 2) Among Materials, Parts and Equipment, 3) **: Significant at the 5% level

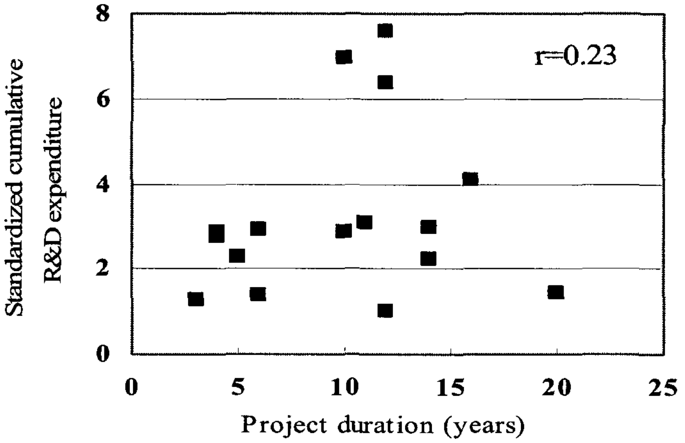


Figure 4: Correlation between Project Duration and Standardized Cumulative R&D Expenditure

Results of the Mann-Whitney U test for hypothesis 5 are given in Table 3, showing support for the hypothesis at an even higher level of significance than the 1% used with product type. Thus, hypothesis 5 was confirmed. Note that significant differences in standardized cumulative R&D expenditures were again, not found.

Table 3: Testing Results of Hypothesis 5

R&D on Materials	Project duration		Standardized cumulative R&D expenditure	
	U-value of Mann-Whitney	Significance probability	U-value of Mann-Whitney	Significance probability
Present n=10 Absent n=7	0.00***	0.001	17.50	0.085

Note 1) ***: Significant at the 1% level

4.1.3. Research Resource Concentration by Market Sector, Product Type and Material Research

The results from the testing of hypotheses 6 and 7 are given in Table 4. Table 4 indicates that a significant difference at the 5% level on research resource concentrations could be found for market sector, but not for product type. From these results, hypothesis 6 is supported, but hypothesis 7 is not supported. However, the significance level was smaller than that of standardized cumulative R&D expenditures.

Table 4: Testing Results of Hypotheses 6 and 7

	Research resource concentration	
	Market sector [1]	Product type [2]
Chi-squared	6.735**	5.586
Significance probability	0.034	0.061

Note 1) Among information & communication, electronics & automobiles and energy & industrial materials sectors, 2) Among materials, parts and equipment, 3) **: Significant at the 5% level

The results from the tests on hypothesis 8 are given in Table 5, showing that hypothesis 8 is not supported. This may be due to the greater research resource concentrations on materials research overall which resulted from the effects of material research in the projects that required large capital investment (No. 1, 7 and 10). Although the duration of material research projects was long, all these projects were not always accompanied by continuous small expenditures. Regarding research costs, it might be necessary to focus on other factors such as the amount of capital investment.

Table 5: Testing Results of Hypothesis 8

R&D on Materials	Research resource concentration	
	U-value of Mann-Whitney	Significance probability
Present n=10	18.50	0.107
Absent n=7		

4.1.4. Results of Multiple Regression Analysis by Market Sector and Presence/Absence of Materials Research

The following findings were made from the previous analyses. Firstly, the R&D project duration varies depending on the market sector or product type (Hypothesis 1, Hypothesis 3). Projects in which materials R&D is conducted have longer durations (Hypothesis 5). Furthermore, project duration depends more on whether or not any R&D is performed on materials, rather than on the product type. Secondly, as for the standardized cumulative R&D expenditures, significant differences could not be found in the market sector or product type. Thirdly, the research resource concentration of R&D projects varies depending on the market sector (Hypothesis 6), but not on the product type.

As any given project has several attributes, it will be beneficial for top management or CTOs in the future to know how the research duration or research resource concentrations of the company's projects may vary, according to the attributes. To estimate the research durations or research resource concentration for the attributes, multiple regression analyses were performed. For project duration, dummy variables (0 or 1) were assigned to each of the items (there were 3 items for market sectors and 2 items for research on materials) within the market sector and research of materials. For the research resource concentration, dummy variables were assigned to each of the items (there were 3 items for market sectors and product types, respectively) within the market sector and product type.

