International Journal of Business, Human and Social Sciences
ISSN: 2517-9411
Vol:9, No:9, 2015

# Radical Technological Innovation–Comparison of a Critical Success Factors Framework with Existing Literature

Florian Wohlfeil, Orestis Terzidis, Louisa Hellmann

***Abstract*—**Radical technological innovations enable companies to reach strong market positions and are thus desirable. On the other hand, the innovation process is related to significant costs and risks. Hence, the knowledge of the factors that influence success is crucial for technology driven companies. Taking a previously developed framework of Critical Success Factors for radical technological innovations as a reference model, we conducted a structured and focused literature review of eleven standard books within the field of technology and innovation management. With this approach we aim to evaluate, expand, and clarify the set of Critical Success Factors detailed in this framework. Overall, the set of factors and their allocation to the main categories of the framework could be confirmed. However, the factor *organizational home* is not emphasized and discussed in most of the reviewed literature. On the other hand, an additional factor that has not been part of the framework is described to be important – *strategy fit*. Furthermore, the factors *strategic alliances* and *platform strategy* appear in the literature but in a different context compared to the reference model.

***Keywords*—**Critical success factors, radical technological innovation, TOMP framework, innovation process.

## I. Introduction

INCREASINGLY shorter product life-cycles force technology driven companies to be innovative, to stay competitive in the long-term [1]. Especially radical innovations enable companies to distinguish themselves from their competitors. According to Schilling, radicalness might be conceived as the combination of newness and the degree of differentness. The most radical innovations would be new to the world and exceptionally different from existing products [2]. Hence, the level of risk is high, but simultaneously the correlated market opportunities of radical innovations are better [1].

Radical innovations are often based on the employment of new technologies. Bullinger defines technology as the knowledge about potential approaches to solve technical problems [1]. Building up and defending successful competitive positions are increasingly dependent on an adequate employment of innovative technologies. As technological development and successful market introduction have independent success parameters, the arising challenges for companies are obviously both, technical and entrepreneurial in nature [1]. Currently, there is a lack of understanding of the concrete factors, that determine the capability to develop and they exploit radical technological innovations in an organization. This innovation capability needs to be interpreted as a combination of parameters, internal and external to the organization. Hence, innovation capability must be perceived as a complex concept as it is influenced by a variety of factors [3], [4].

The concept of Critical Success Factors (CSFs) can help to highlight the decisive factors, which determine the potential success of radical technological innovations. According to Rockart, CSFs thus are, for any business, the limited number of areas where things must go right for the business to flourish [5]. Originally, the CSF-concept was developed at the MIT's Sloan School of Management in the 1970s to condense the key information needs for successful strategic management [6]. CSFs are rather a lens for analysis and managerial attention than concrete recommendations for action. Having detected the CSFs for a specific endeavor, a company can assess its strengths and weaknesses and evaluate the threats and opportunities in its environment [7].

The focal paper will build on previous research by the authors. We have developed a conceptual framework of 25 CSFs for radical technological innovations and mapped them to four main categories: Technology, Organization, Market, and Process [4]. We refer to it as the Technology-Organization-Market-Process (TOMP) framework. We took the TOMP framework as a reference model and conducted a structured and focused literature review of eleven standard books that addressed the topic of radical technological innovation. Thereby we evaluated, expanded, and clarified the set of Critical Success Factors that has been detailed in the TOMP framework.

This paper provides new knowledge in the scientific field of technology and innovation management and therewith sets the foundation for further studies. The paper will also be beneficial for companies that face the challenge of developing and commercializing radical technological innovations. Since the knowledge and awareness of the concrete CSFs reduces the decision complexity for these risky and cost-intensive endeavors, the paper gives support to strategic management decisions for this kind of innovations. Accordingly, the paper has both scientific as well as practical relevance.

The remainder of the paper is organized as follows: the next

Florian Wohlfeil and Orestis Terzidis are with the Institute of Entrepreneurship, Technology Management & Innovation, Karlsruhe Institute of Technology, 76133 Germany (e-mail: florian.wohlfeil@kit.edu, orestis.terzidis@kit.edu).

Louisa Hellmann was with the Institute of Entrepreneurship, Technology Management & Innovation, Karlsruhe Institute of Technology, 76133 Germany (e-mail: hellmann.louisa@gmail.com).

section presents the relation of the paper to existing research. Sections III, lines out the research approach whilst in Section IV, the results of the conducted literature comparison are presented. In Section V, we end up with the conclusion and discussion.

## II. Relation to Existing Research

### A. Previous Studies

CSFs for radical technological innovations have been previously analyzed in several research studies from diverse perspectives, with various focus areas, and with different approaches. Some studies focus on concrete innovation projects and their correlated success. Thereby several studies address successful innovations to extract the key parameters to success [8]-[10], while others address successes and failures within one study to find reasons therefor [11]-[13]. Other studies analyzed the overall innovation portfolio of firms and sought to find out which circumstances are advantageous for the realization and subsequent success of radical innovations [9], [14]-[19]. In contrast to this approach, some studies mainly focus on the innovation process to condense the factors that are decisive at the actual realization of radical technological innovations [10], [12], [13], [18]. Several studies highlight the contrast of incumbent and newly founded companies [16], [19], while others address large established firms only [13], [17]. The mainly used research approaches were quantitative surveys [11], [15], [16], [18], case study research [8]-[10], [12], [13], [17], and field study research [14], [19].

