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Measuring Development Performance in the Electronics Industry

Christoph Loch, Lothar Stein, and Christian Terwiesch

Within a year or so, the computer you purchased last month will probably be obsolete. For a manufacturer faced with such short product life-cycles, the performance of the new product development (NPD) function can determine whether the firm itself is relegated to the scrap heap. With such a close link between NPD performance and a firm's overall success, we need to do more than simply ensure that individual projects are well managed; we need to assess NPD's overall contribution to the company's business performance.

Christoph Loch, Lothar Stein, and Christian Terwiesch develop a two-step model for measuring the performance of the NPD function. In this model, development output performance is the direct driver of business success. In other words, the output and the productivity of the NPD function directly affect a company's profitability and sales growth. Development output performance is driven by development process performance—that is, the operational management of development projects.

Using data from the "Excellence in Electronics" project (a joint research effort of Stanford University, the University of Augsburg, and McKinsey & Co.), the two-step model is applied to a sample of 95 business units operating in three international electronics industries: consumer/small products, computers/communications, and industrial measurement/large systems. This analysis has two main objectives: identifying the key measures of development output performance and their contribution to business success; and identifying the important measures of development process performance and their contributions to development output performance.

Development productivity, measured by development expense intensity, is the clearest predictor of business success. In other words, you can't buy a competitive advantage by pouring more money into R&D. Success comes from more efficient NPD, not simply outspending the competition. In the computer industry, design-to-cost has a positive effect on profitability growth, and design quality has a positive influence on sales growth.

The factors underlying development process performance are much more dependent on the nature of competition in each industry. For example, because competition in the large systems industry still focuses primarily on technical competence, design-to-cost efforts in this industry lag behind those of the computer industry. Important measures of development process performance for all industry segments examined in the study include supplier involvement in the design, early prototyping, a team-based development organization, the use of team rewards, and value engineering.

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Introduction

It is widely agreed that the development of new products is of increasing importance to profitability and competitiveness in many manufacturing and service industries. This is particularly true in "high-tech" industries, which are characterized by shorter and shorter product life cycles, increasing market segmentation, and growing technological complexity. In spite of this increasing importance, to date there is no single, commonly agreed upon set of performance measures for the development function. Proposed measures are a mixture of input and output indicators together with some measures evaluating the process used. In addition, most are defined at a micro level, identifying success predictors for individual development projects. Little is known about performance measurement of a company's overall development function. This lacuna leaves "a gap between discrete innovation projects and industry characteristics" (a field in which substantial empirical work has been conducted) [1].

The present article explores how the performance of the overall development function can be measured, and how it is connected to success at the level of the firm. We thus propose to contribute to closing the above-mentioned gap. We aim to do this by distinguishing three performance concepts: first, the firm's *business performance*—the measure of the firm's success in the market. Second, *development output performance*—the measure of the development function's contribution to the firm's business objectives, and how it in turn influences business performance. And third, *development process performance,* which measures the quality of development execution (e.g., project management or competence) that drives output performance.

It is important to understand that process performance is an important driver of output performance, but not directly of business success: development processes determine at which cost and how fast new products and services of what performance and quality can be introduced. New products, in turn, together with their cost position and the way they are marketed and sold determine business growth and profits [9,21]. For example, it is possible that development processes are excellent and capable of attaining a specific output dimension, say a high rate of product introductions. If, in this same case, however, the market values high technical performance over innovation rate, then the company may still fail. Hence, the right development performance dimension must be chosen first, and only then can the right process drivers of this dimension be found. Within this framework, we identify by statistical analysis the most important performance measures for both types of performance.

The analysis in this article is based on data from the "Excellence in Electronics" Project jointly undertaken by Stanford University, the University of Augsburg, and McKinsey & Company. Ninety-eight electronics companies in the U.S., Japan, and Europe participated in the 1992–1993 study, answering detailed questionnaires on development, marketing, manufacturing and strategy.

The article is organized as follows. First, we give an overview of past work in this field. Then we develop a framework for evaluating development process and output performance. Based on the framework, we define development output dimensions, determine their statistical relationship to overall firm success, and make the link between process (operational development process variables) and output performance. Finally, we summarize managerial insights from the study and close with a brief summary and outlook on further research.

BIOGRAPHICAL SKETCHES

Christoph Loch is Assistant Professor of Operations Management at INSEAD. His research is on process design and performance measurement in the development of new products and services. Prior to joining INSEAD, he was a consultant in the Munich Office of McKinsey and Company in Germany, working mainly with clients in the electronics industries. He holds a Ph.D. in Business from Stanford University.

Lothar Stein is a director in McKinsey and Company's Munich office in Germany. He is a leader in McKinsey's worldwide technology management and electronics practices. In his client work in Europe and the U.S., he has focused on the design and implementation of major change programs to improve productivity, innovativeness, and profitable sales growth. He has published several articles on the management of technology and has recently co-authored a book on the topic: *Wachstum durch Verzicht: Schneller Wandel zur Weltklasse, Vorbild Elektronikindustrie.* He holds a Ph.D. in Physics from Munich University.

Christian Terwiesch holds a Master's degree in Business Information Technology from Mannheim University, Germany, and is currently a Ph.D. candidate at INSEAD. His research interests are in new product development.

Overview of Past Work

We need to point out first that much of the literature does not make a distinction between the terms R&D

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and development. Some authors use R&D with an emphasis continuously varying between fundamental explorative work not directly resulting in new products and direct commercialization [31]. Our study is geared toward managing the development of new products. The literature cited below is all relevant to development, but we keep the term R&D wherever it is used in the original sources.

Following the distinction between project level and firm level described in the introduction, we structure past work into two groups. We first review the research conducted at the project level, though given the amount of research already conducted at this level, only key concepts of the literature will be presented [5–8,22,23,30,37]. The second part of this section is then dedicated to research at the firm level.

Classic studies on development performance focused on the individual project level. These studies managed to find and confirm a number of key project success drivers. The important and statistically significant drivers are: understanding user needs and internal and external communication [23]; attention to marketing, "efficiency of development," and authority of R&D managers (the SAPPHO study by Rothwell et al. [30]); and product superiority, project definition, and synergies with marketing [6,7].

Cooper [8] presents 12 clusters of R&D performance, each composed of several subindexes. Within each cluster, the sample is divided into three groups—high, medium, and low scorers. The "important" clusters are identified as those with the largest difference in the percentage of successful projects between the high scoring and the low scoring group. The three most important clusters turn out to be product superiority, quality of marketing activities, and quality of predevelopment activities. The clusters are a combination of R&D output, process, strategy, and external market conditions (for e.g., product superiority, sharp and early product definition, synergy with rest of product line, and market attractiveness).

Zirger and Maidique [37] build on these earlier studies and on their own survey of 330 new products in electronics. They confirm and expand on earlier findings and derive a framework of key R&D capabilities for project success. Three functions involved in product commercialization are identified as: marketing, R&D/engineering, and manufacturing. Similarly, there are three key success factors: *functional competence* of the three functions, *strong communication* with the customer, and finally *strong management execution,* or the ability to hold together the three functions and steer them in a coherent direction. In addition, external factors such as a large and growing market or weak competition increase the likelihood of success in certain development projects. This study is more ambitious than ours, as the marketing and manufacturing functions are included. However, the goal of our study is to make the concept of "functional development competence" operational and measurable.

