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Understanding the history of industrial innovation: developments and milestones in key action fields of R&D management

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The management of R&D and innovation in industrial companies is often said to be on its path to a major transformation within the next decades. Key drivers include technological developments, enabling a higher degree of digitisation or automation and a cultural shift towards democratisation and openness, both leaving behind organisational models of single inventors or centrally organised R&D departments see e.g. [Bul16], [Sch16], 17]. A key question is, if there is a next big thing or a disruption coming up in industrial innovation. Referring to a rather non-academic statement, it might also be that "*it's all just a little bit of history repeating*"[1]. This is the reason why we propose a historical analysis of previous developments and milestones in the key action fields of R&D Management as a basis for an in-depth analysis of potential future developments.

1. The interrelation between R&D and industrial innovation in transforming environments

Research and development (R&D) today is described as "*activities and processes that lead to new tangible or intangible assets*" [Bro99] that include "*novel, creative, uncertain, systematic, transferable and/or reproducible activities*" 15]. Following the definition of accounting principles, research aims at new scientific or technical knowledge or understanding. Development focuses on the transfer of research results or other knowledge into the planning or production concept of new materials, products, processes systems or services before commercial production or use[2]. In the context of this paper, we understand R&D as an integral part of industrial innovation. It includes the phases of basic research, technology development, pre-development and development of solutions for example in the form of products, processes, services, business models or integrated combinations of those. Our understanding of innovation in a broader definition includes the successful realisation or implementation of ideas for example in a market, in an organisation or in society [Fra18] and is thus covering the entire life cycle as well as the innovation system of ideas realised or implemented.

2. Literature review on the history of industrial innovation

The findings described in this paper are derived from an extended literature analysis, looking in detail into the history of R&D and innovation management and into the scientific discipline of innovation research. Key progress compared to previous approaches is the application of a structure allowing categorising the historical development of R&D management within key action fields. This enables the authors to identify innovation paths in each action field and analyse historical developments on a more detailed and structured level. Looking into the literature available on the history of R&D and innovation management, the classification into so-called generations is among the most common approaches. Periods considered for the generations of R&D and innovation management vary between the authors as

[1] „History Repeating", written by Alex Gifford and performed by the Propellerheads featuring Shirley Bassey, 1997
[2] According to International Accounting Standards IAS 38 and International Financial Reporting Standards IFRS

for example for the first generation. This generation is starting according to some authors in the last quarter of the 19th century e.g. [Fre74] and for others after the second world war e.g. [Rot94]. Additionally, generations are hardly differentiable between each other and many characteristics of early generations are still existent in today's company structures. This is due to high variations in the maturity of R&D and innovation management in companies depending for example on their size, regional location, age or sector of activity. We understand the notion of generations in this paper as development phases that can be transferred on the level of individual companies, organisations or innovation systems to better allocate their current state and to identify potential for improvement. Therefore, they are not necessarily bound to the specific time horizons to which they were initially allocated. For this reason, the analysis refers to development paths in each of the action fields of R&D management rather than to the generations of R&D and innovation management. The analysis of the history of industrial innovation will be complemented by selected literature from the field of innovation research see e.g. 14] and generic literature on R&D Management see e.g. [Rig16], [Bro99].

3. Assessing industrial innovation activities in companies from an R&D management perspective

For understanding future developments in industrial innovation, it is assumed that essential learnings can be extracted from a better understanding of past developments. This is especially the case for long-term trends, circular repetitions and interrelations between relevant parameters or influence factors. Based on the underlying structure of the R&D assessment model of the Fraunhofer Institute for Industrial Engineering IAO [GBW15], the proposed paper will investigate developments and milestones in the key action fields of R&D management as a baseline for an in-depth analysis of potential future developments. This includes the action fields of R&D (1) strategy, (2) organisation, (3) processes, (4) employees and (5) methods & tools (see Figure 1).

