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Quality in research: an empirical study

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Abstract

The quality movement has found successive applications in manufacturing, marketing and new product engineering. Recently, the requirement by many clients that suppliers be certified by third parties and the need to improve the performance of R&D firmly raise the question: are quality approaches applicable to R&D?

Our argument is that the quality movement is applicable to R&D but, most of all, it brings a new cognitive mindset to the concern of managing R&D effectively. Firms stand to gain enormously from R&D organizations that function with high levels of diligence and awareness.

This paper is divided into four sections. The first section reviews partial approaches to quality in R&D and proposes a conceptual framework. Research questions and the study methodology are described in the second section. Findings about the meanings and practices of quality in R&D form the core of the third section. A discussion of the maturity model of R&D management is contained in the fourth section, and is followed by a conclusion.

1. Approaches to quality in R&D

In the vast number of publications concerned with quality, little discussion is focussed on R&D. The topic of quality in R&D has been studied under various themes in the past, in particular with respect to effectiveness in innovation [1, 2]. Quality in R&D has different meanings depending on one's viewpoint. Six approaches to the study of R&D quality can be found in the literature, as displayed in Table 1.

- *Decision methodologies for assessing risk and appropriability* of R&D investments are based on the premise that quality is best achieved by up-front analysis where the value of information is high. Because of the high levels of uncertainty, firms often find that private returns on R&D investment are low [3–5]. Many firms have developed methods to estimate the value of business opportunities associated with alternative R&D investments [6, 7].
- *Formal management systems* inspired by concurrent engineering and life-cycle project management are probably the most important stream of efforts [8–10]. The Japan Union of Scientists and Engineers (JUSE) has promoted formal mechanisms which form the cornerstone of many quality assurance programs [11]. Many internal quality assurance programs and third-party certifications, such as ISO-9001 or EN-2901, outline the policies and procedures which

TABLE 1. Segmented approaches to quality in R&D

	Time of applications		
	Ex ante decisions	Process analyses	Ex post evaluations
Formal quantitative approaches	Decision methodologies for assessing risks and appropriability • risk/return analysis • cost/benefit analysis • appropriability	Formal administration systems • ISO-9000 • JUSE • SEI process assessment	Science indicators • Intellectual property - bibliometrics - patents - citations • Social returns
Structured judgment approaches	Strategic planning and audits • corporate reviews • allocation of resources • strategic planning	Effectiveness of R&D organizations • discriminating factors for innovation success/failure • coupling of R&D with other functions • entrepreneurs and teams	Peer reviews • judgments as to quality and relevance • guidance and assessment

are to be followed in designing, building and documenting products [12].

- *Scientific indicators* are linked to the search for formal methods to evaluate quality and pertinence in R&D. Scientific indicators aim to assess the quality of research by using papers, citations, co-citations or patents [13, 14]. The explicit assumptions are that: (i) publications in scientific journals and patents are legitimate indicators of *research output*; (ii) citations attributed to these publications are legitimate indicators of *research quality*.
- *Strategic audits* focus on whether R&D has the level and direction to become an indispensable competitive weapon [15]. Committees of experts or scientific advisory boards are often formed to judge the quality of planned research programs [16]. Strategic audits often rely on ex post evaluations of R&D programmes to engage in ex ante judgments of future research plans [17]. Examples are (i) the evaluation of the Engineering Research Centers by the National Academy of Engineering in Washington, or (ii) the CURIEN task force established to assess the Bureau de Recherche Géologique et Minière in France.
- *Effectiveness in innovation*. Quality in R&D has also been approached in the search for the discriminating factors of success or failure in the transfer and utilization of information necessary for innovation [18]. The SAPPHO project, conducted in the early 1970s, found that the single measure which clearly discriminated was an understanding of users' needs and customer interactions, corroborating findings by Von Hippel [19]. The critical role of the entrepreneurs (individuals or teams) in coupling the technology with the market was also highlighted [1].
- *Peer reviews*. Peer reviews examine both the quality and the relevance of research activities within a reference social system. Peer reviews cover not only technical aspects, but also business and organizational factors [20]. Criticisms and defences of peer reviews abound [21, 22]. Peer reviews are based on the collective judgment of panels of knowledgeable scientists, who are sometimes criticized as interested in perpetuating established institutions and disciplines. However, business firms increasingly use peer reviews to assess research performance and guide the planning of research activities.