The analysis of these studies showed that there are plenty of factors influencing the success of radical technological innovations. Some of them are controllable from within the organization (internal factors), but others are external and uncontrollable. Furthermore, the studies are non-uniform, and in some cases, they are even contradictory. Varying contexts could be the reason for the contradictory nature of some of the factors. The contexts for each individual innovation project determine the appearance or nonappearance of some factors [20]. Thus, the CSFs for a radical technological innovation need a more detailed examination that aims to differentiate the factors shaping the context for the creation of innovation on the one hand, and the actual innovation process on the other.

The next paragraph provides a brief overview of the results from our previous research that has been conducted in order to analyze the CSFs, which are caused by the context and the process for the realization of radical technological innovations.

### B. The TOMP Framework

In our previous course of action, we have developed a conceptual framework of CSFs for the strategic management of radical technological innovations – the TOMP framework. For data collection and interpretation, we chose a holistic approach. 23 case studies that deal with the development and commercialization of mainly radical technology-push innovations with a high level of novelty were deliberately selected. By following the rules of qualitative content analysis, these case studies were successively analyzed to derive the CSFs [4]. To classify the CSFs, we used and extended an existing framework of Tornatzky and Fleischer, which highlights the impacts on a firm's technological innovation decision making [21].

Our resulting TOMP framework (cf. Fig. 1) contains 25 CSFs that constitute to four main categories determining innovation success: Technology, Organization, Market, and Process. The categories technology, organization, and market shape the innovation context, which cannot be influenced directly by innovation managers. However, the innovating entity needs to be aware of these external preconditions and handle with them. The innovation process itself could be run much more flexible and, consequently, forms the direct sphere of influence for the innovation managers. It is split up chronologically into its three phases: Product Development, Market Introduction, and Diffusion [4].

The TOMP framework was used as reference model and correspondingly as research guide for the subsequent literature comparison of the focal study.

## III. Research Approach

An essential step in the procedure of theory building is comparison of the emergent concepts with extant literature. This involves analyzing similarities, contradictions, and their underlying reasons. Linking results to the literature is important in most research, but it is particularly crucial in theory building based on case study research as the findings often rest on a very limited number of cases [22]. Similarly, the TOMP framework is based on 23 case studies.

The central research questions for the focal literature analysis are the following: Which factors are mentioned in the literature to be critical for the success of radical technological innovations? Are these factors congruent to the compiled set of CSFs in the TOMP framework? Are any factors missing or superfluous? Is there any distinction made between CSFs that are influenced by the innovation context and CSFs that are influenced by the innovation process? Do the four main categories of the TOMP framework (technology, organization, market, and process) serve as a sound classification of the relevant CSFs? How do these categories correlate with each other?

For answering these questions, we focused on secondary literature, in particular books. Books and monographs are written for specific audiences. Especially academic books follow a theoretical slant and provide a thorough overview of the state of the research within a defined scope. The material is usually presented in a more ordered and accessible manner than it is in journals. Therefore, they are particularly useful when it comes to a comprehensive analysis of a complex topic [23], [24].

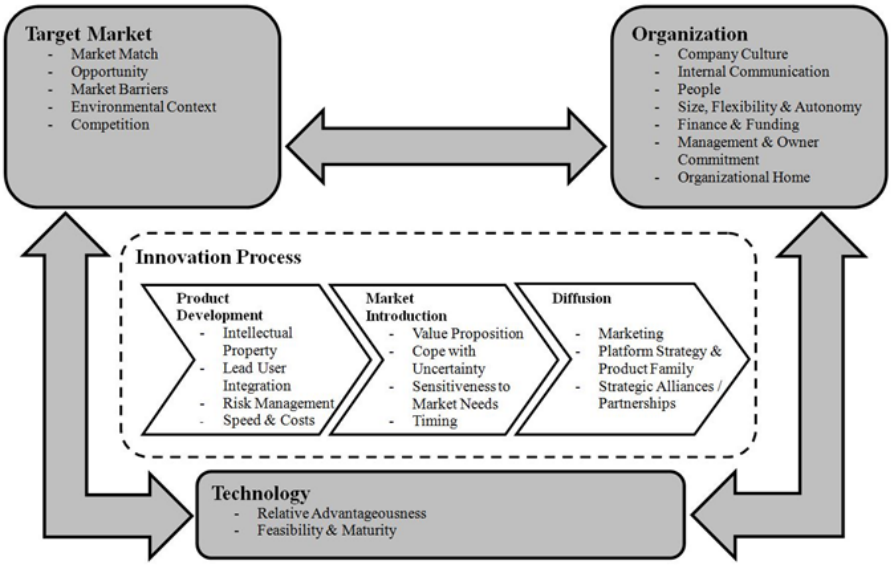


Fig. 1 The TOMP Framework [4]