The internal R&D audit process of the 3M company, a very successful practitioner of innovation, supports the findings of the previously mentioned studies [22]. 3M predominantly uses measures at the project level, but most of them can also be aggregated to R&D as a whole. The company 3M reports that program ratings of this audit are good predictors of the commercialization success of a new product. They distinguish between three types of factors: *technical factors* (overall technology strength; personnel; product performance vs. competition; manufacturing implementation and technical success probability), *business factors* (financial potential; 3M competitive position in product value and channels; and probability of marketing success), and *overall factors* (organizational planning, strategy and clarity of goals; program balance; and strength of interactions with marketing, manufacturing, and other labs). A final predictor of project success is the degree of similarity to existing 3M technologies and products.

Finally, Clark and Fujimoto [5] in their landmark study of the world auto industry use three key R&D performance measures: *engineering productivity* (engineering hours per normalized project), *time to market* (again for a normalized project), and *total product quality* (which includes conformance quality and "product integrity," a high level measure of product performance and consistency with an overall company identity). In a follow-up report, Cusumano and Nobeoka [10] add to these the number of products introduced, design manufacturability, market share/growth, and a return on R&D.

Fewer studies have been done on R&D performance on the firm level than on the project level. We now summarize some important findings of the firm level R&D performance literature. Morbey [25] examines the connection between R&D expense and profitability from annual reports of 800 U.S. companies between 1976 and 1985. He finds that R&D expense is a poor predictor of profits, but a good predictor of growth. This analysis lumps together fundamental research and direct commercialization and looks only at development input (does not allow for efficiency differences between companies). Therefore, it is interesting to explore development influence on success further on a managerial level.

The model of Foster et al. [13] is a ''return on R&D investment tree'' with an R&D return ratio at the top, defined as profits generated by R&D over the R&D investment. This ratio is then broken into R&D productivity (a measure of internal capabilities) and R&D yield (a measure of external profit potential from innovations). The key R&D output measure in this model is ''Technical Progress,'' defined as the performance increase from one product generation to the next. Within this framework, activities with the highest value for improving R&D productivity are identified as: spotting technical opportunities; increasing ''development efficiency'' (personnel quality and staffing, initiating and terminating projects, planning projects); and increasing ''operating efficiency'' (identifying customer needs, coupling with marketing and manufacturing). External R&D yield is determined by demand outlook and the industry cost curve. The authors argue that ''surrogate measures,'' such as the number of products introduced or the number of patents held, are only of value if they have a ''linear relationship'' to R&D effort (input). A related approach, using a return on investment (ROI) type ''effectiveness index'' over many R&D projects, is offered in [24].

Several studies propose what Foster calls ''surrogate measures'' of R&D inputs and outputs. For example, Cordero [9] names as output measures: quantitative monetary measures (revenue, rate of return, percent of new product sales, and business opportunities); quantitative nonmonetary measures (market share, number of new products, success rate, publications and patents); and qualitative measures (profile, subjective reviews). The main input measures are R&D expense, intensity, and manpower.

Szakonyi [32] concentrates entirely on the process, proposing to measure R&D effectiveness by the presence and sophistication of formal procedures in 10 areas: Project selection, planning, idea generation, quality control, people motivation, crossdisciplinary teams, and coordination with marketing, manufacturing, finance, and strategy.

Similarly, Brown and Gobeli [4] present a ''top 10 list'' of R&D performance measures in seven categories, based on their own case studies. The seven categories are resources, project management, people management, planning, new technologies, outputs, and financial results. The measures within the categories are operational in character (for example, number of field complaints for ''outputs'').

Griffin and Page [14] provide some structure among the measures mentioned in this section by reporting on the 1990 Product Development and Management Association task force on product development success and failure. Through interviews with academics and practitioners, they identify 14 of the most widely used product development performance measures and classify them into four categories. In addition, they identify a number of measures that are ''most desired,'' but unused. These measures are summarized in Figure 1. The most important reasons cited for their underutilization are: lack of systems, adverse company culture, and lack of accountability.

We used this structure as a key ingredient in our framework with the intention of further exploring the relation between project success and success at the firm level. This framework is presented in the next section and enables us to perform statistical analysis on product development performance at the firm level.

Refining the Concept of Development Performance

R&D literature and practice provide a variety of performance variables. In the framework in Figure 1, we identified all of the measures that could be reproduced from our data set. We chose the Griffin and Page survey as a basis for defining development output performance, because it is current and because it surveys performance variables considered to be relevant to business practice as well as scholarly research. When designing a regression model linking these development performance measures to firm success, however, it became clear that not all of them have had a direct impact on firm success.

Development produces outputs for the firm (such as new products) at a cost (development expenses). Development output and productivity are the drivers of business success, together with the sales/marketing and the manufacturing function. Only some of the measures identified fall into this category, whereas others are *process* drivers. That means they have a direct impact on development output, but the link to business success is indirect. This causal relation between development process, output, and business success is similar to the model offered by Cordero [9].

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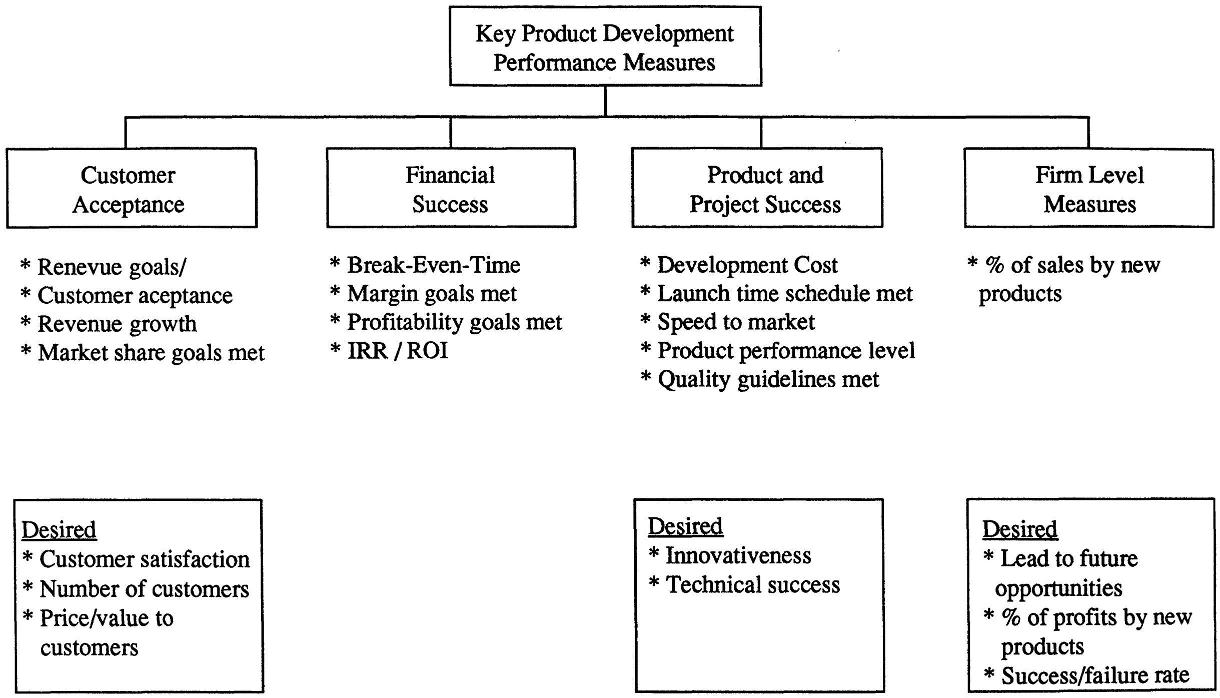

Figure 1. Performance measures found by Griffin and Page [14].