As a model of strategic change, however, the quality movement is holistic. Quality in R&D is concerned with ways to manage the innovation process effectively at the strategic and operational levels [23]. The development of cognitive mindsets which emphasize diligence and attention to detail is also promoted. A set of beliefs, a strategic vision, aims to modify organizational processes and involve employees to attain effectiveness in R&D output.

The Baldridge competition uses a comprehensive framework indicating that many factors influence quality, in particular leadership and a variety of managerial practices [24]. The European Foundation for Quality assesses quality by attributing equal weight to outputs and managerial factors (EFQ, 1993). Many executives and quality experts have doubts concerning comprehensive approaches which are based on judging managerial practices rather than a clear measurement of outputs. However, holistic approaches are selected by researchers who study the innovation process [25, 26].

- The evaluation of actual R&D effectiveness can be achieved first through internal assessment by corporate clients, strategic audits or quality assurance. Quality can also be assessed by external certification, buyers or third parties who rely on standards such as ISO-9001-3, EN-2901, etc. Ultimately, and often indirectly, quality in R&D is evaluated by individual customers.

2. Research questions and methodology

The extension of quality to R&D is sometimes seen as a fad, but for most executives quality is another name for effectiveness in R&D. The questions which we chose to investigate are as follows:

1. What does quality mean in the context of R&D management? Do managers view the topic of quality in R&D as a single criterion or as a multi-dimensional construct?
2. What approaches to managing quality in R&D are associated with distinct competitive situations?
3. What distinct practices are associated with the different approaches to managing quality in R&D?

Our methodology involved the following activities. First, issues for discussion were sent to the R&D vice-presidents of 50 firms. Second, interviews were held with research directors in 50 large international firms. Third, a measurement instrument was designed and responses from 45 executives were analyzed. Our final sample was composed of firms from the following regions:

- North America 17
- Europe 14
- Japan 14

3. Findings and observations

Findings will be presented in three sections covering the meaning of quality, managerial practices, and a taxonomy of approaches to quality in R&D.

3.1. The meaning of quality

The construct of quality in R&D which emerges from our investigation is multi-dimensional. In interviews, many executives stressed that quality in R&D mostly meant the transfer of R&D results to concrete applications. A statistical analysis to uncover the dimensions which underpin the concept of quality led to the identification of four factors, as depicted in Table 2.

Concerns for quality in R&D are not limited to narrow issues such as statistical tools. On the contrary, the construct of quality refers to a holistic managerial view combining: (i) strategic choices, (ii) administrative processes, (iii) cross-functional integration, and (iv) upward involvement of scientists and engineers. Four dimensions describe the construct of quality in R&D.