TABLE I
LIST OF ANALYZED BOOKS

| Authors | Title | Year | Reference |
|---|---|---|---|
| Kelly & Kranzberg | Technological Innovation - A Critical Review of Current Knowledge | 1978 | [25] |
| *Tornatzky, Fleischer, & Chakrabarti* | Processes of technological innovation | 1990 | [29] |
| *Christensen* | The innovator's dilemma | 1997 | [26] |
| *Jolly* | Commercializing New Technologies - Getting from mind to market | 1997 | [30] |
| *Tidd, Bessant, & Pavitt* | Managing Innovation - Integrating Technological, Market and Organizational Change | 2005 | [27] |
| *White & Bruton* | The Management of Technology and Innovation - A strategic approach | 2007 | [31] |
| *Boutellier, Gassmann, & Zedtwitz* | Managing Global Innovation - Uncovering the Secrets of Future Competitiveness | 2008 | [32] |
| *Schilling* | Strategic management of technological innovation | 2010 | [2] |
| *Byers, Dorf, & Nelson* | Technology Ventures – From Idea to Enterprise | 2010 | [28] |
| *Trott* | Innovation Management and New Product Development | 2012 | [33] |
| *Vahs & Brem* | Innovationsmanagement - Von der Idee zur erfolgreichen Vermarktung | 2013 | [34] |

Before conducting the focused literature comparison based on the TOMP framework detailed in this paper, a large number of academic textbooks that address the topic of technology and innovation management were reviewed. As it is impossible to review every single piece of the literature, the purpose was to study the most relevant books that focus our topic best. For selecting appropriate books, clearly defined criteria were followed to evaluate the books relevance. This included a consideration of the subject area, the overall quality, the literature type, the language of publication, the geographical area, and the publication period. The set of selected books contains the most suitable books with respect to these criteria. To assess sufficiency, we iteratively checked what constitutes an acceptable amount of content, in terms of both quality and quantity [23].

We finally chose eleven academic standard books that address the topic of technology and innovation management on a holistic base (cf. Table I). The chosen books were published from 1978 until 2013 in the USA, UK, and Germany. Ten of the eleven books were written in English. We deliberately added one book that was written in German to take at least into account the German-speaking scientific literature. We selected timeless factual-books (e.g. [25], [26]) and multiple released academic textbooks (e.g. [2], [27], [28]). With respect to quality, we focused on books that were based on sound data and were composed of recognized scholars within the field. They should follow a clear scientific style, be quoted in renowned studies, and they accurately utilize references.

In order to derive both similarities and differences in the perception of the CSFs for radical technological innovation, the literature has been deductively scanned. We took the TOMP framework as a research guide. The index and the table of contents of each book were scanned for each CSF. If a CSF was described in a book, the corresponding phrases were highlighted and a short summary of the author's opinion was written. Following this procedure, the eleven books were worked through and the CSFs were systematically checked. For collection, storage, organization, and categorization of the data we used the reference management software Citavi 4.

## IV. FINDINGS

### A. Main Categories

Within our TOMP framework, we made a distinction

between CSFs that are influenced by the *innovation context* on the one hand and the *innovation process* on the other hand [4]. The analysis of the eleven books shows that most of the authors similarly distinguish between the innovation context and the innovation process. Tornatzky and Fleischer state that the context in which technological innovation takes place can have a significant influence on the outcome of that process. Thus, the innovation context does serve to constrain or facilitate the concrete process. They claim that there are three elements in a firm's context, which influence the process of developing and commercializing radical technological innovations: organizational, technological, and environmental context [21]. In our perception, the environment influences the market, but the market is central to the task of innovation commercialization. Correspondingly, our conceptual framework is slightly more focused on the influence of the concrete target market for the focal technological innovation.

Four CSF-categories are central in our TOMP framework: technology, organization, market, and process. We stated that there is a correlation between certain categories. For being successful, these categories need to match to each other. Accordingly, the *organization* needs to match to the *target market*. Furthermore, the *technology* needs to match to the *organization* and to the *target market*. The *innovation process* itself needs to match to the complete *innovation context* [4].

We found these estimations being confirmed in the literature. According to Christensen, exploiting radical technological innovations in commercial organizations requires that the addressed market match to the characteristics of the concrete organization. Regarding this, he emphasizes that, for example, small, emerging markets cannot solve the near-term growth and profit requirements of large companies [26]. Furthermore, the customers in the focal target market want a solution to their problem and usually do not care what technology is employed [28]. Of course, good technology can help companies to achieve competitive advantage and long-term financial success [33]. However, matching the market to the technology is decisive for being successful. It is important to find a market that values the characteristics of a concrete technology. While developing a concrete product is a technological challenge, finding the right market is a strategic marketing challenge [26]. Numerous new products have offered technologically advanced features compared to its alternatives but have failed to match customer requirements and were subsequently rejected by the market [2]. In their efforts to provide better products than their competitors, suppliers often overshoot the requirements of their target market. They serve customers more than they need and are willing to pay for [26]. For the customers it is the ratio of benefits to cost that determines value [2].

However, technology by itself will not lead to success. Organizations must be able to convert intellect, knowledge, and technology into concrete products that customers want. Therefore, new ideas are the starting point for innovation. The process of transferring these intellectual thoughts into products represents innovation exploitation and thus its commercialization [33].

