Journal of Production Systems and Logistics
Volume 3 | Article 5
Published: June 2023

Reference-phase Model for the Transfer Process of Deep Tech Innovations

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Abstract

The term Deep Tech is receiving major attention from start-ups, venture capitalists, and governmental decision makers as this special group of technology does have a strong impact on societies and national innovation systems. In European countries, commercialization and industrialization of Deep Tech-related products lacks behind in international comparison. Nevertheless, academic research about the reasons and circumstances in this field is scarce. To fill this gap in research, a comprehensive Deep Tech transfer reference-phase model is developed based on the current state of knowledge that incorporates the entirety of the technology transfer process from science to industry. Taking Deep Tech characteristics into account, four reference phases are set up and described along three descriptive characteristics (TRL, focus, target state) and four requirement categories (knowledge, resources and infrastructure, financial requirements, actors in focus). The analysis and synthesis show that the requirements within the single phases do highly change due to an adapted focus and target state over the technology transfer process. With the present work, a sound understanding of the technology transfer process for Deep Tech is established which enables future researchers to derive phase-specific key success factors and valid governmental recommendations for the technology transfer of Deep Tech.

Keywords

Technology Transfer; University Technology Transfer; Valley of Death; Reference Phase; Deep Tech

1. Practical Relevance and Target

Over the last years, the German innovation system proved to be strong when it comes to basic research and findings. In the following, the number of patents granted is used as a major indicator for representing the output of research and development processes. For the five countries with the highest gross domestic product (GDP) in 2021, Figure 1 shows the relative output of their research system in relation to commercialization success. The number of total patents granted[1] per million employees is used as an indicator of the relative output of the research system. To evaluate success in commercialization, the number of unicorns[2] per million employees is considered (unicorn-intensity).

[1] The number of total patents granted is composed of the number of resident and abroad patents granted.

[2] Start-ups with a total market value of at least 1 $ billion.

This Paper has been reviewed by the Certified Reviewer Community of publish-Ing. – 2 reviews – double blind

DOI: https://doi.org/10.15488/13791
ISSN: 2702-2587

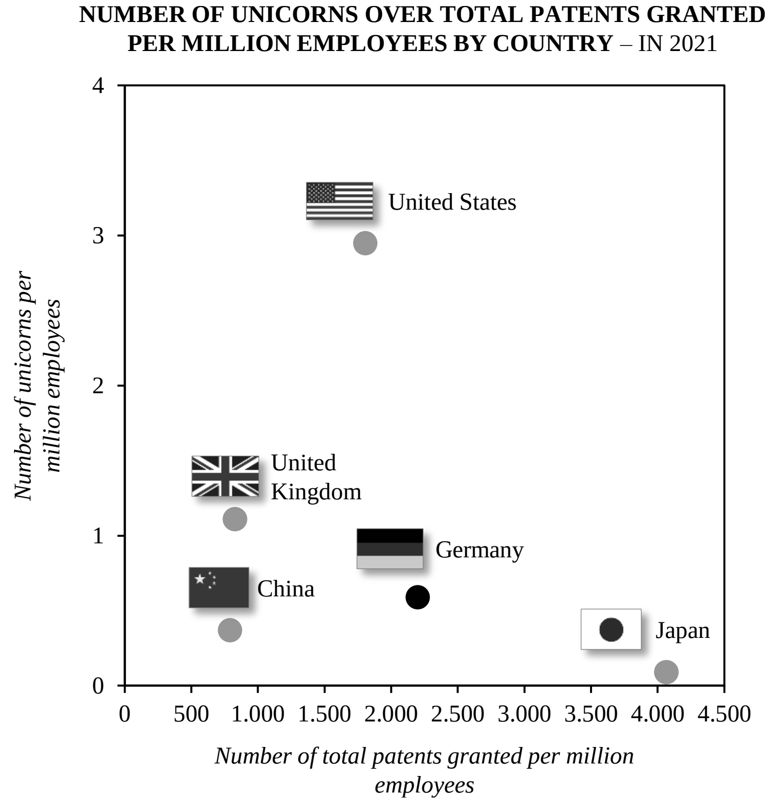

Figure 1: Number of unicorns over total patents granted, each per million employees by country in 2021 [1–3]