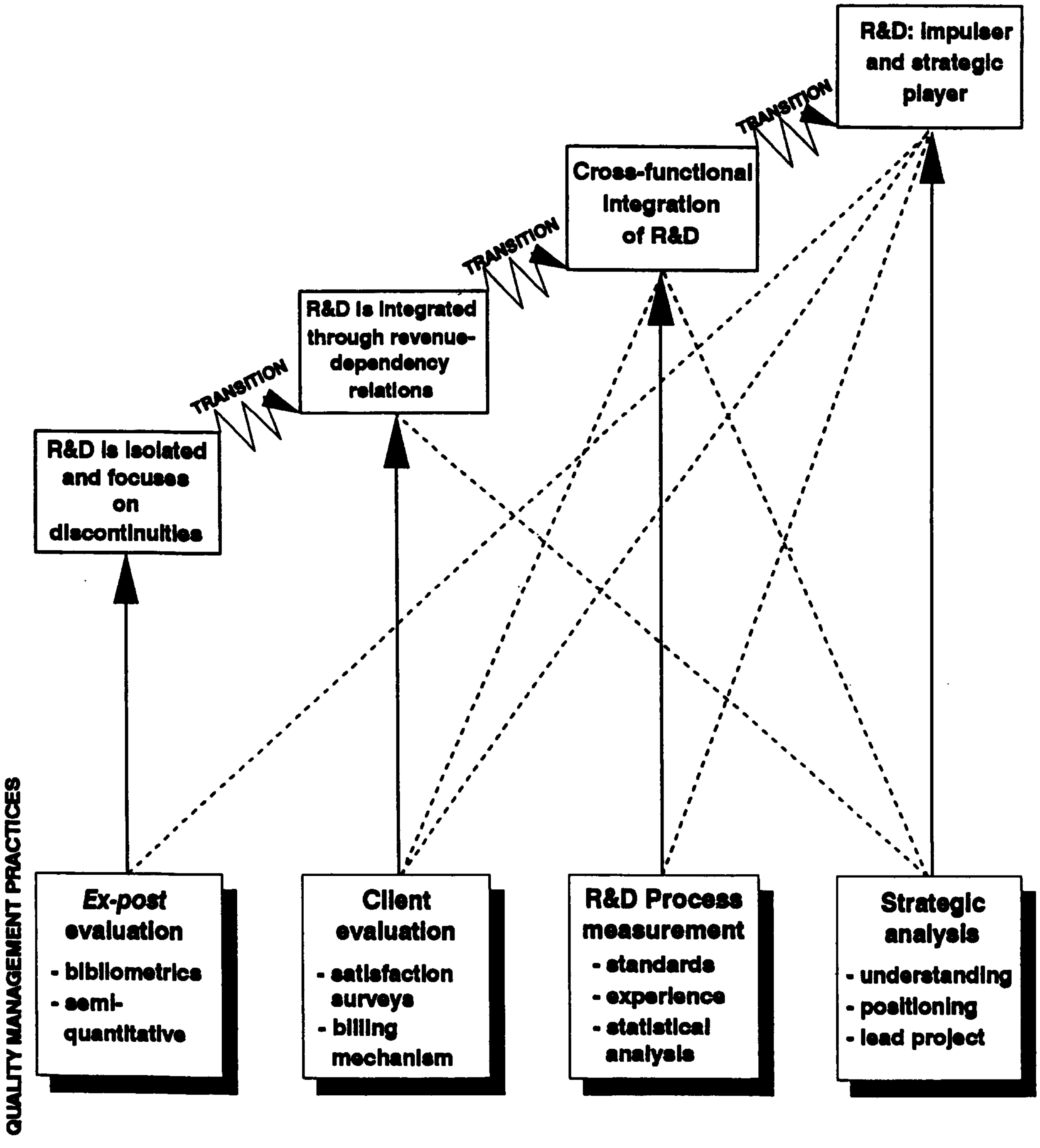

Fig. 1. R&D transitions and varying quality management practices.

TABLE 2. Dimensions characterizing the construct of quality in R&D

	Factor	% of variance explained
Strategic decision • choice of appropriate scientific platforms • strategic value of R&D information • applicability and transferability of R&D results	F2	15·1
Administrative processes • definition of clients' expectations • participation of clients • evaluation of R&D processes and reviews • information systems • training	F1	37·9
Cross-functional integration and project management • interfunctional integration of R&D with production, marketing and engineering • reduction in time-to-delivery • control of projects	F3	10·5
Involvement of scientists and diligence • design and execution of research programs • attention in observation and measures • training of scientists	F4	10·2
Total variance explained by four factors		73.7

3.1.1. Quality through ex ante strategic analysis

Strategic choices ensure quality by selecting both the right technical base and the appropriate set of projects to transfer to operations. The focus is on the identification of fertile scientific platforms, the provision of pertinent R&D information in corporate planning and the choice of projects which will lead to applications in divisions or external clients.

3.1.2. Quality through administrative processes

Processes achieve quality in R&D by ensuring that work activities are done well and kept in focus. Processes help structure activities in a life-cycle perspective as follows: (i) definition of clients' expectations; (ii) participation of clients in projects; (iii) evaluation and reivew of product development processes; (iv) information and metrics.