Table 6: Results of the Multiple Regression Analysis (n=17)

Multiple regression equation	R^2, F-value (t-value)
$U=9.5 - 1.2X_1 - 0.4X_2 + 1.9X_3 + 3.0Z_1 - 4.3Z_2$ ----- (1) Where, U: Project duration X: Market Sector X_1: Information and Communication X_2: Electronics and Automobiles X_3: Energy and Industrial Materials Z: Material Research Z_1: Presence of materials research Z_2: Absence of materials research	0.81, 9.521*** (X: 1.859*, Z: 5.231***)
$V=0.39 + 0.01X_1 + 0.12X_2 - 0.15X_3 - 0.09Y_1 + 0.02Y_2 + 0.07Y_3$ ----- (2) Where, V: Research resource concentration X, X_1, X_2, X_3 : the same above Y: Product Type Y_1: Materials, Y_2: Parts, Y_3: Equipment	0.52, 1.839

Note *: Significant at the 10% level, ***: at the 1% level

Table 6 shows the results of the multiple regression analysis for project duration and research resource concentration. A multiple regression equation (1) or (2) regarding the relationship between market sector and material research or between market sector and product type was obtained through multiple regression analysis of each item. The coefficient of determination (R^2) was 0.81 for the project duration or 0.52 for the research resource concentration. A significant difference was found in equation (1), but not found in the equation (2) in terms of F-test. No significant difference in equation (2) is considered since the significance probability on the product type was relatively high (0.061) as shown Table 4. It is found from the t-value that the presence of research on materials is greater than market sector for the contribution to the change of project duration.

Table 7 shows the prediction of project duration for each item calculated by multiple regression equation (1). For example, the combination of information and communication sector and absence of materials research leads to the shortest project duration (4.0 years), whereas the combination of energy and industrial materials sector and presence of materials research leads to the longest project duration (14.4 years).

Table 7: Prediction of Project Duration

Market sector	Materials research	Prediction of project duration
Information and Communication	Present	11.3
	Absent	4.0
Electronics and Automobiles	Present	12.1
	Absent	4.8
Energy and Industrial Materials	Present	14.4
	Absent	7.1

4.2. Analysis of Processes from Product Launch to Commercialization

4.2.1. Finding Patterns in Cumulative Expenditures

After tracking and investigating the cumulative expenditures from each project, it was concluded that projects can typically be categorized into four patterns, as shown in Figure 5.

Pattern 1: Projects were cancelled after being unable to achieve profits in a single year. These projects were clear failures from a commercial perspective. In this pattern, a product was launched, but deficits continued and cumulative losses grew. So, this pattern indicates that the product sold to some degree, but for reasons explained below, profits were not realized. Furthermore, these projects were cancelled when they were judged to have no future profit potential. In this study, six projects fell into this category.

Pattern 2: Projects were cancelled after achieving profits in a single year but reflecting losses in successive years. These projects were also failures from a commercial perspective. After these projects were launched, they seemed to head smoothly towards commercialization, but for the reasons explained below, failed to sustain profits, could not recover and cumulative deficits grew, resulting in cancellation of the project. In this study, two projects fell into this category.

Pattern 3: The projects achieved profits in a single year, profits continued thereafter, but were not able to recover sufficiently cumulative losses. Projects in this pattern are currently still underway and are set to recoup cumulative losses over time, but this has not yet been achieved, and it is unclear whether the cumulative losses can be recovered. So, it cannot be determined at present whether or not the project is a success or failure. Normally it would have already been commercialized, but errors in forecast were made mainly due to unexpected advances or other phenomena in existing technologies and the market did not expand exactly as predicted. In this study, two projects fell into this category.

Pattern 4: Cumulative profits of projects were achieved and the project was a success as a business. Projects in this pattern were able to cross the so-called "valley of death." In this pattern, the target market started up well, competitive technologies could be developed, access to markets was gained and after commercialization there was a good balance between cost and price while market share and profit steadily increased. In this study, seven projects fell into this category.