### *B. Concrete Critical Success Factors*

The research questions, which concrete CSFs are mentioned in the literature, whether these factors are congruent to the compiled set of CSFs in the TOMP framework, and if there are any missing or superfluous CSFs have not yet been answered in the paper. As the four main categories of the TOMP framework have been found to be a sound classification of the CSFs for radical technological innovation, these questions will be answered by focusing on each of these categories. Due to the sample of eleven analyzed books, the universality of the CSFs cannot be totally validated. However, to underpin the relevance of certain CSFs, it could help to show that distinct patterns repeatedly emerge in a similar form. Therefore, Table II delivers an overview of the concrete indications with page numbers and thus the frequencies of the CSFs that were found in the analyzed eleven books.

#### 1. Technology

In the literature, great importance is attached to the category of technology. Thereby, a technology's *relative advantageousness* seems to be crucial for the innovation success. However, it is not sufficient to carry out a simple technical comparison to gain the competitive advantage of a focal technology [28]. The key is customer's perception of the technology [27]. It is necessary to identify why a potential customer might look for an alternative to the existing solution. This may be caused by lower costs, superior performance, or greater reliability [27], [32].

Beside its advantages, the technology's behavior should be predictable and there should be few possibilities of errors [21]. Only a fully developed, high quality and error-free product will be successful in the market. Therefore, the underlying technology needs to be feasible and mature [34].

Both factors *relative advantageousness* and *feasibility & maturity* are discussed in the studied books. However, the CSF *relative advantageousness* is described in much more detail (eight times) than the factor *feasibility & maturity* (three times). Probably, this is because a customer's perception of a technology mainly addresses its relative advantages of a technology. Nevertheless, the relative advantages of a technology depend on its feasibility & maturity and are thus a precondition for the market success.

#### 2. Organization

The conducted literature analysis highlights that the innovating *organization* has a huge impact on the probability of innovation success. The firm itself, it is internal structure, and the degree to which it uses formalized and standardized procedures and controls can constrain or facilitate the realization of radical technological innovations [2]. Tornatzky and Fleischer define the organizational context in terms of firm size, centralization & formalization, complexity of its managerial structure, internal communication, quality of its human resources, and the amount of slack resources available internally [21]. Especially for radical innovations, an innovation-friendly *company culture* is crucial. This should be built on trust, openness, communication, creativity, conflict

management, and error tolerance [28], [32].

The influence of company size on innovation success is ambiguous [25]. Size and the structure of a big company brings advantages like economies of scale in R&D and learning benefits, but similarly disadvantages such as inertia and governance problems [2]. The challenge is to find the most appropriate fit with the particular circumstances [27]. When it comes to radical technological innovations, the organic and flexible structures of small units are more suitable than the mechanistic structures of big entities [33]. Flexible structures facilitate free communication [28]. *Internal communication* is an important factor in order to coordinate successfully the innovation process and to pursue innovation goals [34].

Since the innovation process is costly, securing funds is decisive for the success of an innovation project [25]. In big companies, innovation projects have to compete with other projects whereas small companies and start-ups have to face the problem of finding external investors [27], [33]. As the realization of radical technological innovations is a very uncertain endeavor, *management and owner commitment* is important to encourage and motivate the operational team. The management should clearly communicate the organization's goals, foster a climate favorable for innovation, support the project, and strongly reward innovation success [21].

To reap fully the benefits of an innovation an adequate *organizational home* must be found. Companies should seek to embed the innovation project in an organization that fits the requirements of the focal innovation [26]. However, it is often hard to fold back the project team into the organization if the project is completed [2].

The involved *people* are the most important element in the innovation process and should be motivated and enthusiastic [25]. Cross-functional and interdisciplinary teams help to foster innovation and the management needs to assign the right people in the different stages of the innovation process [2], [30].

The factors *company culture, internal communication, finance & funding, and management & owner commitment* are described and analyzed in detail in the selected literature and thus seem to be relevant factors for the strategic management of radical technological innovation. As the factors *people* and *size, flexibility & autonomy* are mentioned in ten of eleven books, these factors seem to have a great influence on the innovation success. The factor *organizational home* has not been emphasized and discussed in most of the reviewed literature (just twice). Moreover, the books by Tidd et al. [27], Schilling [2], and Byers et al. [28] emphasized the importance of a company's strategic direction for the success of a radical technological innovation.

3. Target Market

Beside Jolly, all authors value the importance of the *target market* for radical technological innovations. The choice of the right target market is crucial [34] and the company has to make sure that there is an interesting market for their product with respect to market size and potential [31]. Therefore, the *opportunity* in that addressed market should be big enough. As already mentioned, this is a question of *market match*. Small markets do not satisfy the growth targets of big companies, but may be suitable for start-ups or medium-sized companies [26]. The innovating organization has to ensure that the focal product suits to the market [2]. Thus, the company has to assess its own technological capability and the current market needs [33]. At that point, it is important to monitor the market continuously and to be aware of what the market needs are. This is not only important for existing markets but also for new and changing markets and is especially crucial in dynamic market environments [27].