3.1.3. Quality through cross-functional integration

Cross-functional integration means that decisions take into consideration functional and life-cycle perspectives. Cross-functional teams integrating R&D with marketing, engineering and production are used to reduce costs, time-to-market and rework in product development.

3.1.4. Quality through involvement and diligence

The bottom-up involvement of scientists in providing information to senior R&D and operating management, for the design of research programs breaks isolation patterns. The value of information integration means that diligence is an important dimension of quality in R&D. A high level of involvement also requires the training of scientists in the modes of implementing quality programs.

3.2. Managerial practices concerned with quality

The managerial practices which senior R&D directors use to achieve quality in R&D are numerous. Quality is achieved through strategic analysis, administrative processes, scientific evaluation and business relationships with clients. Table 3 lists the ten practices most often used. Table 4 gives the major dimensions of quality, which we will now analyse.

3.2.1. Strategic analysis practices

Strategic analysis does not mean that senior management provides clear mandates and objectives to R&D. On the contrary, the issue of quality forces R&D management to become an active participant in the firm's overall strategic process. The following practices have been observed.

- *Understanding corporate strategies and their R&D requirements*: Effective R&D participation in the firm's corporate planning starts with a thorough understanding of the firm's mission and the strategic thrusts which R&D is to serve. Analyses conducted by R&D begin with efforts to understand the corporate mission or the individual mission of each business unit. R&D can then infer the thrusts which need to be served.
- *Exploratory analyses*: Multi-disciplinary groups are used to carry out exploratory identifications of future markets. Groups are headed by seasoned scientists, but key roles are set aside for younger scientists and operating executives. Groups focus on economic trends, sustainable advantages, potential benefits for clients, evolving technologies, etc.
- *Competitive positioning and technology assessment*: Firms conduct competitive assessments on a periodic basis by reviewing patents, publications, products, positioning of the firm's key technologies, etc. Competitive analyses appraise the likelihood of gaining intellectual property rights and appropriating benefits.
- *Deliberations of R&D with senior management*: Senior managers have limited time to explore the possibilities opened up by emerging technologies. Formal monthly, quarterly or yearly seminars are held by many firms around relevant themes so that explorations of technical opportunities can be brought to senior management's attention. Systematic deliberations and debates between R&D, top management and operational managers help to close the gap between corporate needs and technological possibilities.

3.2.2. Engineering of processes

Practices focussing on processes can be grouped under a number of headings. Engineering of processes outlines the product development steps to be carried out by multi-functional teams, including marketing, research, engineering, sup-

TABLE 3. Ten practices most often used in managing for quality in R&D

	Rank	Focus
analysis of strategic vectors which R&D must serve	1	ex ante
competitive positioning in technology and product	2	ex ante
interfunctional project teams	3	process
ex post evaluation of projects	4	ex post
participation of R&D in strategic planning	5	ex ante
internal and corporate client surveys	6	ex post
meetings between researchers and clients	7	ex ante
periodic reviews of processes for product development	8	process
cross-functional exploration teams	9	ex ante
common data bases and design methodologies	10	ex ante

TABLE 4. Dimensions of practices most often used to enhance quality in R&D

Managerial practices most often used	Dimensions revealed by factor analysis[a]			
	Strategic analyses	Engineering processes	Ex post evaluation	Evaluation by clients
understanding corporate strategies	0·59			
competitive positioning and assessment	0·83			
surveillance of intellectual property	0·75			
exploration groups	0·74			
risk analysis	0·68			
strategic audit	0·81			
deliberation with senior management	0·65			
cost/benefit analysis	0·83			
competitors' benchmarking		0·68		
modeling of processes		0·81		
reviews of systems and processes		0·77		
common databases		0·86		
common methodologies		0·88		
documentation and reporting practices		0·76		
personnel transfer		0·75		
certification (ISO, SEI, etc.)		0·78		
system of 'metrics'			0·68	
ex post evaluation of accomplishment			0·63	
scientometrics			0·79	
peer reviews			0·67	
meetings between R&D and clients				0·60
survey of clients				0·71
senior management assessment				0·59

[a]Correlation of each practice with revealed dimension; 0·05 level of confidence.

plies, production and finance: design reviews are arranged to ensure compliance with specifications, standards, procedures and regulations. New processes are put into practice when experience shows that practices must be modified.