This model characterizes technical output as a result of R&D resources (see Figure 2).

Business success depends not only on development output, but also on the efficient use of the resources. Cordero refers to this variable as ''quality of resource deployment,'' a term that basically fits his concept of productivity as defined later in this section. However, Cordero's work is neither based on empirical evidence nor does it provide any guidance for managerial action. In contrast, the present article contributes to both of these dimensions, building on data from 95 business units and providing managerial performance and process variables.

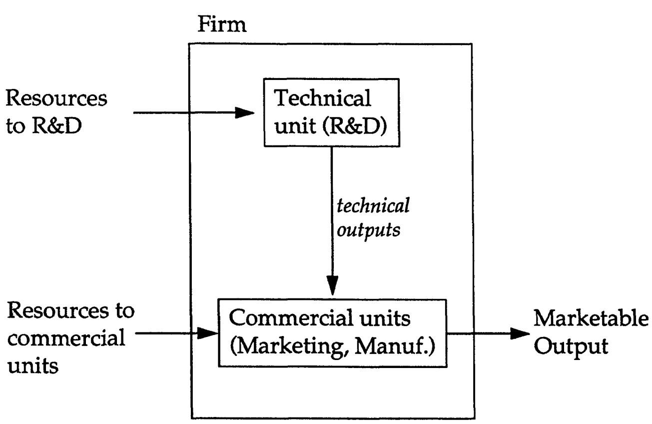

Figure 2. A model of performance measurement by Cordero [9].

Reflecting the process-output-success chain, we divide the development performance concept into two. The first, output performance, includes development output as well as efficiency; it is the direct driver of business success. The second is process performance, which influences output performance through the operational management of development projects. This framework combines the project and firm level views and is summarized in Figure 3.

Starting from this two-step framework, we perform two separate regression analyses: the first links key development output performance dimensions to business success, and the second identifies key development process performance dimensions that drive output performance.

The output regression is conducted in two steps: first, a factor analysis is performed on the set of output performance measures constructed from our data set, attempting to reproduce as many measures from the literature as possible. The factor analysis constructs groups of correlated variables, or underlying ''dimensions'' of drivers. Second, the factors serve as independent variables in a regression model identifying the most significant drivers of business success. Three

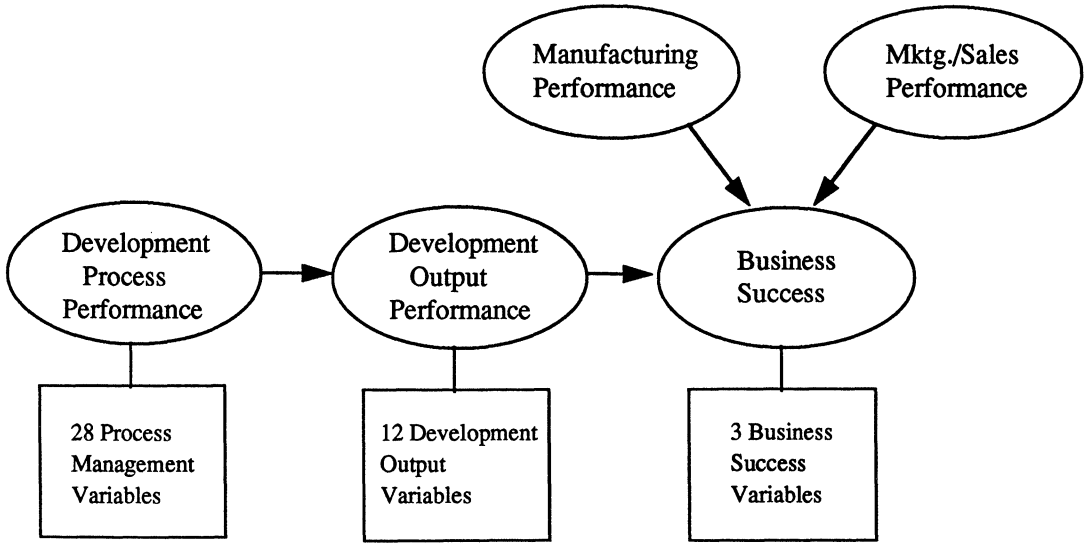

Figure 3. A framework of development performance.

business success measures are used as dependent variables in the development output performance model. The factors found in the output performance regression serve as dependent variables in the process performance model. All variables are listed in Exhibit 1, and the methodology is described in the appendix.

The questions we try to answer with the two regression models can be summarized as follows.

Regression model 1: *Output Performance.* What are the most significant measures of development output performance, and how do they contribute to business success?

Regression model 2: *Process Performance.* What are the most significant measures of development process performance, and how do they contribute to development output performance?

In particular, in each model the following questions are to be answered:

1. What are performance dimensions that can be identified from the set of measures found in the literature?
2. How do these dimensions drive success?
3. How do the relevant development output performance dimensions change across industries, reflecting differing strategic success factors?

Although the sample contains companies from Japan, the U.S., and Europe, for the purpose of this analysis we are not interested in country-specific differences. We controlled for the regions in both regression models by adding regional dummy variables, they were not significant. All companies in the sample participate in global markets and thus must obey the same market rules. Hence the influence of development output on business success can be expected reasonably to hold across regions, despite possible variance in success. It is not as clear whether companies in Japan, the United States, and Europe use different processes to achieve development output. Nevertheless, a full investigation of regional differences is likely to produce interesting results; however, such an investigation is beyond the scope of this article.

The Data

Our analysis is based on a sample of 95 electronics companies in the U.S., Japan, and Europe. During 1992–1993, these companies completed detailed questionnaires on operations and strategy as part of the "Excellence in Electronics" project jointly undertaken by Stanford University, the University of Augsburg, and McKinsey & Company. Many of the world's leading companies agreed to participate in the survey, providing us with data on 12 of the 25 leading computer producers and four of the six biggest TV manufacturers, to cite two industry examples. The objective of this project is to gain a better understanding of the industry dynamics in electronics and to understand key success factors in development and manufacturing. The unit of analysis of our work is the individual business unit with its specialized product lines; this method enables us to analyze big companies serving multiple markets without crossproduct effects. In

Exhibit 1. Definitions of Variables

Variables Describing Firm Success:

All firm success variables are measured on the business unit level. Data on the product line level were not uniformly available, thus variable definition on this level would have resulted in comparability problems.