The intensity of patent grants in 2021 was higher in Germany (2,199 patents granted per million employees) than in the United States (1,806), the United Kingdom (827), and China (789). This indicates the strong capabilities of the German research system, only surpassed by Japan (4,065). [2,3] However, analyzing the commercialization of scientific findings, the German innovation system lacks behind when it comes to building companies with a potentially large impact. With a unicorn-intensity of 1.11, the United Kingdom outperforms Germany (0.58) in the commercialization of fundamental research, whilst the gap with the United States (2.95) is even bigger. Yet, Germany is ahead of Japan (0.09) and China (0.37). [1,2]

This divergence between research and innovation did not pass unnoticed. In Europe and Germany new investment vehicles and mechanisms for technology transfer based on high-tech research are planned. Not only has the *Zukunftsfond* of the *European Union* (EU) been established [4]. Additionally, the set-up of a 1 € billion fund is targeted as a combined initiative of Germany and France within this technological segment [5]. Adding to this, the EU granted a budget of over 10 € billions for the period of 2021 to 2027 for the *European Innovation Council* (EIC) to develop and expand breakthrough innovations. Its model combines research on emerging technologies with an accelerator program and a dedicated equity fund to scale up innovative start-ups and small and mid-sized enterprises (SMEs). [6]

Amongst others, the COVID-19 pandemic and the effects of climate change are further leading to increasing governmental commitments to accelerate the commercialization of Deep Tech which should help tackle such challenges. [7] A recent example is the case of *BioNTech.* The company successfully developed the first mRNA[3]-based vaccine and received significant governmental funding as well as political attention. This one is not an isolated case. On a national level, the *Kreditanstalt für Wiederaufbau* (KfW) established a new fund solemnly dedicated to Deep Tech and managed by the *High-Tech Gründerfond* (HTGF). [9] Besides these public financing streams, private capital Deep Tech investments increased globally and more than fourfold

[3] Messenger RNA molecules, that direct the synthesis of protein molecules [8].

between 2016 and 2020 as depicted in Figure 2. These numbers include minority stakes, initial public offerings (IPOs), private investments, as well as mergers and acquisitions (M&A) of start-up and scale-ups. [10]

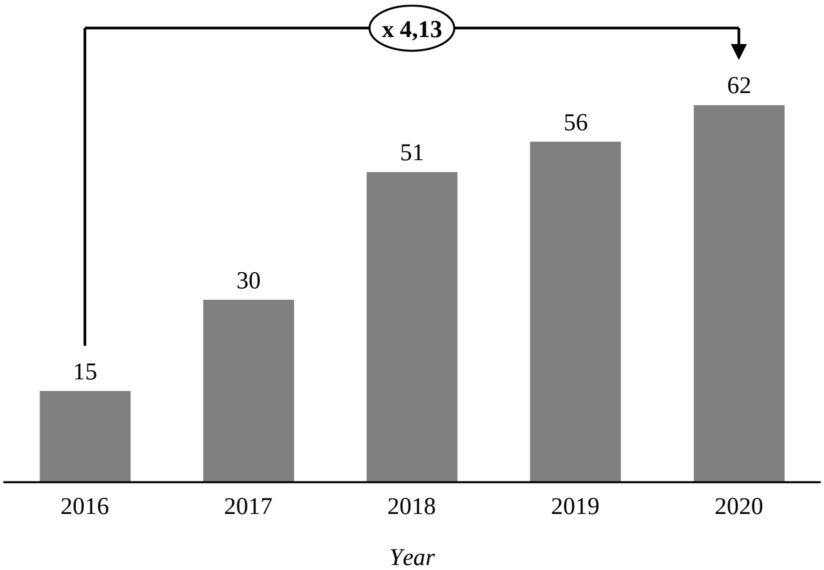

Figure 2: Global Deep Tech investments between 2016 and 2020 in $ billion [10]

Nevertheless, funding alone does not guarantee successful exploitation. The technology transfer – referring to the shift from scientific findings and concepts towards industrial execution – must be set up successfully based on a holistic perspective. Technology transfer has emerged as a subject of academic research for model theory as early as the 1970s. [11] Since then, possible transfer pathways with various objectives have been researched: transfer through university and government research institutes [12,13], international technology transfer [14–16] and multi-organizational transfer [14]. Since it is broadly understood that technology transfer bears significant impact on the competitiveness of a national economy [17] – especially within complex and investment-intensive technological fields – understanding its dynamics in different technological phases and respective requirements is essential.