- *Innovation teams*: Innovation teams act as microcosms of the life cycle of innovations. Teams aim at representing opportunities, obstacles and controversies surrounding the proposed innovation. Teams include R&D stakeholders, internal or external clients and sometimes suppliers. Debates are encouraged from the early stages through stepped-up interactions between R&D, marketing, operations and senior management.
- *Metrics for R&D*: Efforts to measure work processes lie at the heart of the quality movement. Most firms use simple models to understand and measure R&D activities. Many software programs are available to build models. The development of metrics presupposes the modeling of actual or desired R&D activities.
- *Experiment design methods*: Concepts of quality are multi-dimensional: performance features, reliability, breakdown probabilities, compliance with internal and external standards, durability and average life, maintenance and maintenance costs, aesthetics, etc. To take multiple dimensions into account, complex design methodologies involve high implementation costs.
- *Quality controls during project management*: Rigor is introduced in *exploratory research* by methods such as peer review committees and close contact with senior management. However, product development projects use practices such as the participation of prospective clients in defining requirements, and work teams that bring together upstream players and downstream players (advanced development, production, procurement, etc.).

3.2.3. Research evaluation practices

Evaluation practices focus on displaying past accomplishments and the ex post assessment of scientific quality.

- *Measures of accomplishments*: R&D is not always a de facto concern of senior management. Promotion of R&D's credibility depends on quality demonstration of the past impact of R&D on income-generation, cost savings, new products, etc.
- *Ex post R&D evaluation*: Evaluation of the quality of the scientific platform consists of a major group of practices involving (i) peer reviews, (ii) scientometrics, and (iii) technology assessment.

3.2.4. Business relation practices

The structuring of business relations is shaped by three groups of practices: (i) installation of revenue-dependency systems; (ii) meetings between internal clients and R&D staff; (iii) mobility of R&D personnel.

- *Revenue-dependency systems*: Such schemes aim to orient R&D activities through contractual agreements between R&D and internal clients. Applying a revenue-dependency model provides many desirable features, but it also has major drawbacks. Senior management has to counterbalance the revenue-dependency scheme by providing resources for longer-term research activities.
- *Meetings between clients and R&D personnel*: Frequent meetings are required to define specifications, resolve issues and identify problems. Travel budgets allow the R&D staff to meet internal clients during all phases of a project, and after the transfer of results.
- *Mobility of R&D personnel*: Staff mobility, such as transferring personnel from development activities to downstream operations (manufacturing or distribution) is a key practice for quality. In many firms, mobility from operations to R&D also plays a role. On average, approximately 5% of personnel per year move from R&D to other functions.

3.3. A taxonomy of approaches to quality in R&D

The penetration of quality practices in R&D was unequal amongst our 45 firms. Some firms were concerned with processes, others with ex post evaluation and still others primarily stressed the strategic role of R&D. To understand the various groups which formed our sample, a hierarchical cluster analysis was performed. Four clusters emerged. Table 5 compares the four clusters along a series of dimensions.

3.3.1. Managing R&D at the science frontier

In this group, R&D serves two strategic vectors: (i) developing and controlling intellectual property, and (ii) interfacing with governmental R&D support programs. The National Research Council of Canada's Micro-structural Consortium is a good example. Extensive research programs are conducted in the area of gallium arsenide with the participation of Canada's major telecommunications companies. The object is to master alternative circuit design technologies. The consortium has been very succesful in exploring technical avenues at the pre-competitive stage. Its performance in terms of publications, citations and patents has been quite exceptional [27].