The ease of market entry depends on its structural characteristics. Potential *market barriers* are economies of scale, government regulations, switching costs, capital requirements or a tight patent situation [28], [31]. Thus, innovation leaders can deliberately establish barriers to hinder their competitors to enter the market [32]. High entry barriers particularly discourage new entrants, since they make it difficult or expensive to enter an industry. One way to deal with existing entry barriers is to choose a cooperative strategy, i.e. entering a partnership [2], [34].

Quite many authors value the analysis of a company's *environmental context* to be important for the subsequent innovation success. The goal is to detect possibilities and opportunities but also threats and problems from outside the organization. Common tools for the external analysis are Porter's five-force model and stakeholder analysis [2], [31], [33]. One important part of external monitoring is to pay attention to the *competition* in the target market. The company should have a competitive strategy, which drives new product planning [33]. On the other hand, benchmarking and learning from competitors can help to strengthen the company's position in the market. Subsequently, there are positive and negative impacts of competitive rivalry on a company's innovativeness [25], [21].

Nearly all five CSFs that have been assigned to the category *target market* in the TOMP framework are discussed in rich detail in the chosen sample of books. The factors *market match, market barriers, external environment,* and *competition* are each mentioned from five to eight authors. Just the factor *opportunity* was only described three times. A reason therefor could be the fact that all the other CSFs contribute to the factor *opportunity* of the certain target market. Depending on the level of market barriers, the competitive situation, the external market environment, and the matching of the market with the technology and the focal organization, the attractiveness of the correlated market opportunity is shaped.

4. Innovation Process

a) Product Development

During the *product development* phase, the question on how to protect a company's *intellectual property* immediately arises. Since knowledge and innovation are vital for competitive success the management of intellectual, property is important [28]. Protecting an innovation ensures that the innovating company earns the lion's share of the returns [2].

The optimal protecting strategy has to be adjusted to the company-specific needs and should be linked to the commercialization strategy [30], [34]. To ensure that the final product meets customer requirements, involving customers in the new product development process is crucial. *Lead user integration* is one possibility to integrate future customers that help to get early market feedback and supports the diffusion process of technology-intense products [2], [33]. Dealing with radical technological innovation implies high risks and uncertainty. Risk can be described as the possibility of loss [28]. Within radical innovation projects, risks have to be constantly identified and assessed. To take finally calculated risks, a sound *risk management* needs to be in place [33]. In the face of shorter product life cycles, the period to reap the returns is ever shrinking for the innovating company [32]. Thus, being efficient with respect to *speed & costs* within the product development is essential [2].

TABLE II
LIST OF INDICATIONS FOR CSFS FOUND IN LITERATURE

| | Critical Success Factors | | [25] | [29] | [26] | [30] | [27] | [31] | [32] | [2] | [28] | [33] | [34] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Technolo | *Relative Advantageousness* | | | 126-133 | 226 | | 412 | 39-40 326-327 | 183 | 240 | 66-69 | | 73 |
| | *Feasibility & Maturity* | | 68 | 128-129 | | | | | | | | | 75 |
| Organization | *Company Culture* | | | | 180-181 219 | | 327-328 | 136-137 | 28-29 | | 294-297 | 94 | 190-220 |
| | *People* | | 12-14 | 156-160 | 168-170 | 374-377 | 476-484 | | 38-39 | 266-269 | 290-291 | 103-104 | 177-189 |
| | *Size, Flexibility & Autonomy* | | 91 | 155-156 161-163 | 134-138 | | 473-476 | 176-178 | 273-274 | 213-220 | 283-287 | 101-103 | 81-82 |
| | *Internal Communication* | | | 105-111 | | | 421 | 111 355-356 | 38 | 267-268 | | 575-576 | 399-406 |
| | *Finance & Funding* | | 71 | | 103 | | 536-539 | 71 | 196-199 | 136-152 | 391-453 | 295-298 | 80 |
| | *Management & Owner Commitment* | | 192-202 | 160 | | | 413 | 112-113 130-131 | | | 291-293 | | |
| | *Organizational Home* | | | | 134-135 | | | | | 270-271 | | | |
| Target Market | *Market Match* | | | | 121 226-227 | | 350-354 | | 149-150 | 239-240 | | 62 | 416-417 |
| | *Opportunity* | | | | 38-39 164-165 | | | 68-69 | | | 258 | | |
| | *Market Barriers* | | 96-97 | | 228 | | | 50-51 | 16-17 | 100-101 116 | 85-86 | | 420-422 |
| | *Environmental Context* | | 11-12 | 94-103 173-174 | | | 441-442 | 47-53 | | 114-118 | 79-83 | 388-389 | 120-122 |
| | *Competition* | | 95-96 | 169-171 | | | 146-152 | 51; 69 | | 115 | 81 | 386-389 | |
| Innovation Process | Product Development | *Intellectual Property* | | 94-96 | | 110-119 | 259-263 | | 85 | 188-205 | 237-238 | 156-189 | 458-466 |
| | | *Lead User Integration* | | | | | 491 | | 152 | 246 | 258 | 67 | 269 |
| | | *Risk Management* | | | 227-228 | | 413 378-384 | | 27-28 | | 138-157 | 95 | |
| | | *Speed & Cost* | | | | 312-318 | 387-388 | | 18 | 240-241 | | 436-437 | 46-50 |
| | Market Introduction | *Value Proposition* | 53 | | 183-187 | | 258-259 | | | 77-81 | 56-59 | | 43; 73 |
| | | *Cope with Uncertainty* | | 170 | 156-157 | | 330-332 378 | | 168 | 97-98 | 138-146 | 85-89 | 32-33 |
| | | *Sensitiveness to Market Needs* | 219-229 | 87 | 102-104 217-218 | | 236-239 | 39 | 168 | 239-240 | 253-255 | 65 | 46; 417 |
| | | *Timing* | | | 122-124 | 318-320 | | | 227-230 | 93-104 | 108-113 | 401-402 | 108-111 420-421 |
| | Diffusion | *Marketing* | 327 | | 143 | | 422-425 | | | 297-304 | 270-274 | 64-66 | 393-415 |
| | | *Platform Strategy & Product Family* | | | | | 31-32 | 307-312 | 18-19 | 222-223 | 222 | 381-383 | 55 |
| | | *Strategic Alliances & Partnerships* | | 172-173 | | 249-281 | 461-490 | 212-232 | 21-22 | 159-177 | 89-94 | 234-267 | 84-85 |

