Success factors in R&D: A meta-analysis of the empirical literature and derived implications for design management

by Kenneth Brown, Helwig Schmied, and Jean-Claude Tarondeau

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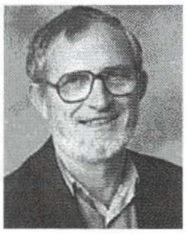

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Introduction

In our world of shortening product life cycles and standardized products, design has become the chief means of differentiating product ranges from those of competitors, creating additional perceived value for customers, and building up a recognizable brand image. For this reason, design has in many organizations become a central corporate function,[1] and the management of design has evolved into a profession and scientific discipline in its own right (Chung, 1998). Today, design management may be considered an integrative discipline that unites the efforts of an organization with a view to creating a product or service offering that is both appealing to customers and in line with longer-term corporate objectives.

As an integrative discipline, design management is highly interdependent of other corporate functions in its endeavors, and necessitates close interfacing with functions such as marketing, production, and R&D (Borja de Mozota, 1998). The product creation process is particularly affected by this. Indeed, the future success of a product is typically determined as much by its technical properties as by its aesthetic appearance. In order to play its integrative role in the overall product development effort effectively, design management needs to take the contributions of the technical functions, especially R&D, into account.

This article is a cross-disciplinary effort aimed at linking the discipline of design management to that of R&D management. The first step in this endeavor is the exploitation of the knowledge accumulated on the subject so far. Using a systems approach, we present a framework that summarizes the current state of knowledge of what determines the success and failure in R&D in such a way that it may be used for management purposes.

Anticipating, somewhat, the results presented here, it is interesting to note

1. Indeed, "design" as in the aesthetic design of products was one of the first functions considered when the European car industry developed a new methodology for accelerated product development, in Project SICPARI (Gerhardt & Schmied, 1997; Brown, et al., 2002).

that in this field, very little research has been devoted to the impact of aesthetic properties on innovation success, while in design management, it appears that technological considerations are much less represented (Veryzer, 2000). We therefore expect our findings to be highly complementary to the discipline of design management, and will therefore briefly discuss our interpretation of the implications for design management in the conclusion of this article.

Literature on R&D management

Management scholars and professionals have recognized that R&D is one of the corporate functions most difficult to manage. Its outcome is by definition uncertain, thus making it difficult to plan, predict, and optimize. To make things worse, its engineers and scientists are extremely averse to any type of control exerted by "unproductive" administrative staff (Allison, 1969). On the other hand, successful R&D may lead to considerable profitability through product and process innovation. For this reason, a wide range of literature discusses how R&D should best be organized and managed. To constitute a sound basis of the current state of knowledge, we have left anecdotal literature aside and concentrated on sources of empirical evidence.

Empirical studies on the factors influencing the outcome of R&D emerged in the 1950s and '60s, most notably the studies of Carter and Williams, 1957, 1958; Burns and Stalker, 1961; and Myers and Marquis, 1969. In 1972, project SAPPHO suggested a methodology for comparing pairs of successful and failed innovations under similar boundary conditions. Using statistical means, successes and failures of individual innovations are compared with the occurrences of certain conditions or actions in an effort to find the most pertinent "success factors."[2] This methodology of pair-wise comparison was adopted by a series of subsequent studies on the same topic, and included new definitions of success, such as technical success, respect of budget and time constraints, customer satisfaction, and overall perceived success. Other similar studies follow a different approach by asking executives their opinions of what causes success and failure in R&D projects (Myers and Sweezy, 1978; Peters and Waterman, 1982; Slevin and Pinto, 1986), yet it must be noted that the results of these surveys are seldom tested.[3]

The available number of R&D success factor studies is overwhelmingly large, and so is the number of ascertained success factors. Our first analysis counted more than 300 distinct success factors for R&D. In order to create an overview of factors that determine R&D success, nevertheless, we exploited only studies with sufficiently representative samples and clear results, and we consolidated success factors from different studies when there was a clear similarity. The current sample of 96 exploited sources includes not only well-known studies in the Anglo-Saxon hemisphere, but also sources found in German and French literature.[4]