Practices to enhance quality in R&D at the ex ante stage concern: (i) project selection, (ii) technology assessment, (iii) exploration teams, and (iv) decision support systems. The most often used practices pertaining to processes are: (i) establishment of procedures, (ii) project management, and (iii) periodic reviews. Ex post evaluation practices are concerned mostly with: (i) the economic impact of R&D, (ii) peer reviews, and (iii) scientific indicators.

3.3.2. Managing R&D in revenue dependency

In this second group, R&D activities are integrated into the operations of the firm through the introduction of revenue dependency schemes. Internal corporate clients buy research services from the R&D division to solve their, or their

TABLE 5. A taxonomy of distinct approaches to quality in R&D

	Science frontier R&D	Revenue dependency R&D	Cross-functionally integrated R&D	Strategic change R&D
strategic vector served by R&D	Mastery of intellectual property Relations with public R&D programs	Cost leadership and reduction Support to clients' competitiveness	Rapidity of adaptation New product development	Constant introduction of new products Entry and exit in various markets
dominant conception of quality in R&D	Project management system Ex post evaluation	Introducing customer voice Review of new product development systems	Cross-functional integration R&D information Rapidity in time-to-market	Strategic pertinence of Selection of scientific platforms
ex ante quality practices	Project selection methodologies Technology assessment Exploration teams Decision support systems	R&D/customer meetings Project selection Technology assessment Cost/benefit analyses	Technology assessment Competitive analyses R&D/customer meetings Competitive bench marking	Competitive analysis Technology assessment Advice to senior management Risk analysis
practices related to process	Policies and procedures Project management Periodic reviews	Periodic reviews Modeling of R&D activities Metrics and indicators	New product systems Periodic reviews Measurement method	Personnel transfer Administrative support to R&D Decision support systems
ex post practices	Economic impact of R&D Peer reviews Scientific indicators	Clients' surveys Measures of accomplishments Scientific indicators	Strategic audit Clients' surveys Certification	Competitive assessment Peer reviews Scientific indicators

customers', operational problems. Hydro-Quebec is an example of R&D activities managed in a revenue dependency scheme. The purpose is to ensure that R&D activities serve the needs of internal clients in such areas as production, transport and distribution of electricity; except for a percentage allocated to corporate programs, most R&D activities are financed by internal customers through problem-related contracts.

The most important strategic thrusts served by R&D are cost reduction and client support. Practices to enhance quality by ex ante decisions stress R&D/customer meetings and cost/benefit analysis. Organizational processes to improve quality are oriented toward periodic reviews of policies and procedures, modeling of R&D activities and the development of metrics to assess activities. The most commonly used ex post evaluation practices are client surveys and the measurement of accomplishments.

3.3.3. Managing R&D with cross-functional integration

A number of firms have successfully developed methods to integrate R&D with marketing, engineering, purchasing and manufacturing. Product development is managed in a life-cycle perspective and involves the merging of functional viewpoints to achieve cost reduction and speed in time-to-market.

In our sample, Fuji-Xerox is a good example. At the early stages of a project, senior marketing and R&D executives discuss ways to merge market needs and technical possibilities: product attributes are defined as part of the corporate marketing mix. Product development is then handled by cross-functional teams which are submitted to periodic reviews. Scientists often follow their product into operations.

The main strategic vectors which R&D serves are (i) the ability of the firm to deliver high-quality products, and (ii) the rapidity of adaptation to market changes. The dominant conceptions of quality in R&D are cross-functional integration and reduction in cost of R&D and lead time. The most commonly used quality management practices are technology assessment, competitive analysis, product development systems, strategic audit and international quality certification.

3.3.4. Managing R&D for strategic change

One group of firms has gone beyond process preoccupations. The goal is no longer to develop and produce high-quality products at the right time, but to use scientific information to explore new markets: these firms are under pressure to maintain a constant flow of new products.

Sony Corporation is a good example. Experience, policies and procedures ensure that, given innovative concepts, products can be developed rapidly and efficiently. The critical problem then is to stimulate a flow of ideas between senior management and R&D: vertical, bi-directional communications bring R&D right into the strategic arena.