- Profitability = ROS (return on sales) 1991 before extraordinary items and taxes
- Profitability growth = ROS growth from 1989 to 1991
- Sales growth = Revenue growth from 1989 to 1991

Variables Describing Development Outputs:

- Proportion of products first to market = percentage of significant product innovations that were first to market 1991
- Proportion of significant changes in product introduction = percentage of significant product innovations over the last 3 years
- Technical product performance = product performance as perceived by marketing, R&D, and top management (self-reported estimation, crosschecked with separate reports from R&D, marketing, and manufacturing)
- Strategic Performance Position = percentage of sales created by technically superior products (self-reported estimation, crosschecked with separate reports from R&D, marketing, and manufacturing)
- Proportion of sales from products introduced the last 12 months = as of 1991
- Proportion of sales from products introduced the last 3 years = as of 1991
- New products normalized by life cycle = number of significant product line changes/innovations in 1988–1991, multiplied by product life cycle
- New major products compared to industry = number of new major products compared to market average 1991
- Unit cost reduction compared to industry = unit cost reduction (%) in 1991, normalized by industry average

Variables Describing the Development Process:

Focus and Structure of R&D

- Team vs. functional structure = 0/1 for a functional/team based organization of the R&D department
- Focus = number of parallel projects in the department
- Project duration = average duration in months

Project Management

- Team size = average size of a project team
- Meeting schedules = deviation from schedule in percentage
- Meeting budgets = deviation from budget in percentage (these two variables are measures of process discipline and control)

Exhibit 1. Continued

- Integrated SW testing = 0/1 for the application of integrated SW tests
- Early use of prototypes = 0/1 for using prototypes in the specification phase of the project[a]
- Concurrence of project phases = the time the project was simultaneously in more than one phase, in % of total project duration
- Change of specifications = number of changes in detailed specifications over the course of the project
- Number of milestones = number of milestones used in the project
- Number of design reviews = number of design reviews used in project

Crossfunctional Integration

- External sources of ideas = use of external sources for idea generation (Likert scale 1–5)
- Early marketing involvement = 0/1 for an early involvement of marketing[a]
- Reverse engineering = number of reverse engineering analyses
- Preferred parts lists = proportion of parts coming from the preferred parts list. This is a measure of manufacturing process information passed on to development
- DFM information = use of manufacturing information for product design (Likert scale 1–5)
- Value engineering = 0/1 for a use of value engineering
- Early manufacturing involvement = 0/1 for an early involvement of manufacturing[a]
- Design complexity = number of parts normalized by number of finished products
- Early purchasing involvement = 0/1 for an early involvement of internal purchasing department[a]
- Early supplier involvement = 0/1 for an early involvement of suppliers[a]
- Joint supplier designs = 0/1 for a joint cost reduction redesign of the product together with the supplier
- Cooperation with basic research = Likert scale 1–5

People Management and Learning

- Team rewards = 0/1 for rewards based on team performance, not on individual performance
- Job rotation = how many engineers were involved in job rotation on the business unit level (%)
- Training per employee = active training per R&D employee
- Crossfunctional training = proportion of engineers involved in cross functional training (normalized by duration).

[a]These perceptual variables have been discussed widely in the popular press; this lends some limited credibility to the assumption that the perceptions are consistent across companies. The perceptual variables were the best proxies available.

some cases, we included more than one business unit per company.

The 95 usable observations were grouped into three different industry clusters: Consumer/small products, computers/communications, and industrial measurement/large systems. Sample sizes and industries in the clusters are shown in Table 1. Whereas the industries in a cluster are far from homogeneous, they are characterized by important commonalities in key drivers of competition: the consumer products industry has progressed the farthest toward maturity, characterized by short product life cycles, fierce price competition, and low value added. This is demonstrated by the recent rise of Korean manufacturers and a shift of manufacturing to low wage countries, even from Japan [26]. On the other hand, the measurement and large systems industries still exhibit less severe competition and product differentiation, whereas the computer industry is in between, rapidly moving toward maturity [21, p. 199]. As an example, stereos have a life cycle of less than 6 months in some cases, computer life cycles have come down to under a year, whereas industrial measurement systems or large PBXs still live several years.

Measures of Development Output Performance

This section describes the output performance regression model. All development output variables are included in Exhibit 1. Business success is operationalized with three separate measures: profitability (ROS 1991 before extraordinary items and taxes); profitability growth (ROS 1989–1991); and growth (sales 1989–1991). The three separate measures take into account that absolute profitability levels vary between industries and that ROS usually decreases in phases of high growth: profitability and growth represent, at least partially, conflicting strategic goals, which is also reflected in the results of [25]. This difference in the strategic role of the three business success measures precluded combining them into a summary measure.

Our lack of a priori knowledge about the relevant dimensions of development output performance precludes a *confirmative* factor analysis of the output variables constructed. As a result, we have chosen an *exploratory* approach yielding five dimensions of output performance. The key difference between the two approaches is that the former specifies all factors ex ante and then statistically ''proves'' this choice, whereas the latter extracts factors from the data in a way that maximizes the proportion of overall variance explained [15]. In the next step, the factor scores from this analysis are used as independent variables in the output performance regression analysis against measures of overall success.

The reader should bear in mind that *development performance is only one of several business success drivers,* as is shown in Figure 3. Marketing/sales and manufacturing performance are omitted from our model and thus represent a source of unexplained variance. In an *exploratory* analysis such as this, the main task is to *identify* the relevant success drivers. In our regression model we, therefore, concentrate on statistical significance. The overall explained variance varies across the regressions (it is highest for the computer industry, see appendix). Once key success drivers are clearly identified, one can begin teasing out their relative importance. This must, however, be left to future work.

Identification of Development Output Performance Dimensions

Using the initial set of performance variables, factor analysis enables us to extract more general dimensions

Table 1. The Excellence in Electronics Survey

Industry Group	Number of Observations	Example Industries
Consumer/small products	20	TV, VCR, phones
Computer/communication	39	PCs, minicomputers, printers, PABXs, data communication
Industrial measurement and large systems	36	controls, mainframes test/measurement, medical systems

of performance. Factor analysis correlates a set of variables against each other, identifying groups of variables (if they exist) that are strongly colinear and thus collectively measure the same thing. These variable groups are called "factors" and represent more general "dimensions" of performance. Here, the factor analysis leads to a five-factor solution in Table 2.

The left column shows the nine performance measures from the literature that we were able to construct; the upper row lists the five factors found. The choice of five as a number of factors is based on the explanatory power of these factors and is explained in the appendix. Accordingly, overall variance explained is reported quite high as 78% in the bottom row. The numbers in the body of the table are the correlations between the performance measures and the factors. The table shows that each measure clearly connects to only one factor, the crosscorrelations to other factors are all very low.

The first factor is *market leadership,* which is associated with the proportion of products first to market, and with the proportion of product introductions representing significant innovations. This dimension measures development ability to tackle new needs that are not yet satisfied in the market and cannot be copied, and to successfully launch them before other competitors. Market leadership is intensively discussed as a strategy that may or may not be appropriate for a given company. Influenced by marketing's ability to correctly identify market needs, market leadership, in the context of this study, measures development ability to successfully execute strategy.

The second factor identified is *design quality,* which encompasses two different measures of technical product performance, as opposed to quality of conformance in manufacturing or industrial design. Technical design quality is widely considered to be an important aspect of development output.

The third factor is the *innovation rate,* which combines the number of major new products introduced, compared to the industry average, and the overall number of product introductions normalized by the product life cycle in the industry. This standardization eliminates the industry product life cycles from the data. Thus, this performance dimension expresses development speed, the capability to bring out products in rapid succession, relative to the business unit's competitors. This capability is generally considered important in the fast-paced electronics industries. As measured here, the innovation rate dimension does not contain any information about how it is achieved, for example, through fast processes or through large resources. The latter is indirectly measured in the productivity ratios and explicitly contained in the process performance model.