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Review approach

Apart from their sheer number, the main difficulty in providing a comprehensive overview of R&D success and failure factors is the difficulty in finding appropriate categories. The factors identified in literature are very different in kind; they do not at all seem to "fit" together to form a comprehensible whole. Using a systems approach, we distinguish between factors that may be controlled from within the organization (or group of organizations) carrying out an R&D effort, and external factors (Balachandra and Friar, 1997). Uncontrollable factors, however, include not only external characteristics of the environment, but also factors that are uncontrollable because they are the unchangeable *results* of earlier behavior and actions (Rothwell, 1977). Similarly, factors that can only be influenced

2. Rockwell, one of the main authors of the SAPPHO study, defines success factors of innovation as the "factors associated with success and failure in industrial innovation and the characteristics of the technically progressive firm" (Rothwell , 1977, p. 191).

3. Indeed, when the success factors found in these studies were tested by other authors (Johne & Snelson, 1988; Pinto & Mantel, 1990), several theorized factors turned out to be statistically insignificant.

4. Only a selection of these sources could be referenced here. A complete list may be found in Brown (2002).

before the project begins, but no longer once it is underway, are also considered uncontrollable. Together, these uncontrollable factors constitute a set of variables that need to be taken into account through appropriate action within the organization if the R&D effort is to be successful.

We order internal, controllable factors into the classes structural-cultural, procedural, and humanistic. While structural-cultural factors describe what the organization "is," procedural factors describe "how" the organization operates, and humanistic factors describe "who" the people in the organization are, what they know, how they are trained, and so forth. Factors contained in all three categories have an influence on the behavior of individuals, of groups such as project teams, and on the organization as a whole. This behavior in turn influences—together with environmental factors—the outcomes of its efforts—that is, the system's output. Figure 1 below shows the holistic framework we use to classify and discuss R&D success factors.