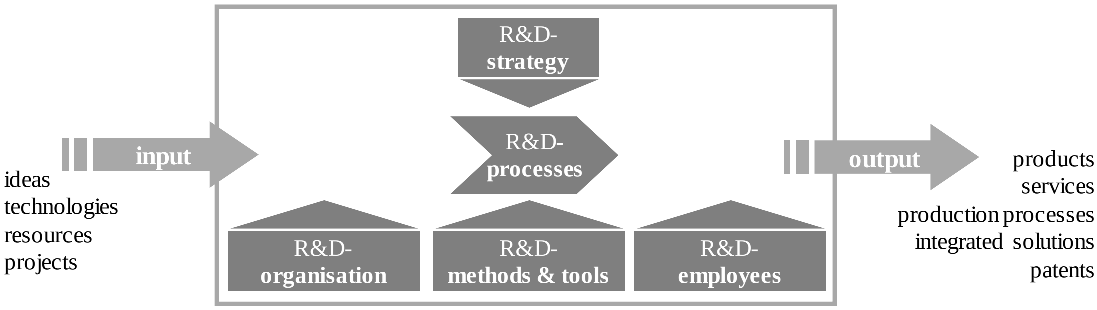

Figure 1. Key action fields of the Fraunhofer IAO R&D assessment.

The key action fields of the R&D assessment model are specified as follows [GBW15]:

1. **R&D strategy:**
   This action field includes the definition, monitoring and realisation of the R&D strategy. Furthermore, it consists of the monitoring of the external and internal strategic perspective to continuously analyse developments relevant to R&D. From an external perspective, this involves information on competitors, markets, technologies and customers representing influence factors from a company's wider environment. From an internal perspective, it includes for example core competencies, technological competencies and assets, strategic configuration of solutions as well as R&D programme management. The key question of this action field is if a company defines its R&D strategy in a structured and methodological manner under consideration of all relevant influence factors.
2. **R&D organisation:**
   Organisation and communication structures in the R&D department and its partner network are in the centre of this action field. The related question is, if the organisational structure is consistent to best support the flexible, efficient and target-oriented collaboration to support all R&D activities.
3. **R&D processes:**
   This action field includes the sub-groups of idea generation, research, pre and concept development, product, production and service development and process improvement. The major question related to R&D processes is, if current processes are defined efficiently, target-oriented in a flexible and integrated manner.

4. **R&D employees:**
   The acquisition and retention of R&D employees, personal development, motivation and incentives as well as the organisational culture are in the sub-groups of this action field. Referring to the competencies of R&D employees, the consistency with the other action fields and the question if development options and motivational frameworks are suited to reach R&D objectives.
5. **R&D methods & tools:**
   The action field of R&D methods & tools involves the application of IT systems, R&D methods as well as risk and project management in R&D. It questions if methods and tools are applied consistently to support the other action fields efficiently and in a competent way.

The maturity model of the R&D assessment that allows the analysis of industrial innovation systems from an R&D perspective will not be considered in more detail for this purpose see [GBW15].

4. The history of industrial innovation related to the key action fields of R&D management

Leading ideas similar to the topic of R&D management were already described in the year 1643 in the publication "*New Atlantis*" by Francis Bacon, resembling to a kind of "*central intelligence and R&D agency*" [Kro87], [Bro03]. Nevertheless, the starting point of industrial innovation in the form of R&D and the raise of the topic of R&D management is generally said to begin in the last quarter for the 19th century. The topic was pioneered by German chemical firms in the context of dyestuff innovations [Fre74], [Mow09]. In the following chapter we categorise the developments described in literature in relation to the action fields of R&D management. Interestingly, referring to the song "*It's all just a little bit of history repeating*", the challenges of R&D management described sound similar to the challenges that are most commonly mentioned today: new industrial countries and competitors are rising, risk and uncertainty are increasing, advances of technological frontiers happen at much higher pace and the risk for incumbents to be disrupted is growing [KKC93], [Rot94], [MiM99], [Nio99], [Par03], [Nob04], [KPP14]. Therefore, these trends will be analysed in more detail to identify overlaps and recurrent trends and developments, especially among prospective trends highlighted in literature.