The fourth factor is *product line freshness.* The vari-

Table 2. Dimensions of Output Performance

Variable	Market Leadership	Design Quality	Innov. Rate	Prod. Line Freshness	Design to Cost
Proportion of products first to market	0.91	0.07	−0.09	0.11	−0.12
Proportion of significant changes in product introduction	0.83	0.31	0.14	0.02	0.04
Technical product performance	0.17	0.84	−0.01	−0.04	−0.03
Strategic performance position of the business unit	0.14	0.79	0.12	−0.02	0.27
Prop. of sales by products introduced the last 12 months	−0.03	0.01	0.84	−0.12	0.11
Prop. of sales by products introduced the last 3 years	0.06	−0.11	0.77	0.21	−0.05
New products normalized by life cycle	−0.11	0.12	0.19	0.80	−0.32
New major products compared to industry	0.31	−0.22	−0.09	0.77	0.21
Unit cost reduction compared to industry	−0.08	0.17	0.07	−0.06	0.91
Eigenvalue	2.14	1.70	1.37	0.94	0.87
Variance explained	23.7%	18.8%	15.1%	10.4%	9.8%
Cumulative variance	23.7%	42.5%	57.6%	68%	77.8%

ables associated are proportion of sales from products introduced within the last year and within the last 3 years. This factor explicitly contains the influence of the industry's life cycle. But since the life cycle is the same for every competitor, it does not explain why this factor differentiates between companies. The factor measures in addition how current a business unit's product line is, and how ''fresh'' and up-to-date the products are. Product line freshness is often cited as a differentiator, particularly in the PC and consumer electronics industries.

The fifth factor is *design to cost,* representing as the only variable ''unit cost reduction.'' The importance of cost reduction reflects whether an industry is driven by product performance and innovation or by cost and price. Unit cost reduction is driven by purchasing prices, manufacturing efficiency, and design. Experience suggests, however, that design and product manufacturability drive the largest part of cost reduction potential in many cases, sometimes up to 80%. Thus, this factor measures development capability of designing manufacturable and cost-efficient products.

The factors identified previously represent output measures of development. In addition, we defined three productivity measures, in order to include resource consumption in the analysis. The three productivity ratios are shown in Table 3. Expense intensity is related to sales. Personnel intensity is not a productivity ratio in the strict sense, but it captures differences in salaries (e.g., education levels) and infrastructure (e.g., investment in development tools). The last ratio measures development efficiency in producing new products rather than sales, as do the first two ratios. Each ratio highlights a different aspect of productivity. Thus, we include all three in the regression model.

Significant Development Output Performance Dimensions

After defining five performance dimensions and three measures of productivity, we need to evaluate their

Table 3. Development Productivity Measures

Personnel intensity	$\frac{\text{(Development employees)}}{\text{Total employees}}$
Expense intensity	$\frac{\text{(Development expense)}}{\text{Sales}}$
New product productivity	$\frac{\text{(Number of new products)}}{\text{(Development employees)}}$

All variables are measured for 1991. New product productivity = (no. of significant product line changes and major modifications)/(no. of R&D employees).

relevance to business success. We compute the factor scores of the 95 observations and use them as independent variables. We perform subregressions within each of the three industries to get a feeling for the industry-specific performance dimensions. The methodology is described in the appendix. Because we are interested in identifying significant development performance drivers of business success rather than the exact regression coefficients, the complete results of the regression model have not been included. The ranges of explained variance in the models are shown in the appendix.

The computer and the measurement/large systems clusters generate significant statistics. However, we find no statistically significant results for the consumer electronics industry (20 observations). The data set may simply be too small given the noise level in the model. However, the consumer electronics industry is also the one where manufacturing efficiency and marketing matter the most (the contribution of nonmanufacturing cost to total cost is lowest [21,32]). Thus, the lack of significant results may also suggest *for this particular industry* that development performance in fact is of lesser importance and that manufacturing and marketing studies may produce better predictors of business success than a development study.

Table 4 shows the statistically significant performance dimensions by industry (indicated in the left-hand column) and by business success measure (indicated in the top row). Also included are their significance levels and signs of their relationships to the success variables.

The clearest result of this analysis is that development productivity, measured by expense intensity, stands out as a critical driver of business success across both industry clusters. The computer industry is influenced by two additional variables: design-to-cost has a positive influence on profitability growth and design quality positively correlates with sales growth. The signs of all relationships are as expected.

The measurement and large systems industry cluster shows no additional business success driver of statistical significance. This cluster was not subdivided into its industries because of the strategic similarities discussed earlier, and also because the size of the data sets (this is a problem particularly for the process performance regression below). To look for additional insights, we did attempt the separate regression within this cluster for large systems and measurement systems. We found that design quality has a 1% significant positive relationship with sales growth in the

Table 4. Statistically Significant Output Performance Measures

	Business Success Measure		
Industry	Profitability (ROS 1991)	Profitability Growth (ROS 1989–1991)	Sales Growth (Sales 1989–1991)
Measurement/ Large systems	Dev. expense intensity (–)[a]		
Computer	Dev. expense intensity (–)[a]	Dev. expense intensity (–)[a] Design to cost (+)[b]	Design Quality (+)[b]

[a] Significant on the 1% level.
[b] Significant on the 5% level.
(+) Denotes a positive and (–) a negative relationship.
Sample: computer $n = 39$ and systems $n = 36$.

large systems industry and with profitability in the measurement industry. Neither relationship appears in the overall regression for the cluster because it is ''washed out'' by the data of the other industry in both cases.

These findings are surprising and disturbing. They are, at first glance, consistent with a short-term oriented strategy of slashing development expense irresponsibly at the cost of destroying the company's long-term prospects. However, all the business units in the sample compete in world markets in order to stay, and indeed, all are still in business today. It is thus unlikely that these results point toward a ''slash-and-burn'' strategy. Given this ''steady-state'' argument, the best explanation is that the successful companies are able to use fewer dollars to get the necessary development results to compete. This is further discussed and interpreted in the section on managerial insights below.

Finally, we need to indicate how strongly the business success variables interact. In the measurement/large systems industries, sales growth and profitability growth are highly correlated with a coefficient of 0.68. This suggests that growth was largely achieved without market share battles. In the computer industry, in contrast, 1991 profitability is closely correlated with profitability growth ($r = 0.80$). This indicates that the profitable companies became even better.[1]

Measures of Development Process Performance

In this section, we describe the development process performance regression model. The seven dependent variables in this regression are the scores of the five output performance factors plus the two productivity ratios, identified as significant in the previous section. We attempt explaining these output performance measures by a number of process quality measures serving as independent variables.

The current state-of-the-art in development process management emphasizes the link to strategy, project management, integration across functions, and people management and learning (see, e.g., [34]). We operationalize these four areas of development process quality with 28 individual measures shown in Figure 4.

These 28 measures could be constructed from the ''Excellence in Electronics'' survey data. The first group of measures is labeled ''focus and structure,'' because we could not construct a direct measure of the linkage to overall strategy. As a proxy, we use measures of development structure (team organization vs. organization around technical functions) and focus (number of parallel projects) and of the organizational

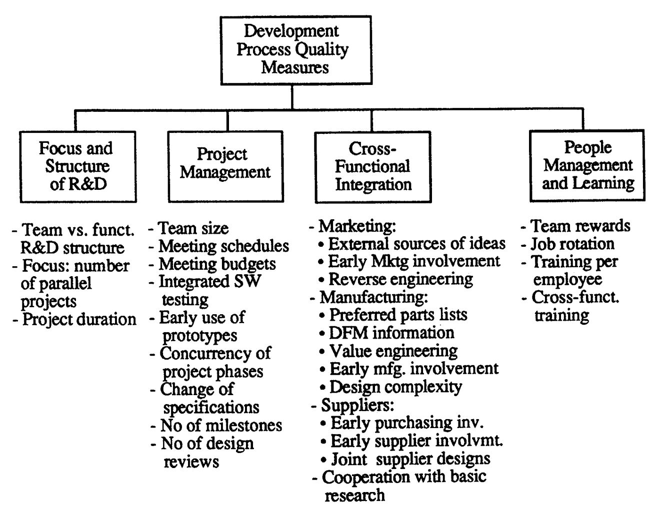

Figure 4. Measures of development process performance.