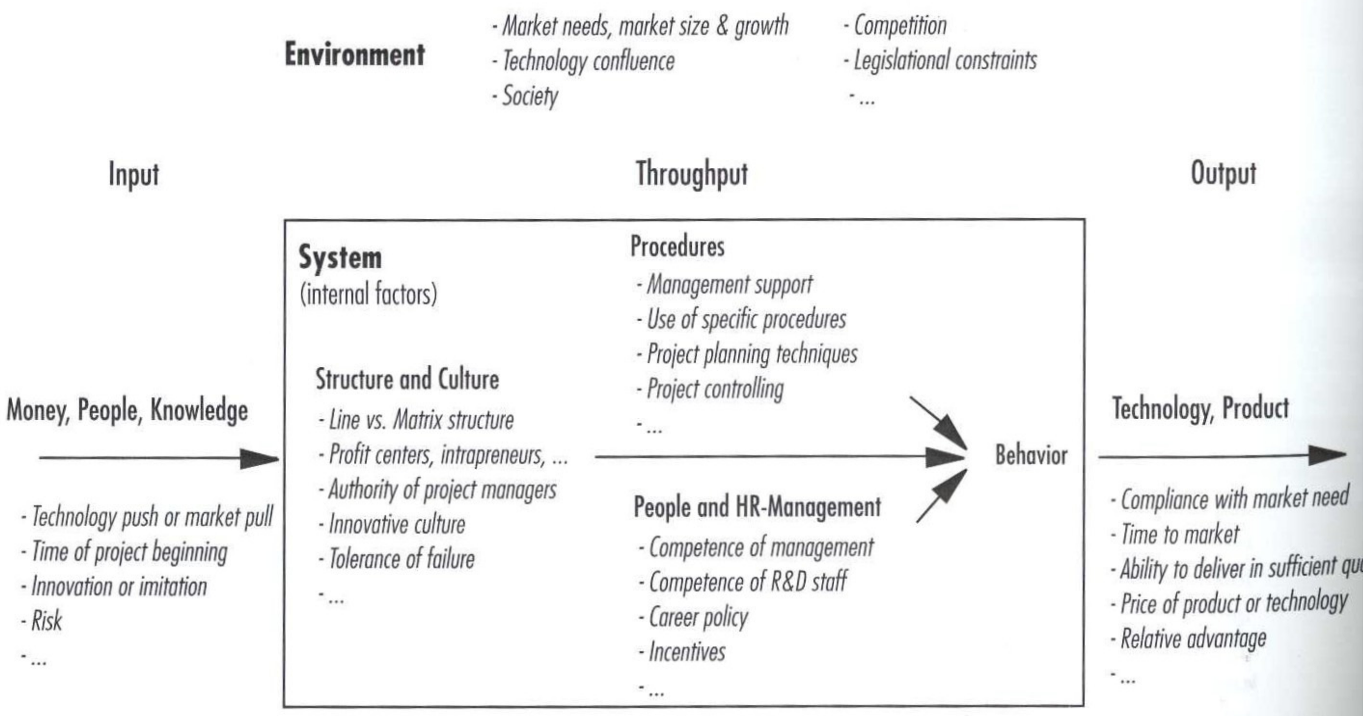
Uncontrollable success factors

Contrary to what some researchers may believe, R&D activities are generally not an end in themselves, but are carried out with the objective of (eventually) creating financial returns. Since it is in the environment that R&D results must ultimately prove their worth, environmental characteristics constitute the boundary conditions for R&D success. Following the model of Porter (1982), we distinguish between the environmental subsystems technology, market, competition, and government/society.

The environmental subsystem technology describes the current state of the art of available and emerging technologies. Success factor studies have shown that changes in technology can be both a success and a failure factor. When technologies evolve very quickly, these may make current products, or even current R&D efforts, obsolete. On the other hand, many R&D projects turn out to be successful only because certain needed technologies become available in time.

Apart from the technological environment, the other subsystem of the environment that immediately comes to mind for R&D success is, of course, the market, because it is in the marketplace that new products must prove their qualities, no matter how well they may have performed in the laboratory or on a test bench. Within the market, the factors attractiveness,

Figure 1.
Holistic classification scheme of success factors.



need, size, and growth were generally confirmed as success factors, only market dynamism was rejected. Difficulties of market entry, such as high costs or loyal customers, were identified as failure factors.

The competition includes all organizations that, currently or potentially, satisfy the same customer need and thus absorb the same buying power the R&D effort hopes to address. Competitors deserve particular attention because they may indulge in aggressive actions to harm one's own organization to gain market share—for example, by competing on price. The studies generally confirm that competition has pertinent influence when financial returns on R&D are unsatisfactory, particularly when they develop new products faster, or are protected by patents. Surprisingly however, the existence of a strong, dominant competitor was not confirmed by all studies as a factor for R&D failure.

The influence of the subsystem government/society on R&D success was not unequivocal. While government support played a significant part in fostering success in the samples of several studies, others could not empirically confirm the influence of governmental funding on R&D success. Much more than governmental support, legal encumbrances and constraints were found to significantly influence the outcome of R&D activities, such as uncertainty about federal regulatory policies or future rulings, antitrust complications, consumer and environmental safeguards, and legal restrictions on the access to or the use of pertinent technologies. Concerning society, public support and resistance were found by Baker, et al. to influence success and failure (1988).

With few exceptions, the empirical data thus confirm the intuitively assumed impact of environmental factors on R&D success. They are now of help in interpreting output factors.

For instance, in the light of the uncontested importance of market-related factors, it now appears clear why several studies could find that products using advanced technology could be more successful than others, while others found that advanced technology is not significantly related, or even negatively correlated to the success of a new product. It appears that advanced technologies can only be successful if market needs for the technology exist. Further empirical results however show that this should not lead to the conclusion that technology-push strategies may not be successful, provided that the technology is entirely mastered. Brown (2002) showed that initial technology push or market pull did not correlate with success, while confirmed market interest at the beginning of the main project effort did.

Whether technology push or market pull, the main driver of success identified by many of the studies is product advantage, superiority, or uniqueness with respect to customer needs—for example, by incorporating unique features, by providing higher quality, or by allowing the customer to reduce costs or do something previously impossible. This may explain why patentability was univocally confirmed as a success factor. On the other side of the scale, undistinguished products without any particular user advantage are often associated with failure, although contrary observations exist, which show that non-unique products can be economically more successful than innovative ones. In this context, it is interesting to note that of the success factors studies analyzed here, only technological product advantages were taken into account, although it is apparent that many products succeed in the marketplace due to their superior aesthetic design.