These projects showed that there is a time lag between the point of product launchand the period of maximum cumulative losses. A lag can appear if sales do not grow even if the initial product launch is successful, or if the project goes into losses due to the costs associated with product improvement, handling of customer claims, and other aspects causing profits to be squeezed. In the case of pattern 1 or 2, the maximum cumulative loss occurs at the time of cancellation, but up to that point even more time and money have been invested. The periods from product launch to cancellation were 10 years maximum and 2 years minimum for pattern 1, and 9 years maximum and 7 years minimum for pattern 2. For more on this aspect, see the section below on failure analysis.

Furthermore, in patterns 3 and 4, in cases where the cumulative losses occurred gradually over a long period, or in cases where the cumulative loss grew large, it goes without saying that management considered cancelling these products.

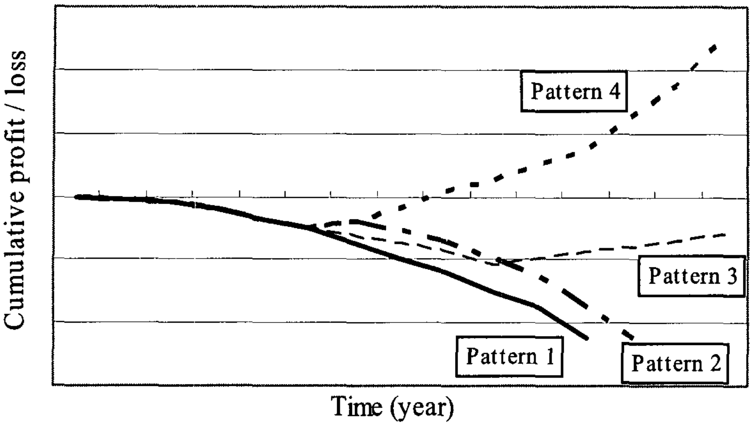


Figure 5: Time Cumulative Profit / Loss Curve

4.2.2. Analysis of Failure Cases

There are a variety of reasons for the failure of the six 'pattern 1' projects and the two 'pattern 2'projects, but the primary factors are summarized below and in Table 8. Firstly, a major reason for the failure of five of the 'pattern 1' projects was a technical problem, and the reason for the failure of the remaining project was, vaguely, a market-related problem. On the other hand, with 'pattern 2' projects both of them failed due to market-related problems.

The two specific technical problems were as follows. The first problem is that technical breakthroughs to reach higher levels of performance could not be achieved. Two projects in this study fell into this category, but in both cases, different technology in other companies met performance demands. Other companies did enter the market successfully and there was expectation that a large market would become available if technical breakthroughs could be made. More specifically, project failure was tied to the problem of whether or not the decision-making in the selection of technology was in fact correct. Additionally, when the probability of success of a project turned out to be lower, the R&D manager should have avoided dragging on the project even if it was requested by a big customer. The second problem is the case in which projects could not lower costs. This applied to three projects in this study. In each case, other companies eventually emerged as successful businesses. When selecting technologies to achieve performance targets, there may have been problems in evaluating low-cost manufacturing processes and other items, or insufficient assessment of risk, which could have led to failures in achieving cost targets.

On the other hand, the specific reasons for the failure of one of the 'pattern 1' projects and two of the 'pattern 2' projects were all the same, namely, that the company was not able to keep up with explosive development during the market expansion period. This represents a misreading of the market that expanded beyond anticipated extents. It may be due to project management problems causing a shortage of short-term resource investment and/or the inability to invest resources in excess of an allowed risk level as determined by the size or other characteristic of the company. As a result, the project exceeded allowable risk that was impossible to foresee at the beginning. In such cases, perhaps one of the possible solutions is to make an alliance with other firms early on during the project. In this study, three projects fell into this category.

With the relationship between the period from product launch to cancellation and the reasons for the failures, there were large differences between technical and market-related problems. This is because compared to projects with technical problems, those with market-related problems had more developed products and higher sales. As a result, the project was expected to become profitable so the period of continuation of the project was longer.