Over the last years, this need has led to the development of various technology transfer models of which most are of qualitative nature [18]. The models vary in their focus and granularity, but often fail to provide practical guidelines or policy recommendations and remain on a mostly hypothetical level [19,20]. Overall, existing models are not satisfying the researchers‘ and policy makers' needs. Some only focus on one dimension throughout the process, e.g., technology [21] or finance [7]. Others examine only specific stages within the broader development and transfer process. Hereby, attention is notably concentrated to university technology transfer [22–24] or the gap between research and commercialization, the so-called Valley of Death (VoD) [22]. Since Deep Tech has only been explored lately in the context of technology transfer, scientific investigation is required. Thus, a Deep Tech specific transfer model from which viable recommendations for practitioners can be derived is missing. Therefore, the research at hand aims to define a first reference-phase model that takes the implications based on the special requirements and characteristics of Deep Tech into consideration. As derivation from this goal, answering the research question *"How can reference phases of Deep Tech transfer be described and differentiated?"* is targeted.

2. Fundamentals of the Research Situation

To ensure a successful conceptualization of the reference-phase model based on the practical relevance and target, it is necessary to define the underlying terminologies and concepts. Therewith, a common understanding of the elements covered by this research is achieved.

2.1.1 Technology Transfer

In this chapter, the underlying definition of transfer of technology is described. First, the basic theoretical definition of a "technology" is established. For this purpose, the authors use the generalist view of technology as a tool [25] or information necessary to design and produce a specific good or enable a service. It is generally applicable, and the results of the process are reproducible. [26] Second, the concept of transfer of technology is examined. It has been used to describe and analyze a broad range of organizational and institutional interactions, always involving a technology-related exchange. The general concept of technology transfer by BOZEMAN is "the movement of know-how, technical knowledge, or technology from one organizational setting to another" [13]. It is a multidimensional research field with a variety of possible contexts. Transfer can occur between countries (international technology transfer), companies (inter-firm technology transfer) or within a heterogenic partnership network (universities, government research labs, companies) [14,27]. The spotlight within this paper lies on the latter with a focus on the processes within which ideas and concepts from research-related activities reach the commercialization phase of a marketable product or service.

Contrary to prior research about university technology transfer – where the detailed investigation ends with the technology leaving its original entity [28] – the authors include the commercialization efforts and the establishment of organizational structures as relevant part of the transfer process. Especially the set-up of spin-offs plays a vital role within university technology transfer [29,23]. A spin-off is a new venture founded by individuals who were former employees of the scientific organization. They stay owners of the underlying technology and transfer it to the newly established entity. [30] This process is also referred to as *academic entrepreneurship* [31]. Spin-offs have a high societal impact, especially through long-term job-creation [32] as well as significant economic value. [31]

To summarize, technology transfer is described as the planned, time-limited and voluntary process of transferring a technology from a technology provider (explicitly science) to a technology taker (explicitly industry). Technology means a technical artifact together with the associated knowledge. The transfer does not take place as an end in itself but serves the overriding goal of producing technological innovations. [33]

2.1.2 Deep Tech

The term Deep Tech refers to disruptive technologies with a high degree of uncertainty regarding their actual feasibility at the start of exploration. In contrast to common technology, Deep Tech differs in several specific characteristics: Due to their high degree of novelty, there is a major market risk in the initial introduction of Deep Tech innovations, as reactions of market participants, e.g., system integrators or customers, are uncertain [34,7]. In addition, Deep Tech are characterized by above-average financial and temporal investments between fundamental research and market maturity [35]. However, successfully developed Deep Tech have a substantial technological advantage over existing technologies and thus have an exorbitantly high potential in commercialization. Furthermore, they are associated with significant spill-over effects, meaning that they have a major impact on other areas, such as other industries. [36,33]

3. Research Process and Methodology

Based on the practical relevance and target of the paper, a Deep Tech specific phase description in the form of a **reference modeling** is required. Reference models are theoretical models that function as starting point for the development of solutions for specific tasks. Based on the task, a distinction can be made, for example, between procedural reference models, software-specific reference models and industry-specific reference models [37]. Reference models are characterized by the fact that they do not only reflect context-specific contents but ensure an abstraction of their context reference consciously. In the present work, this abstraction serves to synchronize different technology development and transfer concepts. Based on the principles of proper modeling, SCHÜTTE – whose concept is chosen due to its broad application and acknowledgement within scientific literature – describes a procedure model for steering and controlling of the modeling activities within five phases. The procedure starts with an initial problem definition (phase I), based on which a reference model framework is constructed "top-down" for the standardization of terms and model components (phase II). Upon this, the structure of the reference model framework is detailed using structural analogies (phase III). Phase IV functions to complete the framework so that its final application in practice will be beneficial to its users in phase V. Figure 3 5 illustrates the procedure for reference modeling according to SCHÜTTE. [38,39]