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Product advantage is a type of output to strive for when organizing R&D, although it is not yet clear if this is an absolute virtue, or if it is relative to its price. A high product price—that is, a product priced higher than the competitive product—was detected as a "barrier to success" in several studies, but new products with a price advantage were not always found more successful than those with equal or higher prices versus competitors (Cooper and Kleinschmidt, 1990: 50). The reason for these contradictory observations may, however, be a missing distinction between price and cost, as Maidique and Zirger (1984) found that products that allow greater pricing flexibility or are priced with a higher profit margin contribute strongly to economic success.[5]

Product advantage thus seems to be more important for its success than product price. This advantage, however, deteriorates as competitive products appear. Next to product quality and price, the timeliness of R&D output was, therefore, investigated by several studies, with rather inconsistent results. While some studies found that the degree of success in meeting time schedules affected not only economic but also technical success, others found that schedule overruns relate to neither perceived success nor failure of projects. It may be argued that setting up a schedule for a project is an arbitrary act, and that the schedule in itself does not necessarily reflect the readiness of the market for the innovation.

Out of the empirical results reviewed above, it is now clear that environmental factors have a decisive impact on the success of R&D efforts

The "first to market" factor is a topic that is hotly debated in literature. Many authors see it as one of the most important ingredients of successful and profitable innovation (Maidique and Zirger, 1984; Schrader, 1991; Simon, 1989). The logic behind this is that whoever is first to a given market may benefit from a monopolistic position for a short time during which large profits may be reaped and, more important, barriers of entry may be erected against newcomers, such as norms, *de facto* standards, a large market share, a base of satisfied customers, or patents (Gerstenfeld, 1976). However, it must also be noted that followers may have the advantage of lower development costs (Gemünden and Walter, 1993) and less development risk (Tarondeau, 1991). Followers frequently learn from the experience of pioneers, and often will not even enter a market until it proves profitable (Schrader, 1991). Unfortunately, the data in the analyzed studies fails to provide clear guidance on the success probability of pioneer versus follower strategies. Most of the studies display data in favor of pioneer strategies, yet they are clearly contradicted by other studies. A specific study carried out to analyze the influence of product development time on success showed that being first-to-market is not significantly conducive to success, even when innovations are concerned that should be able to take advantage of being first to the market, such as incremental innovations or products introduced to existing markets (de Meyer, 1985). It therefore seems that being first is only worthwhile in very particular market constellations in which imitator strategies are not applicable because of effective market entry barriers (Schrader, 1991). Nonetheless, an early start date of a project was identified as a factor for success by one study.

Factors characterizing a project, such as its start date, its synergy, or its risk, are considered uncontrollable because they can only be accepted or refused at the beginning of the project. In principle, factors such as these can be addressed through project selection. The effectiveness of formal project selection techniques was, however, not confirmed by the studies.

Much like its start date, the synergy of an R&D project, with respect to the technological competencies of the organization, its currently addressed markets, or its overall strategy, was shown to correlate with success. Conversely, a project's financial, technical, and market risk was univocally found to be detrimental to its outcome.

Controllable success factors

Out of the empirical results reviewed above, it is now clear that environmental factors have a decisive impact on the success of R&D efforts, R&D results must be compatible with the environment, and the type of projects carried out must be compatible with both the environment and the system carrying out the R&D activity. To influence the outcome of R&D, however, the R&D system must be built up and managed accordingly. The success factor studies went to great lengths to determine which factors found within the organization influence R&D success. As mentioned above, we divide these internal, controllable factors into the categories structural

5. Intuitively, it appears clear that a low product cost is in any case advantageous. Even if the organization decides to sell its new product at a high price, the higher margin will allow it to invest more into sales promotion and other marketing activities.

and cultural factors, procedural and behavioral factors, and humanistic factors.

Structural and cultural factors

Several studies identified the structure of an organization as a major driver of R&D success. Organizational structures that are less hierarchic and less rigid than those traditionally found in industry were found to be more supportive for successful R&D. Rothwell (1976) showed that the main performers in R&D, the "innovative individuals," are "particularly effective when the management structure is horizontal and decentralized." Bureaucracy, on the other hand, was shown to affect success negatively. Specific types of structures, such as matrix structures or project-oriented structures, were also shown to enhance R&D performance, with some exceptions. Katz and Allen (1985) dedicated a study to the impact of the matrix structure on R&D success and showed that project performance is highest when project managers are perceived to be controlling organizational rewards, and functional managers determine the technical content of projects.