The four factors *intellectual property, lead user integration, risk management,* and *speed & costs* which have been assigned to the *product development* phase within the TOMP framework were found in several books. Each factor is mentioned five to eight times by the authors and described in rich detail. Hence, these factors seem to be crucial for the success of radical technological innovations.

b) Market Introduction

In the phase of *market introduction*, the *value proposition* of a product predetermines how an innovation will be accepted

in the market [25]. The value of an innovation is multidimensional and comprises the worth, importance or usefulness to the customer [28]. It forms the comparative advantage of an innovation over similar products in the market and depends on the customers' expectations and perceptions [2], [34]. This implies that innovative products have to meet customer needs and values to be successful [28]. Therefore, *sensitiveness to market needs* and a strong customer focus is necessary [32]. Especially at the beginning of the product lifecycle, it is crucial for a company to know who the customers are and why they might buy the product [28]. Numerous new products, which offered technologically advanced features, were rejected, since they failed to match customer requirements [2]. For a commercially viable new product, bridging technology uncertainty and market needs is decisive [33]. Even if all technical problems are solved, the uncertainty of commercialization remains to be high [32]. Uncertainty implies that the outcome of an action is not knowable or likely to be variable [28]. *Coping with uncertainty* is a central task of managing the innovation process [33]. Furthermore, the right *timing* of market entry is one of the strategic decisions in innovation management [26]. The optimal timing depends on a variety of factors such as the innovation's advantages, the state of enabling technologies, the threat of competitive entry, and the customer expectations [2]. In principle, there are four strategic options: leader, early follower, late follower, and me-too [34].

The importance of *market introduction* is described in all analyzed books. The four CSFs *value proposition, sensitiveness to market needs, cope with uncertainty,* and *timing* have been extensively illustrated and it is each mentioned six to ten times. Correspondingly, they seem to be relevant.

c) Diffusion

From a business perspective, an innovation is not a success until it has not been established and leveraged throughout the market [2]. The earlier discussion of market introduction highlighted some CSFs crucial to the launch strategy, but the act of bringing a product onto the market is not an end. On the contrary, it is the beginning of its commercialization [33]. Usually, there is a gap between the adaption of an innovation by early adopters and by the mainstream market. To get across this chasm, *marketing* is an important factor. Marketing is a set of activities with the objective of winning, serving, and retaining customers for the firm's product offering [28]. Thus, customers are central and their needs should always be focused [27]. A good chance to recoup the high initial investments of radical technological innovations is by sharing the underlying technology across different market fields and product families by deploying a *platform strategy* [27]. Using standardized manufacturing platforms or components that can be mixed and matched in a modular production system is a good way to balance between efficiency and flexibility. This enables companies to achieve efficiency and reliability advantages at the component level, while achieving variety and flexibility at the product level [2]. Innovation often demands collaboration, either in the development or commercialization process. *Strategic Alliances and Partnerships* can reduce the costs, risks, and time of development and commercialization [27], [32]. Successful collaboration requires choosing partners that have both a resource fit and a strategic fit [2].

All books reviewed address the importance of the *diffusion* stage with the respective factors *marketing, platform strategy & product family,* and *strategic alliances & partnerships.* These factors have been mentioned seven to nine times in the chosen sample of books, thus seem to be important for the success of radical technological innovations. Several authors assign the CSF *platform strategy & product family* to the later phases of the innovation process and correspondingly the *diffusion* phase. However, they emphasize that this factor is more an issue of the *product development* strategy [33]. Furthermore, we allocated the factor *strategic alliances and partnerships* in the TOMP framework to the *diffusion* phase and thus to the later stages of the innovation process. Our allocation of this factor should be questioned as several authors emphasize the importance of collaboration in the *product development* phase as well.