Table 8: Analysis of Failure Projects

No.	Pattern	Major reasons for failure	Specific reasons for failure	From product launch to stop (years)	Sales per year
7	1	Technical problems	Performance targets cannot be cleared	2	<100 million yen
16	1			3	
11	1		Failure to lower costs	2	<1 billion yen
8	1			4	
17	1			6	
3	1	Market-related problems	Cannot keep up with amount of development during period of market expansion	7	1 to 3 billion yen
4	2			9	
10	2			10	

Here the problem remained that the cumulative profit and loss pattern did not match the reasons for failure. If, as stated above, market problem projects had higher sales than projects with technical problem then the hypothesis could be made that the reasons for failure correspond to, if anything, sales more than the cumulative profit and loss. To confirm this hypothesis, peak sales after product launch were examined. As shown in the end column in Table 8, sales were higher for projects with market problem than for projects with technical problem. Also, in projects with technical problems, it is apparent that projects that failed to reduce costs had higher sales than projects that failed to achieve performance targets.

With this information, the following adjustments can be made. Firstly, in the case that sales of products are less than 100 million yen per year, two projects could not meet performance targets. Secondly, in the case that sales of products are more than 100 million yen per year and less than about 1 billion yen per year, three projects failed to lower costs. Thirdly, in the case that sales of products are between 1 and 3 billion yen per year, three projects could not keep up with technical developments during period of market expansion.

4.2.3. Analysis of Success Cases

Successful projects were those that experienced no crucial failures in technology, markets, or other factors. Also, other factors absentin failed projects could have contributed to projects achieving success as a business. Excluding two projects for which success or failure cannot be determined at this time, the key factor contributing to the success of seven projects were analyzed by interviews with management. The results are shown in Table 9.

Table 9: Analysis of Success Projects

Project No	Key factor for success as a business
1	Joint development with user guidance (high probability of successful development, market assured if development succeeds)
2	Company also owns upstream technology
5	Create markets by seeking public-private sector partnerships
6	Interdepartmental cooperation, offer products rapidly by leveraging existing technology
9	Niche market with few competitors, ownership of downstream technology
12	Identifying the true needs of users by maintaining close contact with them
13	Dominate markets with powerful intellectual property

In comparison with the previous studies, it is considered that the key factors in project 1 and 12 correspond to "the understanding of user needs" (Rothwell, 1972; Rothwell et al., 1974). Also, the key factor in project 6 could correspond to "efficiency of development" (Rothwell, 1972; Rothwell et al., 1974). Furthermore, the key factors in project 2 and 9 could make "the technical performance of the product" (Maidique and Zirger, 1984; Zirger and Maidique, 1990) competitive. The key factors in the project 5 and 13 may be something unique. Regarding success rate, 47% (7/15) is obtained except two projects which cannot be determined a success or failure. Although, this cannot be compared to previous studies, about a half of successful projects in product launch failed to succeed in a new product or a business.

5. Conclusion: Implications for Innovation Management

The insights obtained thus far were incorporated into a process model from research to commercialization that may be a useful reference for both top management or CTOs and R&D project managers, as shown in Figure 6. Certain R&D projects pull themselves through the research and development stages to a successful product launch. A variety of characteristics pertinent to project duration and cumulative profit and loss up to that point can be appraised.