The dominant concept of change is to structure connections between strategic planning and R&D. The strategic vectors which R&D serves in this group of firms are (i) the continuous introduction of new products, and (ii) entry and exit in markets. Not surprisingly, the dominant concept of quality in R&D relates to the strategic pertinence of R&D information and the selection of appropriate scientific platforms. Practices most often used in managing R&D with quality are: (i) competitive analysis; (ii) technology assessment; (iii) advice to senior management; (iv) personnel transfer; (v) decision support systems; (vi) peer reviews; (vii) science indicators.

4. Maturity or contingency models

The diversity of approaches could be interpreted as the result of barriers to the penetration of enlightened best practices. Our research findings would thus be consistent with maturity models proposed by A.D. Little, Roy Rothwell [1] and the Software Engineering Institute [28]. Table 6, which describes these major models, suggests that progressive firms move from a low level of

TABLE 6. Major staircase models pertaining to R&D management

	A.D. Little	Rothwell	SEI
focus	Sustainable competitive advantage depends on R&D ability to contribute to product quality, productivity, manufacturing productivity and market responses	The dominant models of innovation, not just technology, are changing. Recent developments suggest the possibilities of strategic integration and networking	Quality is governed by the maturity of management processes used for development and maintenance of software projects
thesis	Research management has entered a phase where science and technology need to be integrated with strategic management	The innovation process has changed form over the years. Technology push has been coupled to market needs. Today, systems integration and networking are key elements	Immature processes lead to low-quality, high-risk dependence on creative individuals. Mature processes make for consistent results, use of appropriate tools and improvements in production capabilities
progress level	Level 1: R&D is managed intuitively but isolated, and oriented toward creativity and autonomy Level 2: R&D is managed objectively and coupled with other functions through formal plans and project management Level 3: Strategic management of R&D and integration with market dynamics and business units. Allocation of resources to sustain advantage	Level 1: Linear process in which scientific discoveries are 'pushed' sequentially to other functions Level 2: Market pull model where R&D reacts to market as a source of ideas Level 3: Coupling model of innovation to enhance effectiveness in innovation Level 4: Integrated model with integrated teams, leading customers and joint ventures Level 5: Systems integration and networking model. Parallel development, customer focus, horizontal strategies and time-based strategy	Level 1: Ad hoc chaotic and risky project management Level 2: Intuitive processes dependent on individuals Level 3: Defined and institutionalized processes Level 4: Measured processes, controlled by metrics Level 5: Processes improved by feedback, high quality and productivity
authors	P.A. Roussel et al., *Third Generation R&D*, Harvard Business School Press, Boston, MA, 1991	R. Rothwell, *Successful Innovation*, R&D Management, Vol. 22, No. 3, 1992	Humphreys, *Software Process Assessment*, Software Engineering Institute, Pittsburgh, PA, 1990

integration of R&D to strategic management in networking contexts.

In a similar fashion, our findings could be interpreted in a maturity perspective. Figure 1 shows the transitions, the flow processes, and the most appropriate measurement methods as R&D moves out of isolation.

The lowest level is that of future-oriented science frontier R&D, without any real impact on day-to-day corporate practices. R&D management focuses on creating favorable conditions for radical breakthroughs. Quality practices are mainly directed towards ex post evaluation: (i) publications, (ii) citations, (iii) patents, (iv) awards, (v) participation in conferences, etc. The second level is revenue-dependency: contracts between R&D and internal clients are developed, so that research efforts are geared toward operational or corporate objectives. Practices to enhance quality focus on the measurement of external revenue and client satisfaction. The third level of transition is cross-functional integration. This is the aim of total quality management (TQM). Within a few corporations, R&D has reached the fourth level, in which R&D is an active participant in the elaboration of the firm's strategy. Indicators and quality metrics to be implemented depend on the level which R&D activities have attained.