In addition to these main structures, independent, accountable substructures, such as internal entrepreneurship teams, were shown to correlate with success. Several studies found the existence of in-house research to explain success, while others found it more effective to have outside companies execute radical innovations. Having certain types of facilities was also found to correlate with R&D success, such as scientific and technical equipment, information systems, office equipment, appropriate buildings, workshops, and production facilities.

Innovative organizational culture was found to be significantly correlated with success by most of the studies. An essential component of an innovation-friendly culture identified by many of the studies was the tolerance of failure, that is, not penalizing people who made an honest effort to innovate, but failed.

Procedural factors

While structural and cultural factors are relatively static and need considerable time and effort to change, altering processes offers a means of directly changing the way the organization handles an R&D effort. Not surprisingly, practically all the analyzed studies found empirical evidence for success when R&D activities were carried out following a well-defined, proficient R&D process. Explicit examples of proficiency include undertaking a deliberate search for new ideas, carrying out technical tasks with care, integrating available technologies, eliminating technical defects before commercial launch, and troubleshooting. Baker et al. (1988) found that projects that disposed of back-up strategies were more successful than others,[6] and failure to be frequent when the R&D effort could not be closed out early in the process or when change procedures (to keep up with the technical evolution of the project) were inadequate.

The studies also looked into procedural factors going beyond the domain of R&D. Particularly, the amount of marketing effort deployed by an innovating firm emerged as an important discriminator for success. The amount of marketing effort ranked first in SAPPHO (1972), and Cooper notes, "The critical role of market orientation, marketing information, marketing communication, and marketing launch strategy was strongly demonstrated. Indeed, a review of the nine factors closely linked to success shows that all but one directly or indirectly pertain to the marketing function of the marketplace" (Cooper, 1979: 103). Later studies revealed that the marketing process should be carried out in parallel with development efforts, and that detecting user needs, buyer price and behavior, the competitive situation, and the size of the potential market are crucial for the economic success of an innovation, which is of course entirely in line with the importance of environmental factors identified above.

> Several studies *identified the structure of an organization as a major driver of R&D success*

Almost all the studies found empirical support for the effectiveness of collaborating with potential customers during the development. SAPPHO showed that failure is often due to lack of user inquiries, inquiries with atypical users,

6. Abernathy (1971), however, warns that the use of parallel strategies is not always effective, and bears notable pitfalls.

misinterpretation, misunderstanding, simple ignoring of answers to inquiries, or lack of "on-the-spot investigations" to follow up on inquiries. In the aftermath of SAPPHO, Freeman (1989) found in discussion with R&D managers that they tend to dismiss the point of understanding user needs as "obvious," but nevertheless continue to ignore it in practice. Our own field experience concurs.

More-recent data suggest that the R&D and marketing processes should be integrated. Since environmental factors must generally be taken as a given, it is the organization that needs to detect changes in the environment and take suitable action to adapt to the environment in order to be successful. Essentially, this means that R&D needs an effective process that encompasses not only the technological effort, but also all activities necessary to make the project a success. Cooper, for instance, found repeatedly that "processes that promote a strong market orientation and the undertaking of marketing tasks in a quality fashion" are correlated with innovation success (Cooper and Kleinschmidt, 1990; Cooper and Kleinschmidt, 1996). Maidique and Zirger (1984) found a process in which "the developing organization, through in-depth understanding of the customers and the marketplace, introduces a product with high performance-to-cost ratio" to be the most important factor for success.

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Several studies also looked into the processes following the actual development effort. Particularly, marketing activities, such as market launch, advertisement and promotion, public relations, sales, and adequate preparation of end users, were found to be correlated with success, as were production activities, such as early start-up preparation.