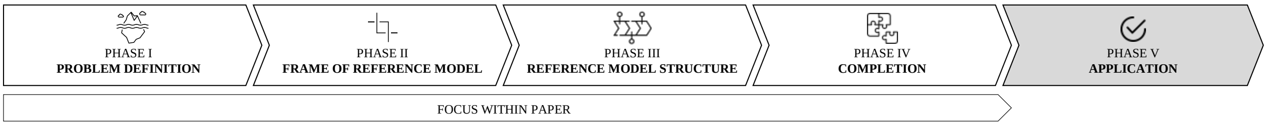

Figure 3: Structured approach for reference modelling in five phases [38,39]

The first four phases defined by SCHÜTTE will be applied within the present paper. By highlighting problems and research needs, chapters 1 and 2 already represented phase I. By deriving descriptive characteristics and requirement categories in chapter 4.1, phase II of the process following SCHÜTTE is completed. To examine the current state of knowledge required for the reference model structure and completion (phases III and IV), an **extensive literature review** is conducted. A thorough analysis of existing literature and publications is performed by utilizing various bibliographical databases as search tools: *SciFinder, Refseek*, *WISO-Online, EBSCO, science.gov,* and *Google Scholar*. To ensure an exhaustive search, a series of keywords within abstracts and titles of published peer-reviewed literature is targeted. The keywords used are as follows: *technology transfer, technology transfer model, technology transfer process, university technology transfer, academic entrepreneurship, Deep Tech, deep technology, Deep Tech start-ups, Deep Tech venture capital, valley of death, and systemic innovation.* Through the combination of various overlapping research with different focus and a comparative analysis of prior models, the theoretical base for the new proposed reference-phase model will be established. Since the definition of Deep Tech derives mainly from grey literature, publications by practitioners like governmental officials, non-governmental organizations, entrepreneurs, venture capital funds, and strategy consulting firms are included within the analysis.

4. Results

In the following, the reference phase model is derived based on the practical relevance (chapter 1) and the fundamentals of the research situation (chapter 2). The structure is based on the approach presented within chapter 3. This chapter finishes with the definition of a holistic reference phase model for the technology transfer of Deep Tech.

4.1 Derivation of descriptive characteristics and requirement categories

The aim of this subchapter is to identify elements relevant for the design of the phases that enable a target-oriented phase description adapted to the scope of the work and thus serve as a frame of the reference model (phase II). In line with the overall objective of the research – the phase-dependent description of technology transfer boundaries – the phases are to be described in terms of specific characteristics enabling a differentiation from one another. Only with the help of such a distinction, explicit measures and their assessment of the contribution to accelerating technology transfer can be determined. Corresponding elements must be described for a clear delimitation. These are derived from the relevant fundamentals of this research work, i.e., Deep Tech and technology transfer (see chapter 3). Additionally, the stage-gate process according to COOPER is used as a basis for the design since it is an established process for structuring and segmenting innovation initiatives from technology and innovation management [40] and therewith a good fit. The elements derived in the following are divided into **descriptive characteristics** for basic phase determination as well as **requirement categories**. The characteristics serve to demark the individual phases of each other. On the other hand, individual expressions within the requirement categories can occur recurrently in different phases.

Descriptive characteristics of reference phases

Based on the analyzed fundamentals, technology readiness levels (TRL) functions as a scientifically recognized and target-oriented mechanism for granular differentiation of technology development stages [41]. Following the Deep Tech description, Deep Tech can be expressed over all **TRLs** as it is created within basic research and leads to market-applicable products [42]. Structuring the reference phases along the individual levels is therefore reasonable and should be included as descriptive feature. As previously described, it is further useful to build the reference phase model upon elements of COOPERS stage-gate concept – an established and proven innovation process segmentation [43]. The dominant principle of this theory is the importance to focus innovation activities on isolated tasks to reach successive (development) gates in a targeted manner [40]. This **focus** is therefore used as a characteristic in the reference phase description. Following this argumentation, **target states** of individual phases are to be defined, which ensure the determination whether a respective phase has been surpassed successfully and whether the underlying focus is to be changed [40]. Since the goal of the paper is to accelerate transfer processes, it must be understood which target states are to be achieved in each phase.