4.1 R&D strategy

Strategic development in R&D has changed from a technology-centred model in the past towards an interaction based management model today. In its first generation, R&D strategy is described as highly independent from the rest of a company and mainly focused towards scientific achievements or breakthroughs [Nob04]. Chemical and physical advances to be applied in products and processes were in the centre of interest and R&D was often motivated by enabling a diversification strategy to overcome legal restrictions for mergers and acquisitions [Mow09]. The relation between in- and output was described principally through the relational model that "*more R&D in*" results into "*more successful new products out*"[Rot94]. The technology driven strategic orientation was complemented from the mid-1960s by a market pull perspective leading to the "*technology push vs. market pull model*". This model is still a common basis for today's strategic R&D orientation in many companies including its incorporated danger of neglecting long-term planning and getting locked into technological incrementalism [Rot94].
Along the timeline, the level of reflection of technological change and transformation as well as the reflection of the potential impact companies, markets and society increased see e.g.[Cla80]. Until the early 1980s, R&D and technology strategy got increasingly integrated into the corporate strategy [Rot94]. Since the late 1990s, knowledge of end-users and suppliers became a key element for the development of R&D strategies [Nio99], [KPP14] starting the development towards a holistic strategic approach combined with portfolio planning. This approach involves both, market pull and technology push and is closely related to a company's core competencies [KKC93].
From a content perspective, a trend away from manufacturing-oriented R&D towards non-manufacturing topics such as information technologies or biotechnology can be observed since 1985 [Mow09]. Over time, initial R&D strategies focused on technologies, processes or products only were widened towards a combination of products with services and is further orienting towards integrated solutions. However, in the areas of information technologies and biotechnologies, a trend towards increasing vertical specialisation was observed since the 1970s [Mow09].
Between 1980 and 2006, R&D activities shifted away from basic research see [ABP18].
Today's R&D strategy is trying to bring together portfolio approaches with the objective of generating breakthrough innovations in models such as the 70 / 20 / 10 rule applied at Google [Nob04], [SRE14]. A catalytic development for strategic planning processes in R&D is the current development in big data management, allowing improved selection procedures in R&D project, portfolio and programme planning and also an improved matching between market pull and technology push mechanisms [BAL17].

4.2 R&D organisation

The first approach for R&D organisation described in literature is referred to as "*the strategy of hope*" in which competent people were hired and provided with excellent surroundings, leaving them alone and hoping for the best. This organisational concept was followed by a project-based approach, introducing the quantification of costs and benefits of individual projects. Already more than two decades ago, organisational structures bringing together functional areas with required R&D disciplines aiming to break up the isolated structures of R&D departments were described in the third generation of R&D management see [RSE91].

Looking at the organisational incorporation of R&D in companies, the assembly line period was followed by the time of corporate research laboratories such as GE's Research Laboratory or Bell Labs see [Ger12]. Based on a continuous differentiation between basic research, advanced development and manufacturing within these labs, academic disciplines were separated from the other, also referred to as the dilemma of an ambidextrous organisation. This development was complemented by an increase in bureaucratisation, especially in research centres of big conglomerates and described as "*a rational approach on a project-by-project basis*" [KeF89], [KKC93]. Following this development, large corporations started to reduce or eliminate central R&D laboratories starting in the late 1970s [Mow09]. The concept to organise R&D activities around so-called missions was a collaborative effort starting in the period after the second world war to reach goals in defence, communication, health and environmental topics [Nio99]. Missions today are discussed as an appropriate organisational form of R&D, not only for reaching technological milestones, but for solving major societal issues see [Maz18].