Maturity models offer dynamic perspectives but oversimplify complex realities. These models are based on the following assumptions:

- Progressing from lower to higher levels is presented as an ethical and normative prescription for enlightened managers, irrespective of their competitive situations.
- Fragmentation of efforts arises from blockages in the adoption of 'best practices'. Human resistance, lack of awareness, or inability to manage are the real causes of diversity.
- Progression toward high level may be blocked by management's lack of *diligence*, but it is predetermined by external causal forces that will eventually win.
- The truly interesting phenomena are not transition strategies but the level of adoption of best practices.

A contingency interpretation is more plausible. Different road-maps and practices are necessary because firms face distinct competitive situations and organizational conditions. Table 7 depicts different contingent situations resulting from (i) the need to introduce a few, or a continuous flow of, new products, and (ii) the need to deploy and integrate R&D activities with the rest of the firm.

Science frontier R&D is involved in technology races to the patent office. Effectiveness requires the mastery of intellectual property and the establishment of a climate for invention and technology transfer. *Revenue-dependency R&D management* is oriented toward problem-solving for informed internal or external customers. *TQM/cross-functional R&D management* is concerned with designing organizational capabilities to deliver a continuous flow of improved products. Cross-functional integration aims to design products that meet final clients' expectations, are manufacturable and are targeted to ensure proliferation in the market place. *Strategic R&D management* uses technology to penetrate new markets and build diversification on solid core competences. Vertical linkages between R&D and top management are necessary to ensure the correct choice of scientific platforms and programs. Building R&D networks and alliances with suppliers is increasingly important.

5. Conclusion

Is quality management applicable to R&D? Our study found that, if some irritants are dealt with to take into consideration the specifics of R&D work, the quality approach is not only credible in the R&D community but is a valuable addition to efficient R&D management. Experience with the introduction of quality management to R&D is considered positive, confirming the hypothesis that the approach is certainly relevant to R&D [23].

Transferring quality concepts and methods to the field of R&D is not an easy process. If the introduction of quality to the field of R&D is poorly managed, it can lead to shocks because of

TABLE 7. A contingency interpretation of variety in R&D management

Type of innovation	Rate of introduction of new product	
	Few	Continuous flow
radical	Science frontier R&D management • technology races • creativity/speed • patentable discoveries	Strategic R&D management • continuous novelty • vertical linkages R&D/top management • networks and alliances
incremental	Revenue-dependent R&D management • predictable cost improvement • solving internal/external clients' problems • contractual negotiation	TQM/cross-functional R&D management • efficiency in product development • horizontal deployment and integration

the specific nature of R&D activities. What is specific about R&D?

- R&D produces information which must be reliable, accessible and transferable. However, research activities, unlike development activities, are characterized by a high level of uncertainty and the exploration of unprofitable avenues. Exploring avenues and testing hypotheses often leads to the production of information whose value is to eliminate bad options. Considering the elimination of false paths unproductive is inappropriate.
- Scientists are accustomed to precision in objective measurements. However, quality metrics, such as the satisfaction of internal, external and future clients, are subjective. To ensure that acceptable instruments are developed, training is needed in measurement methodologies used in the fields of social science and marketing.
- Research and development processes are often nonrecurring. Therefore, statistical analysis methodologies based on manufacturing experience are not always applicable. Transferring these methodologies requires finesse because scientists often have inadequate knowledge of their limitations. The output of R&D is information and product designs that are often difficult to measure. Statistical measures used in quality control as applied to manufacturing need to be modified and supplemented.
- Scientists are often isolated from final consumers. Internal 'near clients' are not the customers who bring in the corporation's revenues, but rather internal participants in the innovation process. Satisfying these internal near clients can redirect R&D efforts towards short-term concerns.
- Quality management proponents are often organizational development specialists, and they sometimes lack credibility among scientists and engineers. In many cases, scientists find the conventional jargon of TQM irritating, especially the emphasis on human relations.

The underlying principles of the quality movement are nevertheless in keeping with the scientific ethos. Emphasis on participation and involvement is accepted as a normal course of affairs: scientists are used to working in open climates with extensive autonomy. Concern for rigorous design of experiment, common measurement practices and openness in scientific information is accepted by scientists as a basic approach. Emphasizing measurement, statistical control and causality models is in keeping with scientists' view of the world.

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