Requirement categories within the technology transfer phases

Requirement categories are necessary to be able to derive precisely tailored, phase-specific support options from the government for technology transfer in the future. Following the previously derived descriptive characteristics, both, the focus within individual phases and the target states between the phases, change. In addition, Deep Tech is characterized by high expenditures of R&D resources [44]. In this context, it is necessary to understand which technological elements are relevant at which point in the Deep Tech transfer process for the individual achievements. From this, it is possible to derive requirements for the respective **type of knowledge** as well as the **resources and infrastructure** required within each phase. A technology undergoes major changes during the development process and the transfer (from theoretical model to prototype to pre-series product [41]). Within existing literature, it is extensively described that complex technological developments often fail due to financing gaps [45]. The motivation and problem description of the present work reinforces this observation (see chapter 1). Structuring and evaluating **financial requirements**, including the type of capital, is therefore essential as a requirement category for transfer phases. The focus on Deep Tech strengthens the need for a detailed analysis of the **actors in focus** involved. Since the value chains of industrialized Deep Tech are complex and various actors from research and industry participate in the development and transfer processes [46], the relevant phase-dependent actors must be considered. The differentiation should thereby go beyond the one made in the technology transfer theory (i.e., technology giver, technology taker and technology mediator [47]). Additionally, due to the high societal relevance of Deep Tech, there is a strong focus on the role of the government within the phases which needs to be applied in the model.

Based on the descriptive characteristics and requirement categories defined, the transfer phase model is successively built up over the following chapters. In chapter 4.2, relevant literature from the research area is used to identify and synthesize expressions within the defined descriptive characteristics and requirement categories.

4.2 Literature Review

In line with the research process, this chapter deals with analyzing the current state of knowledge by presenting the most influential models for the design of the reference model. They will be presented and critically evaluated with focus on the descriptive characteristics and requirement categories derived in chapter 4.1. The relevant models were abstracted from literature based on the procedure presented in chapter 3. This enables a sound theoretical foundation on which the reference phase model is based on. Since the present work aims for a high degree of practical application, all models that are too generic or have the wrong focus are excluded (e.g., models that cover international and inter-firm technology transfer). The models presented in the following chapters are sorted by the way that they reflect the technology transfer sequence covered in this work.

Alternative Model of University Technology Transfer – BRADLEY 2013

The Alternative Model of University Technology Transfer was established by BRADLEY. It focuses on the early stages of technology transfer from a university as a source of scientific discovery. The model consists of a complex network of technology transfer processes carried out by a variety of actors (university scientists, university, entrepreneurs, and Technology Transfer Office). In addition, factors that influence these processes, such as funding sources and university policies and culture, are described. Finally, technology transfer can occur through licensing to existing companies or through the creation of new start-ups or spin-offs. The major contribution is the recognition that this process does not (or rarely does) follow a linear sequence as in most other models. However, its scope is limited to university technology transfer. It ends with licensing or spin-off creation without providing a consideration of the subsequent steps towards industrialization or commercialization. In terms of the reference model structure, BRADLEY provides relevant input for the elements of **focus**, **financial requirements**, and **actors in focus**. In the area of focus, a very specific description is given of which elements and necessities are in the foreground in the individual process steps. In terms of financial requirements, the sources of capital are described with a focus on basic research. The actors are discussed in detail, at the individual level along the phases. [28]

Sequential Model of Development and Funding – AUERSWALD AND BRANSCOMB 2003

AUERSWALD and BRANDSCOMB define a five-phase model to describe the technology transfer process. It consists of Research, Concept, Early Stage Technology Development (ESTD), Product Development and Production. The dimensions examined within the phases are structured along two areas: the technological development phase and the funding sources. Funding sources are not limited to one phase but can have relevance in different phases. Amongst others angel investors, venture capital (VC), corporate venture funds, equity and commercial debt are considered. In addition, a target state is identified for each phase: This is expressed with a patent application based on the research conducted (phase 1), validation of a company after the early stage of technology development (phase 3), or the establishment of a viable company through production/marketing (phase 5). AUERSWALD AND BRANDSCOMB discuss the limitations of their model, particularly with respect to Intellectual Property Rights (IPR). Furthermore, the model is limited to the technological and financial perspective and does not consider other features of technology transfer. A relevant finding is that a design-critical point exists in stage 3 (ESTD), where the transition from invention to innovation takes place. This transition is accompanied by a significant change in funding source (from primarily public funding to private sector funding). According to the previous explanations, the model provides insights for the elements **focus, target state** as well as **financial requirements** for the reference model structure. [45]