In the timeline between 2002 and 2012, an increase in academia-industry collaboration and rise in start-ups and entrepreneurship was predicted (National Research Council (U.S.) 2002, p. 44). This development seems to represent a repeating trend, as it was also mentioned in the pre 1940s era in the pharmaceutical industry. At this time, R&D laboratories were predominantly positioned close to leading academic institutions to take benefit from cumulative accumulation of scientific with economic competencies see [MaF05]. Interestingly, the model of self-organising teams and virtual corporations was already mentioned as the predominant organisational form for breakthrough innovations in the beginning of the 1980s. It was also described as the upcoming organisational form able to overcome the bureaucratic structures of large corporations, exemplified by technology startups in the Silicon Valley starting in the year 1957 [KeF89].

The 1990s were the starting point of agile and flexible structures in corporations, complemented by rapid communication channels [KKC93], [Nio99]. The years after 1985 are also described as the period where open structures, which were a predominant organisational aspect already in the first generation of R&D management, were revived after a period of relatively closed corporate R&D structures. At that period, increased vertical specialisation lead to increasing R&D collaboration between companies on a global level [Mow09]. Additionally, R&D started to get influenced by Japanese management techniques which lead to an empowerment of R&D and project managers at lower levels and the raise of so-called product and project champions [Rot94].

From the beginning of the 1980s, organisational structures were increasingly linked to specific application areas. R&D in large corporations was thus described as being more suitable for incremental R&D, whereas venture capital financed startups as being suitable for fast-growing and breakthrough R&D activities [KeF89].

In the description of an upcoming 6th generation of R&D management, a distributed and sourcing-oriented organisational structure was envisioned, in which the R&D department only plays a role minor to the one known at that time [Nob04]. Considering that this development was described already more than a decade ago, it is still an ongoing development and one of the key trends still said to be shaping the future of innovation and R&D [Fra18].

4.3 R&D processes

R&D processes in the first generation are described as linear processes with the market as the ending point being relatively independent from specific strategic objectives. This period is also referred to as the "*assembly line generation*" of R&D [KeF89]. Over time, starting in the 1960s, R&D processes developed towards a project-based structure in a chain management approach. They started to be supported by traditional project management practices and structures [Nio99]. In the year 2006, Berkhout et al. considered five properties characterising R&D processes. These include (1) open innovation, (2) early interaction between science and business, (3) complementation between knowledge on emerging technologies and emerging markets, (4) networking with specialised suppliers or early users and (5) entrepreneurship [BHV06]. Measurement of R&D activities started to get in the centre or interest in the mid-1990s, including the continuous evaluation of R&D activities through the integrated measurement of input, assets, efficiency and outcome [Nio99]. Priorities towards efficiency aspects and customer service were added to R&D processes at that period, considering the speed of development as a key factor determining R&D competitiveness [Rot94].

Similar to the changes in organisational structures, the 1990s were the starting point for the introduction of agile and flexible structures in R&D processes [KKC93]. This includes for example the application of lean development principles following the example of the company Toyota [MoL06] or agile process structures following the principles of the agile manifesto [FoH01]. Furthermore, integration and parallel development became more and more common in R&D [Rot94]. In addition, since the mid-1980s, R&D processes started to get increasingly distributed on a global level due to extended cross-border flows towards an increased global organisational and system integration [Rot94]. Furthermore, international inbound and outbound investment in R&D started to continuously rise at that period [Mow09].

4.4 R&D employees

The initial role of R&D employees was very similar to employees in academic scientific laboratories and even competing with those. The role of R&D employees and managers changed from the 1970s towards becoming more and more integrated with other organisational functions. Also, the role of R&D managers was more and more transforming from an initial exclusive responsibility for R&D planning and execution towards a more distributed responsibility among other functional managers and R&D employees [Nio99]. However, this trend was reversed for selected projects or products through the rise of the so-called lead engineer or product champion during the 1990s, providing increased responsibility to managers at lower levels in flatter hierarchies covering the entire innovation value-chain [Rot94]. Whereas vertical careers are still the dominant form of personal development for R&D employees in many companies today, specific career models for R&D were introduced already in the 1980s. These allow R&D employees to select between different options, for example between the paths of becoming a specialised expert, an R&D project manager or a general manager [WMW11]. From the 1990s, employee mobility is considered as a key driver for the regional agglomeration of R&D intensive high-tech firms and for technology diffusion in related industries [Mow09].
Education, work habits and motivation are said to be the characteristics changing throughout the history of R&D management. This includes that R&D in start-up companies and the topic of entrepreneurship are increasing in their attractiveness for companies and R&D employees in the 21st century. The pressure to provide rewards to R&D employees is rising since that time to retain and attract so-called R&D performers. Mobility is increasing and also the requirement of bridging the gap between different disciplines that follows an increasing interdisciplinary nature of R&D activities [Nat02]. The diversity of R&D employees is rising not only between disciplines but also between nationalities which leads to a rising complexity to be handled by R&D employees in project teams for example through the involvement of employees from different time-zones, cultures and nationalities [Mow09].