[1] Inspection of the data showed that the profitability levels were *not* the same in 1989, which would be an alternative explanation for a correlation between profitability 1991 and profitability growth.

authority of project teams (org. level of the project managers). Project duration measures the ''ambition'' (technical content) of projects; schedule overruns are listed under project management. The remaining variable names are fairly self-explanatory. The reader interested in precise variable definitions is referred to Exhibit 1.

From practical experience and literature, we expect the following effects of the process measures on development performance: among the variables describing development focus and structure, project structure and authority should increase performance, whereas the number of parallel projects and project ambition should hurt it. (Large projects tend to increase disproportionately in difficulty.) Among the project management measures, all should improve performance except changes in specifications (demand for early spec freeze), and team size, the influence of which is unclear. Likewise, all measures of crossfunctional integration are expected to be positively related to performance. In the people management area finally, job rotation and training are expected to be positive, whereas the impact of team-oriented or process-oriented employee rewards is unclear.

We now report the result of 21 separate regressions, one for each combination of the dependent variables and overall data set, measurement/systems cluster, and computer industry. We structure the presentation of the results into two parts: first, Table 5 reports general results valid across industries. Second, Tables 6 and 7 look at the systems and computer industries, respectively, for industry-specific findings. No specific statements are made for the consumer electronics industry, because of the insufficient number of observations. In this section, we only briefly describe the results. Interpretation and managerial discussion of the results are given later.

In all three tables reporting the results, the productivity measure ''new product productivity'' and the output dimension ''design quality'' are left out, because no process variable had a significant relationship to them. We expect this dimension of development process performance to be driven by the qualification (e.g., creativity and skills) of the designers. Unfortunately, we had no measure of personnel qualification (such as education levels) available in this study.

How can a company achieve excellence in development? Table 5 presents the relationship between the four groups of process variables from Figure 4 and output/productivity. It illustrates that achievements in different dimensions of development have to be achieved with different tools. For reaching market leadership three of the four groups are found to have significant impact: among the various project management methods, the use of prototyping early in the specification phase is significant. Whereas crossfunctional integration with purchasing surprisingly hinders market leadership, people management, using team rewards, supports it.

The use of crossfunctional integration has the broadest impact on development output: using ideas from outside the organization increases the innovation rate, but also personnel intensity. Value engineering has a positive impact on product line freshness, and

Table 5. Process Performance across Industries

	Market Leader ship	Innov. Rate	Product Line Freshness	Design to Cost	Devel. Personnel Intensity	Devel. Expense Intensity
Focus and structure					Team Structure (–)[b]	
Project management	Early use of prototypes (+)[b]					
Cross functional integration	Early purchas. involvement (–)[b]	External sources of ideas (+)[b]	Value engineering (+)[b]	Early marketing involv't (–)[b]	External sources of ideas (+)[a]	Design complexity (+)[a]
People management and learning	Team rewards (+)[a]			Job rotation (–)[a]		

[a] Significant on the 1% level.
[b] Significant on the 5% level.
(+) Denotes a positive and (–) a negative impact.
Sample: computer and systems industries (size $n = 75$).

Table 6. Process Performance in the Measurement/Large Systems Industry Cluster

	Market Leadership	Product Line Freshness	Design to Cost
Focus and Structure		Team rewards (–)[b]	Team-based structure (–)[a]
Project management			
Crossfunctional integration	Joint supplier designs (+)[b]		Design complexity (+)[b]
People management and learning		Job rotation (+)[b]	Early marketing involvement (–)[b]

[a] Significant on the 1% level.
[b] Significant on the 5% level.
(+) Denotes a positive and (–) a negative impact.
Sample size: $n = 36$.

designing less complex products decreases development spending intensity. Early marketing involvement seems to reduce design-to-cost benefits, as does job rotation (see later discussion). Finally, a team-based development organization reduces personnel intensity, supporting earlier experience that teams are fast and efficient, whereas a functional organization has its strength in depth of expertise [3].

Surprising results in Table 5 are the negative impact of job rotation and the mixed benefits of crossfunctional integration; early involvement of purchasing and marketing appear to have some negative side-effects (on market leadership and design-to-cost). This highlights that these management methods may not only be beneficial, as is widely reported, but may also carry a coordination cost. The negative effect of job rotation particularly contradicts our experience. Further research will be required to find additional support for this observation or to identify it as a regression artifact.

Table 6 presents specific findings for the large systems/measurement cluster, found in the corresponding subregression. Only the dependent variables with statistically significant relationships are shown. In this cluster, market leadership is positively influenced by the involvement of suppliers in cost redesigns, supporting recent trends to utilize supplier expertise in product design. Product line freshness is rendered harder to achieve by the use of team rewards, but facilitated by job rotation of development personnel. Design-to-cost benefits are compromised by a team based (vs. functional) organizational structure and by early marketing involvement.

The negative effect of team rewards and team-based structures suggest that the large systems/measurement industry cluster is characterized by comparatively lower product introduction rates, where the traditional functional development organization still offers advantages. Early marketing involvement may reduce design-to-cost benefits, because customer requirements are not necessarily consistent with design-to-cost principles.

Table 7. Process Performance in the Computer Industry

	Market Leadership	Innovation Rate	Product Line Freshness	Design to Cost
Focus and structure				Project duration (–)[b]
Project management	Early use of prototypes (+)[b]	Team size (–)[b] Change of specs (+)[b] Concurrence of phases (+)[b] Joint supplier designs (+)[b]		
Cross functional integration	Early purchasing involvement (–)[b]		Value engineering (+)[b]	
People management and learning	Team rewards (+)[b]		Cross functional training (+)[b]	

[a] Significant on the 1% level.
[b] Significant on the 5% level.
(+) Denotes a positive and (–) a negative impact.
Sample size: $n = 39$.

In contrast; design to cost is supported by design complexity. At first glance, this appears counterintuitive—a higher part count increases cost reductions from design to cost. A possible interpretation is that a company that falls behind and attempts to catch up on design to cost has a higher redesign potential, with more ''low hanging fruit'' to pick.

Table 7 summarizes the results for the computer industry. The drivers of market leadership are identical to the overall regression: the use of early prototypes and team rewards are positive, whereas early purchasing involvement is detrimental. The innovation rate drivers, in contrast, are unique for the computer industry. Project management is important for allowing concurrent project phases, and for changing specifications more often. The latter is contrary to the popular principle ''Freeze specs early.'' Our finding suggests that firms with a high innovation rate change and update specs more frequently. Changing specifications provides flexibility that apparently increases the frequency of innovation. Furthermore, small teams are important, which is predictable. Finally, the innovation rate is supported by supplier involvement in redesigns, as in the large systems/measurement cluster, for example.

Companies with a fresh product line rely on cross-functional training, in addition to value engineering approaches already found in the overall regression. Finally, long, ambitious projects have a negative impact on unit cost reduction potential from design to cost. This further supports the need for project focus found in Table 5.