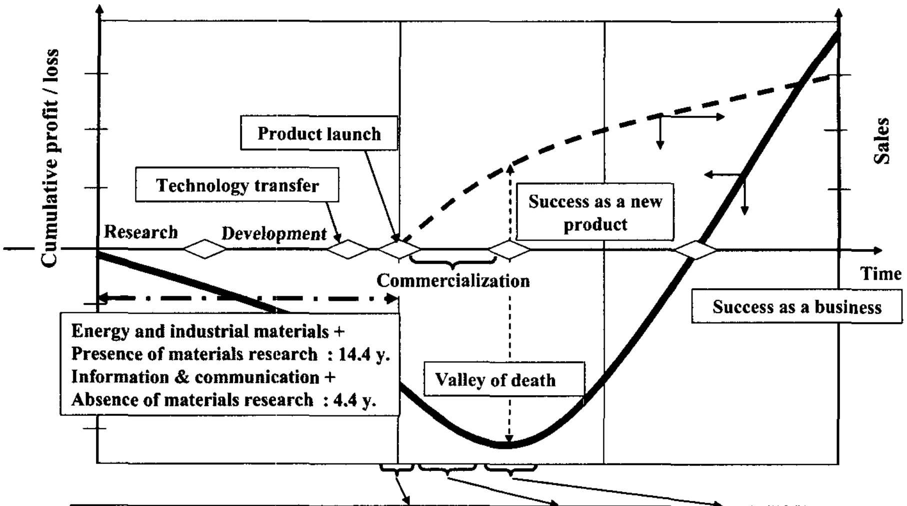
Cumulative losses grow larger when advancing to the commercialization stage after product launch, but with projects that reach a peak by realizing profit in a single year (success as a new product) and thereafter succeed as a business, profit and loss improves smoothly and the project advances to attain recovery of cumulative losses and expand cumulative profits. The approximate period from product launch to success as a new product is a crucial time for success as a business and certainly represents a crossing of the "valley of death." With this process, the focus must be on sales and not only on the cumulative profit and loss.

Management up to and following product launch is summarized as follows.

(1) Management up to product launch

Guidelines can be set for the project duration depending on the project's market sector and presence/absence of research on materials. In contrast to the longest duration of 14.4 years required for the combination of energy and industrial materials and presence of materials research, the combination of information and communication and absence of materials research have the shortest duration, being 4 years. Cumulative losses up until product launch cannot be analyzed by market sector or product type only, but in general there are many projects for which the standardized cumulative R&D expenditures is 4 or less. Caution is required if research is expected to continue beyond that point.

It may be more useful to perform a check using a research resource concentration index than a cumulative R&D expenditure one. In the case of an R&D project having the combination of electronics and automobile and equipment, it is suggested that many resources should be injected over a short period. On the other hand, top management or CTOs should permit project managers to tackle long-term projects with fewer resources in those R&D projects having energy and industrial materials together with materials.



Sales (100 million yen / year)	1 more →	10 more →	30 more →
Technology	Performance clear, Cost?	Performance & Cost clear	Performance & Cost clear
Market	No exploitation	Exploiting	Expansion

Figure 6: A Model of Process from Research to Commercialization

(2) Management after product launch

Tracing cumulative profit and loss provides a powerful tool, but sales should probably be checked simultaneously. The relationship between sales and technological or market factors after a product launch are summarized in Figure 6. From the study carried out, we recommend to R&D managers that the points that must be focused on are different depending on sales, so organizations, systems, and personnel must be handled accordingly.

Regarding reasons for failure, focus should probably be kept on those cases where investment of resources cannot be maintained. It is proper that resources such as human, equipment and money should be injected in the short-term when explosive development is needed during the greater market expansion period than expected. However, it is sometimes difficult for a diversified firm to do that. For example, there is not so much human resource of a specific technology field within the firm since human resource is also diversified and limited in number than that of undiversified competitors. In that case, to avoid a misreading of the market, it is probably necessary to investigate in advance whether to enter sectors where resources may be limited, or how to handle such a scenario that arises after entering that market sector. In addition, it is important for top management or CTOs to realize the fact that about a half of successful projects in product launch failed despite the project members' best effort. This realization leads to actions for risk management such as parallel development of alternative technology.

The following points of this study may be of use in the future for innovating project management. Firstly, the performance of past large projects from R&D to product launch can provide quantitative analysis results by project duration, cumulative R&D expenditures, and research resource concentrations. These results may be used as standard guidelines for continuing or cancelling large-scale projects. In particular, with diversified firms, there are a variety of market sectors, product types, and presence/absence of research on materials. It is hoped that these results will be useful in judging whether to continue or cancel a project. Secondly, information obtained from failures after a product launch can be used by management in the future. In particular, since losses incurred as a result of failure after product launch are large compared to pre-launch failures, there is convincing evidence that information on the causes of failure can be beneficial to management in increasing the success rate of future projects by preventing failures in advance.

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