4.5 R&D methods and tools

The usage of methods and tools is only a minor topic in the descriptions of the R&D generations. However, some major developments can be extracted from literature. The 1960s are described as the starting point of structured project and risk management procedures in R&D [Nio99]. The early 1990s were the starting point of an increased application of creativity methods in the area of abstraction of technical problems or creative problem solving. This development was principally triggered by the theory of inventive problem solving see e.g. [Al′84]. The development of the balanced scorecard model in the beginning of the 21st century lead to a decade of increased application of performance management and measurement models, combined with knowledge management as a key topic that both ceased in their application at the end of 2010s see [KeB99], [BrB04].
Japanese management techniques including Six Sigma, Kanban or lean development and agile methods including scrum or extreme programming started to be commonly applied in R&D departments from the 1990s on [Rot94]. Total quality control through the application of quality management standards or methods such as quality function deployment (QFD) started to become an integral part of R&D at that time [Rot94].
In the second half of the 1990s, the use of linked CAD systems along the production chain, able to interlink information from suppliers, manufacturers and users started to rise in R&D. This development was closely linked to the usage of 3D-CAD and the application of augmented or virtual reality techniques for fast prototyping. In this context also the application of simulation techniques continuously increased, enabled by a combination of developments in underlying methodologies, algorithms and computing technologies [Rot94]. Whereas fully developed internal databases were already mentioned as a key method for data analysis, sharing and electronically assisted R&D at that time, this development is still one of the key trends for R&D and innovation management today. Key enablers for advances in fully developed internal databases are the advances in product data management systems (PDM), product lifecycle management systems (PLM) and advances in big data management. These advances also allow cost efficient usage of digital twins for simulation or the application of machine learning and artificial intelligence in R&D see e.g. [OJS16], [BAL17].
From a strategic perspective, a trend towards the usage of multiple futures for the development of systems-oriented R&D strategies was initiated by the rise of the application of the scenario technique see e.g. [GFS95].
A trend that started in the beginning of the 21st century and that is still ongoing is the redefinition of prototypes. From the initial understanding as being "*fully-functional*" especially for validation purposes previous to manufacturing,

prototypes are more and more considered as first experiments able to involve users for testing in early R&D stages see e.g.[Kel01].
Looking at the history in this action field, the application of methods and tools is either driven by developments in catalytic technologies or by developments in the other action fields. This can be exemplified by the increasing focus on R&D process efficiency in the mid-1990s leading to increased application of performance management and measurement tools as well as towards the application of Japanese management techniques. An example for methods and tools driven by technology development is the rise of CAD applications enabled by both an increase in capabilities and a decrease in related costs of CAD systems.

5. Review of trends and developments influencing the future of industrial innovation

As already mentioned in the previous chapter, many of the prospective trends and developments described at the intersection from one generation to the next are still valid today. Therefore, Table 1 provides an overview of prospective trends and developments relevant for industrial innovation that were described in the literature in the last decades. This confirms that prospective trends and developments described since1994 still highly overlap with those relevant for industrial innovation today and most probably in the future.