Discussion of Managerial Insights

Development Output Performance

We first turn to discussing output performance. The number of significant results is limited by sample sizes and the concentration of our analysis on only development as a business success driver. In general, a missing significant relationship between a development output dimension and business success does not necessarily imply irrelevance: if a specific competence has become widely practiced as an industry matures, the corresponding variable will provide little or no variance. This will prevent significant results in a regression. In spite of these limitations, several striking results about drivers of competitive advantage emerge.

First, we observe across computer and systems industries that development productivity (measured by expense intensity) comes out as the clearest predictor of success. As is discussed in the description of the output performance regression, this finding lends support to some companies' practice of setting certain ''affordable'' levels of development size and spending, which can best be characterized by a percentage of its sales. Porter [28] observes that scale economies and learning effects provide development cost advantages for large firms. This implicitly demands that the development function ''make do'' and support the ongoing business with new products within the limits of this affordable budget. Kluge et al. [21] report that successful developers bring out the necessary new products with fewer development dollars. For the industry as a whole, this implies that spending levels are about right or too high. In other words, hardly any company is underspending on development. Hence, bringing out new products more efficiently is more promising than outspending one's competitors, unless a firm sees a special opportunity or possesses special capabilities.

In addition to this general finding, some performance measures are industry specific. In the computer industry, design quality and design to cost are additional drivers of profitability. This result supports the general assessment that productivity and cost reduction are necessary in light of increasing competitiveness and falling prices. In addition, finding design quality as growth predictor provides an interesting clue to the factors that condition strategic success in this industry, implying that product performance at low cost has been the key to success during the last years.

The results for the large systems/measurement cluster are less telling about strategy, as no significant driver of business success appears besides productivity. However, subregressions on the two industries making up the cluster provide evidence that design quality is relevant.[2] This suggests that the large systems/measurement cluster is driven to an important extent by technical product performance.

In the consumer products industry, we did not find any statistically significant results. It is possible that the size of the data set prevented any meaningful findings. However, the consumer electronics industry is the most mature industry in the sample, mainly driven

[2] Design quality came out as significant on the 1% level for sales growth in large systems and for profitability in measurement systems; see the discussion in the section ''Measures of Development Outcome Performance.''

by manufacturing cost and marketing [21,33]. Manufacturing and marketing performance are more important than in other industries, and product development performance is less important [35]. This may be reflected by the lack of statistically significant findings.

Development Process Performance

We now attempt a managerial interpretation of the process performance regression results. We will look at two relevant views: first, which are consistently important development process management variables, and second, what are the industry-specific determinants of development output?

First, we review the trends that seem valid across all industries: involving suppliers in design (joint supplier design) seems to be beneficial; it helps market leadership in the measurement/large systems industry cluster and innovation rate in the overall regression. Utilizing the expertise of suppliers is currently being ''discovered'' in several industries [13,19,21].

Early prototyping and the use of team rewards have a positive impact on market leadership, whereas early purchasing involvement hinders it in both industries. This finding suggests that this type of purchasing involvement is useful for incremental projects, where components do not change radically from the past, but represents an obstacle for radical projects aimed at market leadership, where the degree of newness is much higher.

Listening to customers and to marketing appears beneficial, but at a cost. Organizations utilizing external ideas have a higher innovation rate (in the overall regression), but also a higher need for development personnel, increasing personnel intensity. Early marketing involvement reduces cost reduction benefits from design to cost, revealing a conflict of goals—marketing's recommendations may not always be consistent with the design changes that lead to lower unit cost. It is the responsibility of management to resolve this conflict within the context of business strategy.

Value engineering offers benefits for achieving product line freshness (in the overall and computer regressions). Furthermore, a team-based development organization is found to be efficient: team structure reduces personnel intensity, and team rewards support market leadership. This finding is consistent with previous experience that project-based organizations tend to trade depth of expertise for higher speed and efficiency.

Finally, design complexity hurts development productivity (increases personnel intensity for computers and expense intensity overall). Simplifying product design and parts count is an important principle of design for manufacture. This principle finds further support in the positive impact of focus (in the computer regression): shorter, less ambitious projects allow a higher cost benefit from design-to-cost efforts. The emerging principle is simplification both of product design and development complexity.

We now turn to process features specific to industries. It is peculiar that in the large systems/measurement cluster, design complexity increases the cost reduction from design-to-cost efforts. Moreover, using design for manufacture information early in the process hurts productivity. The conclusion is that this industry cluster as a whole lags behind other electronics industries in its mastery of design-to-cost methods. The more complex the product design, the easier it is to pick some ''low hanging fruit'' and score easy design-to-cost successes. But the process is not mastered and thus hurts productivity. As explained in the data presentation, the large systems/measurement cluster has not yet progressed as far toward mass production and price competition as the computer industry. Competition is still focused on technical performance, explaining the relative lack of design-to-cost competence.

The computer industry, in contrast, is much more driven by speed and cost, making project management more critical: concurrent engineering and the flexibility provided by changes in specifications positively impact innovation rate, whereas team size impacts it negatively.

We conclude that development process performance is not an absolute concept, but rather depends on the nature of competition in each industry. Few development process principles can be recommended in general. One example is supplier involvement in design, which is just beginning to be implemented widely, until it becomes a competitive necessity rather than a source of advantage. Most process characteristics, however, are beneficial only in certain competitive contexts, but not in others.

Conclusion

In this article, we have developed a two-step framework of development excellence. The first step, development output performance, measures development outputs and productivity. It is one important direct driver of overall business success of a company, apart from manufacturing and marketing/sales capabilities. The second step is development process performance, which measures the quality of the processes used at the project level. This step does not influence business process directly, but impacts the dimensions of output performance, which in turn determine business success. Process performance can be high, but if the wrong output performance dimensions are emphasized, business success will remain poor.

We then have applied this framework to data from 95 electronics companies worldwide. From a starting set of nine output performance measures, we extract five factors, or performance dimensions. Moreover, we are able to interpret our results in the context of the strategic situations in the computer and large systems/measurement industries (although some potentially important performance measures may still be missing). An interesting topic for further research would be to conduct a follow-up on our 1991 data set in order to ascertain the degree of change in the competitive situation in the two electronics industries over the last 3 years. A limitation of the study in this article comes from the fact that not all potentially relevant performance measures could be constructed from our data set. Follow-up research is necessary to understand the relative importance (''bang for the buck'') of different development output dimensions for overall firm success as well as of process measures for output performance. Finally, the difference in process used between companies in Japan, the U.S. and Europe is an interesting question that merits further attention.

The results of our analysis emphasize development productivity as a very important driver of business success in both industry clusters. In addition, the computer industry rewards also design to cost and design quality. In contrast, the large systems/measurement cluster seems to mainly emphasize technical product performance.

Process performance is dependent on overall competitive situation and strategy. A few generally valid process principles can be found, such as supplier involvement in design, which is just beginning to be widely implemented and provides strong competitive advantage. Other process performance dimensions, however, are industry specific, such as project management and speed in the computer industry, and technology and functional expertise in the systems industry. Strategy drives the choice of development performance measures, which in turn must determine the dimensions of process capabilities to strive for. The framework outlined in this article offers a systematic way of addressing this dependency.