The studies also analyzed procedures used by individuals for their impact on R&D success. According to the data, management by objectives—that is, defining objectives clearly, evaluating performance against these objectives, and consequent use of this for decision-making—is confirmed empirically by many studies, especially when the people responsible for attaining them are involved in this definition. It should, however, be noted that Quinn and Mueller found that the overuse of short-term control techniques could contribute to negativistic motivational environments (1963: 60). The data of Couillard and Navarre (1993) suggest that the associated meetings between project team and management need not necessarily be held in a strict atmosphere, but that on the contrary, "informal meetings with feedback" can be associated with success.

The use of project management and controlling techniques, such as work breakdown, time planning using Gantt charts, and critical path surveillance using network techniques (PERT, MPM, and so forth) was also found to be effective by most of the studies, although the data of some studies contradict this finding (Hazebroucq, 1992; Couillard and Navarre, 1993), particularly when such techniques are "overused" (Baker et al., 1988; 906). Couillard and Navarre (1993) found that more "soft" techniques, such as autonomous decision-making, flexibility, and communication could have a much stronger effect on project success, thereby confirming some of the findings cited above.

Humanistic factors

Even the best-structured company with the most proficient processes will not be successful in R&D without the brilliant ideas of scientists and engineers, the organizational talent of good managers, and the hard work of employees. It appears intuitive that the qualifications of the people working in the organization is not enough to determine their effectiveness in achieving results, but the extent to which they are motivated is also of prime importance. As *humanism* is "a doctrine or way of life centered on human interests or values,"[7] its adjective *humanistic* is used in the following section here

7. Definition taken from the Merriam-Webster Dictionary of the English Language.

to circumscribe the factors that relate to the qualification and management of the people of the organization. The success factor studies extensively assessed the influence of humanistic factors, analyzing not only variables that relate to the characteristics of the people in the organization, but also variables that describe the way people are selected, trained, and treated—that is, variables relative to human resources management.

Characteristics of personnel

Several studies analyzed the role of management in the process of innovation, and clearly identified the need for competent managers. "High quality" managers were found to be characterized by an "ability to attract talented people and bring out the most in managers" (Carter and Williams, 1957), high motivation (Krüger, 1988; Rothwell, 1977) open-mindedness with respect to new ideas (Lilien and Yoon, 1989; Rothwell, 1977), and "considerable experience" (Szakasits, 1974). Furthermore, the studies generally showed that when management had formulated a corporate or technological strategy, provided guidance, supported the R&D effort, was involved in it, accepted risks, and allocated sufficient amounts of resources, this correlated with success. Failure occurred when the importance of technologies was misunderstood, which is perhaps why having managers with a technological background on the board has a significant impact on success.

The influence of the project manager on innovation success was, of course, a further widely researched topic. According to the empirical data, an ideal project manager is characterized by good technical qualifications, sufficient experience, adequate administrative skills, and sufficient authority within the organization. "Soft skills" of the project manager were also found to be correlated with success.

Few studies looked at the impact of different management styles. Fiedler found that an "autocratic, task-controlling management style" works best when the situation for getting a task accomplished by group effort is either very favorable or very unfavorable, while a "nondirective, permissive leader" works better in situations of intermediate difficulty (Fiedler, 1965; 18.). Baker, et al., however, found a participative management style to be correlated with success (Baker, et al., 1988; 908). Certain other types of behavior were also found pertinent for project success, such as involvement and commitment to the project. Baker, et al. (1988) found that having the project manager on-site affects perceived success and failure.

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Apart from managers, the people who are expected to have a decisive influence on project outcome are the resources working in it. Indeed, factors relating to the knowledge and experience of employees were generally validated as success factors. Katz and Allen (1982), however, showed that experience increased performance only during the first one and a half years, and that performance declines when people belong to a group longer than four to five years. They attribute this finding to the "not-invented-here" syndrome in which results from other R&D groups are increasingly ignored and are confirmed by other studies. Conversely, job rotation of key personnel was shown to help transfer knowledge and promote innovation success.

Myers and Sweezy (1978) found examples in which the "lack of technical capabilities delayed the solution of a technical problem for so long that a project loses its competitive advantage". Two other studies showed that failure could occur when the project team did not have access to external technologies (Pinto and Prescott, 1988; Montoya-Weiss and Calantone, 1994). Other competencies found to be determinants for project success were production knowledge, market knowledge and marketing proficiency, advertising skills, and experience in determining economic factors.