Table 1. Prospective trends and developments relevant for industrial innovation

Rothwell 1994 **[Rot94]**	**Nobelius 2004** **[Nob04]**	**Howells 2008** **[How08]**	**Kensen, Pretorius and Pretorius 2014** **[KPP14]**	**Schimpf 2016** **[Sch16]**	**Fraunhofer Group for Innovation Research 2018** **[Fra18]**
Greater organisational and systems integration	Increasing complexity	Decreasing availability of R&D talent	Increasing partnerships and collaborations	Increasing share of R&D carried out by external actors	Digital transformation
Flatter and more flexible organisational structures	Towards more radical innovations	Changing nature of R&D activity	Increasing focus knowledge management	Increasing digitisation and automation in R&D	Increasing complexity
Towards fully developed internal databases	Broadening of the technological basis	Blurring of producers and consumers of R&D	Increasing focus on open innovation	More efficient and accelerated R&D	Increasing variety of parties involved in R&D
Towards additional electronic assistance	Increasing globalisation	Increasing control vs. creativity trade-off			Increasing availability of knowledge
More effective external electronic linkage		Emergence of new forms of R&D organisation and new actors			Towards integrated solutions

Clustering the prospective trends and developments collected in Table 1 based on their similarities, clusters that are most often mentioned to be relevant for the future of R&D and innovation are the trends towards digitalisation and the trend towards open innovation. These are followed by the trend towards greater systems integration and the trend towards an increasing complexity. These clusters correspond almost entirely to the prospective trends until the year 2030 published most recently [Fra18].

6. Discussion and Conclusions

Looking at the development path in each of the action fields, it can be observed that, to a major part, each is developing further along the timeline. An exception with more cyclical application of structures is the action field of R&D organisation in which approaches that were common in early development stages of R&D management were decreasing in importance and were then again upcoming in later generations of R&D management. This includes open organisational structures as well as self-organising teams and virtual corporation for the specific context of breakthrough innovations. In the action field of R&D strategy, mission orientation and the incorporation of breakthrough innovation into the strategic objectives of R&D activities can also be considered as recurring topics, both being highly relevant in the beginning of R&D management and again in the 21st century.
Looking into the trends and developments relevant for industrial innovation, it seems that these are highly overlapping over the timeline. Challenges for R&D from decades ago are still highly similar to the challenges that R&D is confronted with today.
In conclusion, it was shown that for some topics in R&D management a look into the past seems more relevant than for others. Topics with cyclical developments are the ones with the highest probability that "*it's all just a little bit of history repeating*" and thus worthwhile to take benefit from previous analyses and learnings. Furthermore, trends and developments seem rather no repetitious, but more long-term oriented and mainly changing by the level of development speed or intensity than by their nature.

Publication bibliography

acatech/BDI (Ed.) (2017): Innovationsindikator 2017. Schwerpunkt Digitale Transformation. With assistance of Marion A. Weissenberger-Eibl, Rainer Frietsch, Torben Schubert, Daniel Bachlechner, Bernd Beckert, Michael Friedewald et al. acatech - Deutsche Akademie der Technikwissenschaft e.V. / Bundesverband der Deutschen Industrie e.V. (BDI). Berlin. Available online at http://publica.fraunhofer.de/dokumente/N-461384.html.

Alʹtšuller, Genrich S. (1984): Creativity as an exact science. The theory of the solution of inventive problems. New York, NY: Gordon and Breach (Studies in cybernetics, 5).

Arora, Ashish; Belenzon, Sharon; Patacconi, Andrea (2018): The decline of science in corporate R&D. In *Strat Mgmt J* 39 (1), pp. 3–32. DOI: 10.1002/smj.2693.

Berkhout, A. J.; Hartmann, Dap; Van Der Duin, Patrick; Ortt, Roland (2006): Innovating the innovation process. In *International Journal of Technology Management* 34 (3-4), pp. 390–404. DOI: 10.1504/IJTM.2006.009466.

Blackburn, Michael; Alexander, Jeffrey; Legan, J. David; Klabjan, Diego (2017): Big Data and the Future of R&D Management. In *Research-Technology Management* 60 (5), pp. 43–51. DOI: 10.1080/08956308.2017.1348135.