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References

1. Adler, P. S. Technology strategy: A guide to the literature. *Research in Technological Innovation, Management, and Policy* 4:25–151 (1989).
2. Adler, P. S., McDonald, D. W. and MacDonald, F. Strategic management of technical functions. *Sloan Management Review* 33:19–37 (Winter 1992).
3. Allen, Th. J. Organizational structure, information technology, and R&D productivity. *IEEE Transactions on Engineering Management* 33:212–217 (1986).
4. Brown, W. B., and Gobeli, D. Observations on the measurement of R&D productivity: A case study. *IEEE Transactions on Engineering Management* 39:325–331 (November 1992).
5. Clark, K. B. and Fujimoto, T. *Product Development Performance.* Boston: Harvard Business School Press, 1991.
6. Cooper, R. G. The dimensions of industrial new product success and failure. *Journal of Marketing* 43:93–103 (1979).
7. Cooper, R. G. and Kleinschmidt, E. J. New products: What separates winners from losers. *Journal of Product Innovation Management* 4: 169–187 (1987).
8. Cooper, R. G. Debunking the myths of new product development. *Research Technology Management* 37:40–50 (July-August 1994).
9. Cordero, R. The measurement of innovation performance in the firm: An overview. *Research Policy* 19:185–192 (1990).
10. Cusumano, M. A. and Kemerer, C. F. A quantitative analysis of U.S. and Japanese practice and performance in software development. *Management Science* 36:1384–1406 (1990).
11. Cusumano, M. A. and Nobeoka, K. Strategy, structure, and performance in product development: Observations from the auto industry. *Research Policy* 21:265–293 (1992).
12. Dyer, J. H. Dedicated assets: Japan's manufacturing edge. *Harvard Business Review* 72:174–178 (Nov.–Dec. 1994).
13. Foster, R. N., Linden, L. H. Whiteley, R. L. and Kantrow, A. M. Improving the return on R&D I and II. *Research Management* 28:12–17 (Jan./Feb. 1985) and 13–22 (March/April 1985).
14. Griffin, A. and Page, A. L. An interim report on measuring product development success and failure. *Journal of Product Innovation Management* 10:291–308 (1993).
15. Hair, J. F., Anderson, R. E. and Tatham, R. L. *Multivariate Data Analysis.* New York: Macmillan Publishing Company, 1992.
16. Helper, S. R. and Saku, M. Supplier relations in Japan and the United States: Are they converging? *Sloan Management Review* 36:77–84 (Spring 1995).
17. House, C. R. and Price, R. L. The return map: Tracking product teams. *Harvard Business Review* 69:92–100 (Jan.-Feb. 1991).
18. Kamath, R. R. and Liker, J. K. A second look at Japanese product development. *Harvard Business Review* 72:154–170 (Nov.-Dec. 1994).
19. Kim and Mueller. *Factor Analysis Statistical Methods and Practical Issues.* Newbury Park, CA. Sage Publications, 1978.
20. Kleinschmidt, E. J. and Cooper, R. G. The impact of product innova-

tiveness on performance. *Journal of Product Innovation Management* 8:240–251 (1991).

21. Kluge, J., Stein, L., Krubasik, E., Beyer, I., Düsedau, D. and Huhn, W. *Wachstum durch Verzicht—Schneller Wandel zur Weltklasse: Vorbild Elektronikindustrie.* Stuttgart: Schaeffer Poeschel, 1994.
22. Krogh, L. C., Prager, J. H., Sorensen, D. P. and Tomlinson, J. D. How 3M evaluates its R&D programs. *Research Technology Management* 31:10–14 (November-December 1988).
23. Marquis, D. G. The anatomy of successful innovations. *Innovation* 1:28–37 (1969).
24. McGrath, M. E. and Romeri, M. N. The R&D effectiveness index: A metric for product development performance. *Journal of Product Innovation Management* 11:213–220 (1994).
25. Morbey, G. K. R&D: Its relationship with company performance. *Journal of Product Innovation Management* 5:191–200 (1988).
26. O'Kane, G. Japanese giants losing grip. *Asian Business:* 42–44 (January 1994).
27. Page, A. L. Assessing new product development practices and performance: Establishing crucial norms. *Journal of Product Innovation Management* 10:373–290 (1993).
28. Porter, M. E. Technology and competitive advantage. In: *Competitive Advantage.* New York: The Free Press, 1985, chap. 5.
29. Rosenthal, S. R. *Effective Product Design and Development.* Homewood, IL: Business One Irwin, 1992.
30. Rothwell, R., Freeman, C., Horley, A., Jervis, N. I. P., Robertson, A. B. and Townsend, J. SAPPHO updated—Project SAPPHO, phase II. *Research Policy* 3:258–291 (1974).
31. Roussel, P. A., Saad, K. N. and Erickson, T. J. *Third Generation R&D—Managing the Link to Corporate Strategy.* Boston: Harvard Business School Press, 1991.
32. Szakonyi, R. Measuring R&D Effectiveness—I. *Research Technology Management* 37:27–32 (March-April 1994).
33. Vaidya, A. Success in television—the Japanese way. *Long Range Planning* 26:72–80 (August 1993).
34. Wheelwright, S. C. and Clark, K. B. *Revolutionizing Product Development.* New York: The Free Press, 1992.
35. Wolff, M. F. Meet your competition. Data from the annual IRI R&D survey. *Research Technology Management:* 17–24 (January-February 1995).
36. Zelkowitz, M. A case study in rapid prototyping. *Software Practice and Experience* 10:1037–1042 (1980).
37. Zirger, B. J. and Maidique, M. A. A model of new product development: An empirical test. *Management Science* 36:867–883 (1990).

Appendix

Research Methodology

The observations were first classified into the industries mentioned previously. The classification was used to define the performance measures. As is usually done in benchmarking, relative instead of absolute performance measures were included. All statistical analysis as well as computation of performance measures was performed on a VAX using the statistical package SAS. The methodology is described later.

Mean Substitution

From the initial sample of 98 companies, three were excluded because they offered very little usable information. Within the 95 usable companies, it was not possible for all variables to obtain a 100% response rate. As the number of missing values was small compared to the total sample size, we substituted these values with the corresponding industry mean. In Table A1, we report in detail the number of substitutions. As the missing values were neither concentrated on a few observations nor on specific variables, we preferred the industry-specific mean substitution opposed to deleting all the corresponding observations. All variables not mentioned had no mean substitution.

Factor Analysis

The factor patterns were rotated using a varimax rotation. Factors were chosen based on the eigenvalue criterion. In the R&D output performance model, the last two eigenvalues are slightly below 1. These two

Table A1. Mean Substitution

Model	Variable	Large/Systems (36 observations)	Computer (39 observations)
Output Performance	Proportion of sales from products introduced the last 12 months	2	3
	Proportion of sales from products introduced the last 3 years	3	3
	New products normalized by life cycle	1	1
	Strategic performance position	1	1
	Technical product performance	2	0
Process Performance	Design complexity	3	0
	Preferred parts list	2	2
	Change of specifications	1	1
	Number of milestones	1	0
	Number of design reviews	1	0
	Team size	1	0

factors were included because they significantly improve variance explained and have a managerially meaningful interpretation. This procedure of enriching a solution provided by the Mineigen criterion is common use in case of having few variables [15,19].

Regression Model

The regression was carried out using the factor scores as independent variables. The factor scores, a result of the factor analysis, are normalized between −1 and 1, with 0 corresponding to the average. The design-to-cost factor was associated with only one variable itself (unit cost reduction), so for this factor and for the productivity measures the variables themselves were used.

The explained variance varied greatly over the regression models. The output regression in the computer industry scored highest with adjusted $R^2 = 0.7$ (profitability) and $R^2 = 0.65$ (profitability growth). No other regression model yielded consistently high R^2; they ranged from 0.1 to 0.5.