The Cash Flow Valley of Death Concept – MURPHEY AND EDWARDS 2003

With respect to the concept of the VoD, the elaboration of MARKHAM is considered fundamental, in which the gap between the availability of resources for research and development and commercialization activities is shown in a structured way [48]. Many models build on this framework and elaborate different gaps, such as funding and capabilities (e.g., business development). An example is the Cash Flow VoD Model by MURPHY AND EDWARDS. In addition to representing cash flow, the model includes a risk indicator ("risk-based discount rate") and defines the typical investors at each stage, divided into public and private sources. Within technology transfer, the VoD represents a critical period for success. For Deep Tech, this phase is particularly relevant, as there is a significant need for capital and above-average development times are required [36]. Therefore, the concept of the work of MURPHY AND EDWARDS is highly relevant for the elements of the reference model structure and provides insights in the areas of **financial requirements** along the transfer process as well as the **focus** in individual process phases (Technology Creation, Market Focused Business and Product Development, Early Commercialization). [22]

Collaboration Model – HARLÉ ET AL. 2017

In 2017, HARLÉ ET AL. designed a process model adapted to the specific characteristics of Deep Tech. It is based on the results of a survey of 8,600 Deep Tech start-ups. HARLÉ ET AL. define three core phases: early, mid and late stage. Within these phases, six sub-phases were distinguished based on the **TRLs**. Other dimensions include phase objectives, partnership formats, a checklist and key success factors. While the framework is limited to the collaboration between start-ups and other stakeholders (e.g., corporate venture capital), single design elements of the model are picked up and adapted within this paper. Separating the phases based on the TRL of the underlying technology appears useful. Further, the inclusion of **target states** ("objectives") to which each phase is directed is adapted and key requirements described by the autors are taken up in the form of **focus**. The latter are described generically in the HARLÉ ET AL. framework and there is a need for a more granular analysis in the context of technology transfer. In addition, HARLÉ ET AL. provide relevant input for the **knowledge type** by distinguishing between market-oriented and technology-oriented requirements and describing the relevant **actors in focus**. Important aspects relating to **resources and infrastructure** are presented in the form of key success factors. [49]

Deep Tech Framework – ROMANSANTA ET AL. 2021

Based on a comprehensive analysis of concepts in the areas of radical innovation, innovation ecosystem, VoD, technology spin-offs, and disruptive innovation, ROMANSANTA ET AL. have developed a comprehensive model to describe Deep Tech-specific phases. Starting with a **focus**-description (Fundamental, Beneath, Complex, Distant, Profound) as well as **target states** (Scientific Discovery, Prototype, Scaleable Products and Services), the model provides aspects in the areas of **actors in focus** and **financial requirements**. ROMANSANTA ET AL. provide a detailed, phase-specific list of actors in focus for technology transfer. Along with this, the sources of funding and metrics of measurement of value for appropriate funding are described. [44]

Life Cycle Model for Deep Tech Start-ups – SCHUH ET AL. 2022

SCHUH EL AL. make an important contribution to conceptual Deep Tech research with their lifecycle-model. The model is structured in four phases, the early phase, research and development phase, growth phase and late phase. Milestones are defined by the stage goals of individual phases that must be achieved as transition to a subsequent phase (**target states**). To ensure a high level of detail and granularity, these four phases are divided into eleven sub-phases. In contrast to HARLÉ ET AL., who use the TRL as their base for phase conceptualization, SCHUH ET AL. use financing rounds of start-ups as referential element. The focus is put on the particularly high capital requirements of Deep Tech. The further structuring comprises five central development fields, the technology, the product, the market, the business model and the organizational development. Along these fields, the development of Deep Tech start-ups takes place and can be included in the **focus**, **knowledge type** and **financial requirements**. The model provides a relevant contribution to systematize and understand the development of Deep Tech start-ups. The multidimensional approach, ranging from financial aspects to phase-specific focus, serves as a relevant input for the reference phase model in this contribution. It provides significant granularity and depth. However, it is based on the life cycle phases of start-ups and thus does not include the full transfer process of technologies coming from research. [50]

Summary of the analysis of existing process models

In summary, the result of the process model analysis is presented in Figure 4. Along the design-relevant features of the Deep Tech reference model derived in chapter 4.1, the coverage within existing literature is evaluated. Following this approach, it is ensured that existing knowledge from relevant preliminary work is comprehensively incorporated into the design of the reference phase model in the following chapter.