Bremser, Wayne G.; Barsky, Noah P. (2004): Utilizing the balanced scorecard for R&D performance measurement. In *R&D Manage* 34 (3), pp. 229–238. DOI: 10.1111/j.1467-9310.2004.00335.x.

Brockhoff, Klaus (1999): Forschung und Entwicklung. Planung und Kontrolle. 5., erg. und erw. Aufl. München: Oldenbourg.

Brockhoff, Klaus (2003): A utopian view of R&D functions. In *R&D Manage* 33 (1), pp. 31–36. DOI: 10.1111/1467-9310.00279.

Bullinger, Hans-Jörg (2016): Jeder ist ein Nobelpreisträger. oder könnte es zumindest werden. Die Demokratisierung der Wissenschaft eröffnet ganz neue Chancen für die Forschung. In : The next 100. Ideen, Visionen, Meinungen zur Welt von morgen. 1. Auflage. Hamburg: Hoffmann und Campe, pp. 34–39.

Burr, Wolfgang (Ed.) (2014): Innovation. Theorien, Konzepte und Methoden der Innovationsforschung. 1. Aufl. Stuttgart: Kohlhammer Verlag.

Clark, John A. (1980): A model of embodied technical change and employment. In *Technological forecasting & social change* 16 (1), pp. 47–65.

Fowler, Martin; Highsmith, Jim (2001): The agile manifesto. In *Software development* 9 (8), pp. 28–35.

Fraunhofer-Verbund Innovationsforschung (Ed.) (2018): Wandel verstehen, Zukunft gestalten. Impulse für die Zukunft der Innovation. With assistance of Wilhelm Bauer, Michael Lauster, Thomas H. Morszeck, Thorsten Posselt, Marion A. Weissenberger-Eibl, Sven Schimpf et al. Stuttgart. Available online at http://publica.fraunhofer.de/documents/N-491577.html.

Freeman, Christopher (1974): The economics of industrial innovation. Harmondsworth, Middlesex: Penguin Books (Penguin modern economics texts).

Gausemeier, Jürgen; Fink, Alexander; Schlake, Oliver (1995): Szenario-Management. Planen und führen mit Szenarien. München: Hanser.

Gelec, Erdem; Binzer, Judith; Wohlfart, Liza; Kern, Manuel; Schubert, Michael; Schüle, Stephan; Schimpf, Sven (2015): FuE - Fit für die Zukunft. Trends und Erfolgsfaktoren in der Forschung und Entwicklung. Edited by Frank Wagner. Stuttgart: Fraunhofer Verlag.

Gertner, Jon (2012): The idea factory. Bell Labs and the great age of American innovation. New York, NY: Penguin Press.

Howells, Jeremy (2008): New directions in R&D. Current and prospective challenges. In *R&D Manage* 38 (3), pp. 241–252. DOI: 10.1111/j.1467-9310.2008.00519.x.

Kelley, Tom (2001): Prototyping is the shorthand of innovation. In *Design Management Journal (Former Series)* 12 (3), pp. 35–42. DOI: 10.1111/j.1948-7169.2001.tb00551.x.

Kenney, Martin; Florida, Richard (1989): The evolution of research and development in US industry: from corporate R&D laboratory to venture capital financed startups. In *Hitotsubashi Journal of Commerce and Management* (24), pp. 41–51.

Kensen, Alex K.; Pretorius, Jan-Harm; Petorius, Leon (2014): Towards the sixth generation of R&D management: an exploratory study. In IAMOT (Ed.): Proceedings of the International Conference for the International Association of Management of Technology. Washington, May 22st to 26st.

Kerssens-van Drongelen, Inge c.; Bilderbeek, Jan (1999): R&D performance measurement. More than choosing a set of metrics. In *R&D Manage* 29 (1), pp. 35–46. DOI: 10.1111/1467-9310.00115.