*C. Results*

When analyzing the sample of eleven standard books from the innovation management literature, it becomes obvious that each book has a certain focus. Some books mainly address the innovation context for the emergence of radical technological innovations [25], [29], [31], while Jolly is targeting primarily the innovation process [30]. The remaining seven books discuss the innovation context and simultaneously the innovation process beside each other [2], [26]-[28], [32]-[34]. White & Bruton and Boutellier et al. focus on big established organizations [31], [32], while Byers et al. mainly target new ventures [28]. Trott, Schilling, Tidd et al., and Vahs & Brem present the topic of radical technological innovations from both perspectives–established organizations and new ventures [2], [27], [33], [34]. Some books highlight the contrast of new, disruptive technologies and sustaining technologies and the correlated consequences for the organizational structure of the innovating company [26], [30], [33].

With these differentiated perspectives on the topic of radical technological innovation, it becomes clear that their realization is strongly dependent on the focal innovation context. Correspondingly, there is no universal set of factors for predicting the success of a specific radical technological innovation as the relative importance of the factors would be different depending on the contextual nature of the focal innovation. Depending on the situation, different CSFs will be more or less crucial, and some factors may even hinder rather than support the success of an innovation [20]. Beside the distinction of the innovation context and the innovation process, the four main categories of the TOMP framework and their necessity to match to each other were validated by the literature analysis.

Furthermore, the general arrangement and the concrete 25 CSFs within the TOMP framework were found to be sound. In

the focal sample of books, the concrete CSFs of the categories *target market* and *technology* are described in detail. Within the category *organization,* the factor *organizational home* is not emphasized and discussed in detail. In our perception *organizational home* addresses the necessity that a radical innovation eventually has to be integrated into the coherent whole of the company's organizational structure if it will not be totally spun out [4]. That this factor is not detailed in the analyzed books is interesting. Immediately the question emerges if this factor is not critical for the success of radical technological innovations or if this represents a lack in literature. Furthermore, the books by Tidd et al. [27], Schilling [2], and Byers et al. [28] claim that an organization's strategy is equally important for the success of a radical technological innovation and that the focal innovation should be compatible to the company's strategic direction. This factor has not been part of the original TOMP framework.

The factors that we have allocated to the phases *product development* and *market introduction* were validated by the analysis of the selected books. With respect to the *diffusion* phase, several authors describe the CSF *platform strategy & product family* to be late in the innovation process. However, in contrast to our perception, they assign this factor to be part of the *product development* strategy. Additionally, some authors emphasize that in the *product development* phase collaboration is of great importance for radical technological innovations. We previously allocated the factor *strategic alliances and partnerships* to the *diffusion* phase. This should be analyzed in more detail. Probably, the types of strategic alliances change along the innovation process. While in the early stages strategically involving customers and lead users is important to cope with uncertainty and design a product in accordance to the market needs, in the diffusion stage setting up a strategic network of suppliers, customers, and partners is crucial to the broad market penetration.

In the TOMP framework, the innovation process is composed of the chronologically ordered phases of *product development, market introduction,* and *diffusion*. Perhaps it is sensitive to perceive these stages as three correlated fields of action and not chronological phases.

## V. Conclusion

This article provides the results of a structured and focused literature analysis of CSFs for radical technological innovations. Taking the previously developed TOMP framework as a research guide, we evaluated the focal set of 25 CSFs. There are some limitations with respect to the conducted literature search. Due to the sample size of our study with just eleven books the results of the analysis are not very generalizable. Extending this sample might lead to a better validation of the generated results. Furthermore, books may contain out-of-date material even by the time they are published [23]. Another limitation could be the fact that there is no uniform concept of the central terminologies. Schilling for example defines radicalness as the combination of newness and the degree of differentness [2], while Vahs and Brem ascribe a high level of novelty and similarly deep and complex changes within the company to a radical innovation [34]. This involves a slightly differing understanding of the central concepts in the analyzed literature. Since the central research objective was to evaluate the TOMP framework, another limitation is the fact that the research project was not started in an unbiased way.

Nevertheless, we found the distinction of the innovation context and the innovation process to be central to the success of radical technological innovations. More research is required to clarify how the innovation context concretely affects the innovation process. Therefore, the central question is which factors constitute the sphere of concern and which the sphere of influence. As the realization of radical technological innovations is a very complex endeavor, a qualitative research approach seems to be appropriate. Qualitative methods enable researchers to examine the many nuances and complexities of a particular phenomenon in deep. Non-standardized, guided interviews with experts in the field of technological innovation could help to generate an answer on the focal question. Additionally, the TOMP framework should be tested in real life environment for validation, e.g. by conducting primary case studies.

## Acknowledgment

This paper has been worked out in a research project funded by 5ME. We would like to thank 5ME for their support.