The composition of the project team, defined by Högl and Gemünden (1999) as "its members' social and methodical competence, preference for teamwork, and heterogeneity in terms of knowledge and skills," was also shown to influence project success. Kuhlmann and Holland (1995) found that equal distributions among scientists and engineers or among technical and administrative staff correlated with R&D success. The data of Johne and Snelson (1988) show that project managers or intrapreneurs should be allowed to select their own team with whom rewards are shared. This could also be beneficial to the often-cited "team spirit" and commitment of a project team, which were also both found pertinent for success.

In most R&D organizations, a number of highly visible individuals, such as champions, entrepreneurs, and gatekeepers, play key roles in the innovation process. In SAPPHO (1972), a champion is understood as a person within the project who pushes the effort ahead, despite the inevitable difficulties. In other sources, this type of champion is called an entrepreneur or an intrapreneur. The SAPPHO study, putting forward empirical evidence concerning the influence of an entrepreneurial champion on project success, was confirmed by many others.

German literature, in particular, has publicized the importance of so-called promoters in innovation (Hauschildt and Gemünden, 1998). Witte (1973) first demonstrated the existence of "power promoters,"—that is, people in an executive position who have the necessary power within the organization to promote an innovation—and competence promoters—that is, people with the necessary technical expertise to lead an innovation—and showed that these are particularly effective when they work together. Other studies confirm the existence and pertinence of the power promoter, but use the term *project sponsor* or *mentor*.

Next to champions and promoters, gatekeepers are one of the most discussed topics in R&D management literature. Following this concept introduced by Allen (1977), certain people within R&D systems are particularly well connected to the outside world and ensure that information about changes in the technological environment enters into the system and gets to the relevant people. In the success factor studies, empirical evidence confirmed this theory.

Human resources management

In principle, human resources management has two possibilities by which it can furnish the needed competencies: recruiting and training. A "good" recruitment policy was indeed correlated with success in a number of cases, as were diverse variables of competency development plans. Morin and Seurat (1991) showed that an explicit career plan for research staff, particularly researchers, correlates highly with innovation success. The data of Katz and Allen (1985) also show that the roles of project managers and functional managers need to be clearly distinguished.

Another popular measure is to use incentives to motivate personnel. The success factor studies that assessed the impact of incentives on R&D success all found a pertinent correlation. A major drawback in using incentives is, however, the evaluation of performance. Since performance is typically measured by the development success of the individual researcher or project team, this induces competition within the organization and thus inescapably leads to the "not-invented-here" effect (Alsbach, 1991; 52). Negative motivation through job insecurity should also be avoided, as it was indeed shown to affect perceived failure, while the absorption of displaced people is correlated with success.

Behavior

According to our systemic model, the structural-cultural, procedural, and humanistic success factors identified above influence the behavior of the organization, which in turn determines its output. The behavior of individuals such as senior management and project managers has been assessed above. The studies analyzed the impact of organizational behavior, as well, particularly concerning communication and cooperation. Good cooperation and communication has indeed been shown by practically all the studies to distinguish between success and failure when it took place within the organization, with external partners, or with both.[8] Hayvaert (1973) even managed to demonstrate a correlation between both good internal and external information with high profitability.

Internal communication and cooperation

Concerning internal communication, we distinguish between communication taking place

8. Even those that put the importance of communication in doubt note that this could be due to imperfections in the analysis of the data—for example, "communication may be highly related to (or perhaps even included in) the assessments of the remaining factors" (Pinto and Prescott, 1988).

within a single function, such as R&D, and interfunctional communication. Allen has pointed out that "improved communication among groups within a laboratory will increase R&D effectiveness" (Allen, 1977; 122), and several studies have confirmed the importance of communication within groups such as project teams. However, it appears that the coordination of the R&D effort with marketing and production has received even more attention by the success factor studies. This could be because cooperation between these dissimilar functions is reportedly very difficult to achieve, or because the lack of cooperation can lead to technologies and products that are technically appealing, but difficult and expensive to manufacture or simply are not in compliance with user requirements. Whatever the case, the studies generally found a positive impact of cooperation and communication between R&D, marketing, and production, and Hayvaert (1973) and Cooper and Kleinschmidt (1996) could show a positive correlation with economic success.[9]