Kesler, Mark; Kolstad, Diana; Clarke, W. E. (1993): Third Generation R&D. The Key to Leveraging Core Competencies. In *The Columbia Journal of World Business* (fall), pp. 34–44.

Krohn, Wolfgang (1987): Francis Bacon. Orig.-Ausg. München: Beck (Beck'sche Reihe Große Denker, 509).

MacGarvie, Megan; Furman, Jeffrey L. (2005): Early academic science and the birth of industrial research laboratories in the US pharmaceutical industry. Cambridge, Mass.: National Bureau of Economic Research (NBER working paper series, 11470).

Mazzucato, Mariana (2018): Mission-Oriented Research & Innovation in the European Union. A problem-solving approach to fuel innovation-led growth. European Commission.

Miller, William L.; Morris, Langdon (1999): 4th generation R & D. Managing knowledge, technology, and innovation. New York: John Wiley & Sons. Available online at http://www.loc.gov/catdir/bios/wiley041/98012030.html.

Morgan, James M.; Liker, Jeffrey K. (2006): The Toyota product development system. Integrating people, process, and technology. New York, NY: Productivity Press. Available online at http://www.loc.gov/catdir/enhancements/fy0801/2006004343-d.html.

Mowery, David C. (2009): Plus ca change: Industrial R&D in the "third industrial revolution". In *Industrial and Corporate Change* 18 (1), pp. 1–50.

National Research Council (U.S.) (2002): Future R & D environments. A report for the National Institute of Standards and Technology. Washington, D.C: National Academy Press (Compass series). Available online at http://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&db=nlabk&AN=86987.

Niosi, Jorge (1999): Fourth-Generation R&D From Linear Models to Flexible Innovation. In *Journal of Business Research* 45 (2), pp. 111–117. DOI: 10.1016/S0148-2963(97)00230-0.

Nobelius, D. (2004): Towards the sixth generation of R&D management. In *International Journal of Project Management* 22 (5), pp. 369–375. DOI: 10.1016/j.ijproman.2003.10.002.

OECD (2015): Frascati manual 2015. Guidelines for collecting and reporting data on research and experimental development. Paris: OECD (The measurement of scientific, technological and innovation activities).

Otto, Boris; Jürjens, Jan; Schon, Jochen; Auer, Sören; Menz, Nadja; Wenzel, Sven; Cirullies, Jan (2016): Industrial Data Space. Digitale Souveränität über Daten. With assistance of Jan Cirullies. Edited by Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. München. Available online at http://www.industrialdataspace.org/publications/ids-whitepaper/.

Paraponaris, Claude (2003): Third generation R&D and strategies for knowledge management. In *J of Knowledge Management* 7 (5), pp. 96–106. DOI: 10.1108/13673270310505412.

Rigby, John (2016): A long and winding road. 40 years of R&D Management. In *R&D Manage* 46 (S3), pp. 1062–1083. DOI: 10.1111/radm.12214.

Rothwell, Roy (1994): Towards the Fifth-generation Innovation Process. In *International Marketing Review* 11 (1), pp. 7–31. DOI: 10.1108/02651339410057491.

Roussel, Philip A.; Saad, Kamal N.; Erickson, Tamara J. (1991): Third generation R&D. Managing the link to corporate strategy. Boston, Mass.: Harvard Business School Press.

Schimpf, Sven (2016): Crowdsourcing, digitisation and acceleration. Is corporate R&D disrupting itself? In : From science to society: Innovation and value creation. Institute for Manufacturing, Cambridge: University of Cambridge, p. 8.

Schmidt, Eric; Rosenberg, Jonathan; Eagle, Alan (2014): How Google works. London: Murray (Ebook).

Wohlfart, Liza; Moll, Kuno; Wilke, Jürgen (2011): Karriere- und Anreizsysteme für die Forschung und Entwicklung. Aktuelle Erkenntnisse und zukunftsweisende Konzepte aus Wissenschaft und betrieblicher Praxis. Stuttgart: Fraunhofer-Verl.