	DESCRIPTIVE CHARACTERISTICS			REQUIREMENT CATEGORIES			
	TRL	FOCUS	TARGET STATE	TYPE OF KNOWLEDGE	RESOURCES AND INFRASTRUCTURE	CAPITAL REQUIREMENTS	ACTORS
ALTERNATIVE MODEL OF UNIVERSITY TECHNOLOGY TRANSFER (BRADLEY 2013)		✓				✓	✓
SEQUENTIAL MODEL OF DEVELOPMENT AND FUNDING (AUERSWALD AND BRANSCOMB 2003)		✓	✓			✓	
THE CASH FLOW VALLEY OF DEATH CONCEPT (MURPHY AND EDWARDS 2003)		✓				✓	
COLLABORATION MODEL (HARLÉ ET AL. 2017)	✓	✓	✓	✓	✓		✓
DEEP TECH FRAMEWORK (ROMANSANTA ET AL. 2021)		✓	✓			✓	✓
LIFE CYCLE MODEL FOR DEEP TECH STARTUPS (SCHUH ET AL. 2022)		✓	✓	✓		✓	

✓ Covered by source

Figure 4: Coverage of descriptive characteristics and requirement categories by existing literature

4.3 Set-up of the Reference Phase Model for the Transfer of Deep Tech Innovations

In this chapter the relevant elements of the different process models analyzed are picked up and adapted to derive the reference model structure (phase III, chapter 4.3.1) and complete the overall Deep Tech transfer phase model (phase IV, chapter 4.3.2) by characterizing the single technology transfer phases.

4.3.1 Derivation of the Reference Model Structure

The overarching goal of this research is to enable the identification of options for action for governmental decision-makers with a minimum of effort and a high fit. In this context, the granularity of the TRL model as an established technology characterization tool does not appear to be target-oriented for decision-making processes within Deep Tech. Therefore – following the process according to SCHÜTTE – an adapted reference model structure, based on the analyzed existing concepts, is required.

The technology development process of Deep Tech necessarily starts in basic research (see definition in chapter 3). This corresponds to phases 1-3 of the TRL-framework [51]. Basic research is to be seen as an isolated area with a strong connection between universities and research institutions to public institutions and funding [22]. Therefore, **“Discovery”** represents the first process phase of the Deep Tech reference phase model. This segmentation coincides with a large part of the existing literature considered (*Scientific Discovery, Research, Exploration, Scientific Discovery / Engineering Innovation*). In this initial phase a concrete, tangible technology does not exist yet. Only experimental conceptual proof is present.

Based on the basic research and conceptual proof, hardware development processes follow, within which the actual technology is created and brought into the realm of an operational product (analogous to TRL 4 and 5) [51]. Following the definition of Deep Tech, its characteristic elements (e.g., hardware components and complex, procedural manufacturing processes) become visible. The technology is thus in the creation or set-up process and the second phase is therefore named **"Deep Tech Development"**. Once again, elements of this phase can be found in many of the works from literature analyzed (*Invention, Technology Creation, Functional Prototype, Prototype, R&D Stage*).

Within the literature analysis as well as the description of the basic problem definition it occurs that the VoD is of extraordinary relevance for the Deep Tech transfer. To ensure the identification of the best possible support options for this phenomenon in the reference phase model, this element must be considered isolated. Following the publication of HIRZEL ET AL., the VoD is assigned to the TRL phases 6 and 7 [52]. Furthermore, the *ESTD, Market Focused Biz and Product Development, minimum viable product (MVP), Scaleable Product and Prototype, and Growth-Stage* phases identified in the literature analyzed can be linked to the **"Valley of Death"**.

As soon as the VoD is surpassed, a market proximity and relevance of the Deep Tech becomes visible and assessable [53]. In this paper, this last phase is described as **"Industrialization and Commercialization"**, which matches to the TRL phases 8 and 9. All literature presented include relevant aspects of this field (*Licensing and Usage, Production and Marketing, Early Commercialization, Industrialization, Societal Impacts, Late Stage*) dependent on their technological or market-oriented focus. In Figure 5, the single phases of the relevant approaches are summarized and structured along the phases of the resulting reference process presented. Content-related similarities between the reference model and the input models are visualized with different colors.