## References

[1] H.-J. Bullinger, Einführung in das Technologiemanagement. Modelle, Methoden, Praxisbeispiele, Teubner, Stuttgart, 1994.
[2] M.A. Schilling, Strategic Management of Technological Innovation, McGraw-Hill/Irwin, New York, 2010.
[3] M. Terziovski, Building Innovation Capability in Organizations. An International Cross-Case Perspective, Imperial College Press; Distributed by World Scientific, London, Singapore, Hackensack, NJ, 2007.
[4] F. Wohlfeil, O. Terzidis, Critical Success Factors for the Strategic Management of Radical Technological Innovation, in: 2014 International Conference on Engineering, Technology and Innovation (ICE) pp. 1–9.
[5] J.F. Rockart, Chief Executives Define their Own Data Needs, Harvard Business Review 57, 1979, 81–93.
[6] T. Butler, B. Fitzgerald, Unpacking the Systems Development Process: An Empirical Application of the CSF Concept in a Research Context, The Journal of Strategic Information Systems 8, 1999, 351–371.
[7] J.K. Leidecker, A.V. Bruno, Identifying and Using Critical Success Factors, Long Range Planning 17, 1984, 23–32.
[8] P.A. Abetti, Critical Success Factors for Radical Technological Innovation: A Five Case Study, Creativity & Inn Man 9, 2000, 208–221.
[9] D.V. Gibson, R.W. Smilor, Key Variables in Technology Transfer: A Field-Study Based Empirical Analysis, Journal of Engineering and Technology Management 8, 1991, 287–312.
[10] W.E. Souder, Improving Productivity through Technology Push, Research-Technology Management 32, 1989, 19–24.
[11] R. Rothwell, C. Freeman, A. Horlsey, V. Jervis, A.B. Robertson, J. Townsend, SAPPHO Updated - Project SAPPHO phase II, Research Policy 3, 1974, 258–291.
[12] V. Chiesa, F. Frattini, Commercializing Technological Innovation: Learning from Failures in High-Tech Markets, Journal of Product Innovation Management 28, 2011, 437–454.
[13] C.M. McDermott, G.C. O'Connor, Managing Radical Innovation: An Overview of Emergent Strategy Issues, Journal of Product Innovation Management 19, 2002, 424–438.
[14] R. Henderson, Underinvestment and Incompetence as Responses to Radical Innovation: Evidence from the Photolithographic Alignment

Equipment Industry, The RAND Journal of Economics 24, 1993, 248–270.
[15] OECD, The Conditions for Success in Technological Innovation, Paris, 1971.
[16] W.M. Cohen, D.A. Levinthal, Absorptive Capacity: A New Perspective on Learning and Innovation, Administrative Science Quarterly, 1990, 128–152.
[17] G.C. O'Connor, R. DeMartino, Organizing for Radical Innovation: An Exploratory Study of the Structural Aspects of RI Management Systems in Large Established Firms, Journal of Product Innovation Management 23, 2006, 475–497.
[18] R.K. Chandy, G.J. Tellis, Organizing for Radical Product Innovation: The Overlooked Role of Willingness to Cannibalize, Journal of Marketing Research 35, 1998, 474–487.
[19] A.B. Sorescu, R.K. Chandy, J.C. Prabhu, Sources and Financial Consequences of Radical Innovation: Insights from Pharmaceuticals, Journal of Marketing 67, 2003, 82–102.
[20] R. Balachandra, J.H. Friar, Factors for Success in R&D Projects and New Product Innovation: A Contextual Framework, IEEE Trans. Eng. Manage. 44, 1997, 276–287.
[21] L.G. Tornatzky, M. Fleischer, The Processes of Technological Innovation, Lexington Books, Lexington, Mass, 1990.
[22] K.M. Eisenhardt, Building Theories from Case Study Research, The Academy of Management Review 14, 1989, 532–550.
[23] M. Saunders, P. Lewis, A. Thornhill, Research Methods for Business Students, Pearson, Harlow, England, New York, 2012.
[24] P.D. Leedy, J.E. Ormrod, Practical research. Planning and Design, Pearson Education, Upper Saddle River, N.J, Harlow, 2009.
[25] P. Kelly, M. Kranzberg, Technological Innovation: A Critical Review of Current Knowledge, 1978.
[26] C.M. Christensen, The Innovator's Dilemma. When New Technologies Cause Great Firms to Fail, Harvard Business School Press, Boston, Mass, 1997.
[27] J. Tidd, J.R. Bessant, K. Pavitt, Managing Innovation. Integrating Technological, Market and Organizational Change, Wiley, Hoboken, 2005.
[28] T.H. Byers, R.C. Dorf, A.J. Nelson, Technology Ventures. From Idea to Enterprise, McGraw-Hill, 2010.
[29] L.G. Tornatzky, M. Fleischer, A.K. Chakrabarti, Processes of Technological Innovation, 1990.
[30] V.K. Jolly, Commercializing New Technologies. Getting from Mind to Market, Harvard Business School Press, Boston, Mass, 1997.
[31] M.A. White, G.D. Bruton, The Management of Technology and Innovation. A Strategic Approach, Thomson/South-Western, Mason, OH, 2007.
[32] R. Boutellier, O. Gassmann, M. von Zedtwitz, Managing Global Innovation: Uncovering the Secrets of Future Competitiveness, Springer Science & Business Media, 2008.
[33] P. Trott, Innovation Management and New Product Development, Financial Times/Prentice Hall, Harlow, England, New York, 2012.
[34] D. Vahs, A. Brem, Innovationsmanagement. Von der Idee zur erfolgreichen Vermarktung, Schäffer-Poeschel, Stuttgart, 2012.