More specifically, R&D-production communication and cooperation was found pertinent by many studies, yet Olsen, et al. (2001) found that such cooperation toward the end of a project is only positively related with project performance for highly innovative projects, not less-innovative projects.[10] Strong cooperation and communication between the system functions R&D and marketing was also shown to be correlated with success by many studies, and even ranked first in a study by Souder (1977). Again, the results of Olsen, et al. are somewhat more differentiated. While cooperation between marketing and R&D was found pertinent for success when it took place at the beginning of a project, cooperation between these two functions toward the end of a project was not significantly correlated with project performance. Brown's analysis even shows a negative correlation between late R&D-marketing communication and success (2002). This surprising finding is attributed to an inverse cause-effect relationship in ailing projects, in which late (sometimes-frantic) communication occurred between R&D and marketing to save the projects at the last moment.

The use of an overlapping approach between R&D, production, and marketing, accompanied by intense communication among all three functions, is generally termed simultaneous, or concurrent engineering, and Hauptmann found it to be "a necessary but insufficient condition for project success" (1996; 161). Brown demonstrated a clear co-occurrence between the use of an overlapping approach and technical, economic, and overall perceived success (2002).

External communication and cooperation

Because the needs of the environment are difficult to comprehend and change over time, exchange of information and cooperation with external partners is vital, and at least as important as internal interaction. Empirical data in the studies support this theory; a majority of the studies found a correlation between external communication and cooperation and success.

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More-specific findings of the studies correspond with the previously identified environmental success factors—that is, communication and cooperation with the subsystems technology, market, and government/society—was found to correlate with success. For instance, use of external personnel and external consultants and communication with suppliers was found favorable to success, while failure co-occurred with insufficient communication with external interest groups and with poor relations with public officials.

The findings concerning behavioral factors thus confirm many of the controllable and uncontrollable factors identified above. Although a cause-effect relationship between these factors and behavior was not investigated

9. Cooper, however, noted that "the mere use of cross-functional teams did not have the dramatic impact on profitability or impact" that had been expected; the team quality had a stronger effect (1996; 27).

10. Cooperation at the beginning of the project was, however, related with performance for both highly innovative and less-innovative projects.

by the studies, it appears intuitively obvious that the internal factors were probably found pertinent precisely because they favor proficient behavior, which seems to be essentially determined by communication and cooperation.

From a systemic standpoint, these findings seem rather obvious, as an open system needs to acquire information from the changing environment in order to act accordingly. R&D organizations evidently need to be set up as "interpretation systems" (Daft and Weick, 1984) that ensure systematic acquisition of information from all environmental subsystems, interpretation and diffusion of this information to all concerned parties within the organization, and appropriate action to produce output that is compatible with the environment.

Conclusions and implications for design management

The present review of the success factors in R&D provides a comprehensive overview of the issues addressed by the R&D management discipline. Design aspects are not among them, a neglect that is unfortunately mirrored in the education of engineers. As design's body of literature demonstrates the impact of design on innovation success, we find that an integration in future engineering curricula is urgently needed to help bring these two disciplines together.

The remarkably large number of empirically grounded success factors identified in the studies may at first sight lead to despair, especially since several studies showed that a balanced mastery of all factors is necessary for success (Cooper and Kleinschmidt, 1987; Pinto and Mantel, 1990; Sappho, 1972). A closer look at the results, however, reveals that the central element for R&D success seems to be *communication and cooperation,* and that balanced mastery of so many internal factors constitutes the boundary conditions for such behavior to occur. For success to occur in R&D settings, intensive communication and cooperation is needed not only within the R&D department, but also with dissimilar functions, such as marketing, production, design, external partners, and potential customers (Tarondeau, 1994).

Organizing communication explicitly among these functions may be an appropriate means of integrating the various disciplines necessary for innovation success (Brown, 2002). This could also be a promising approach to integrate the design function further in technological projects. Much further work is necessary to validate this assumption and design appropriate tools. Our current work on communication engineering concentrates on this aspect, and will be the subject of forthcoming publications. ■

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