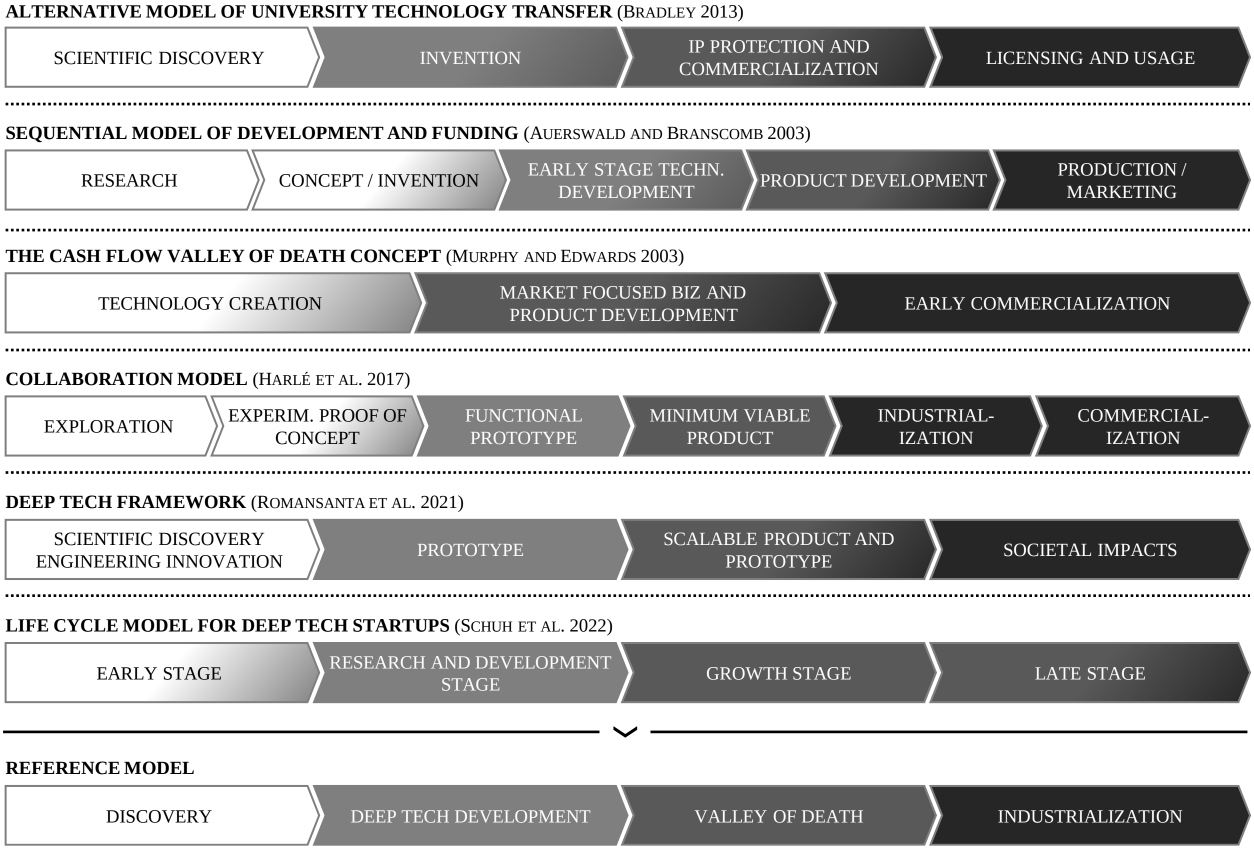

Figure 5: Derivation of the tailored reference model structure based on existing literature

4.3.2 Characterization of the Technology Transfer Phases

As – according to SCHÜTTE – final phase covered within the underlying research process (IV), the completion of the reference phase model is conducted. Upon the previously set up reference model structure, the individual technology transfer phases are described along the descriptive characteristics and requirement categories.

Discovery of Deep Tech Innovations

The **focus** of the initial phase of the transfer of Deep Tech innovations lies in fundamental technology research mainly conducted in universities of research institutions for applied science [45,50]. The aimed **target state** is therefore a proven concept mostly in form of a patent [45,49,50]. Furthermore, a core team in charge of further development and scaling needs to be created [50]. The required **knowledge** for such achievements of target states is foremost from scientific nature. General concepts of new developments and improvements need to be understood and combined. At the same time, knowledge about future-relevant potential application markets is required. Therefore, technical and business needs need to be understood by the development team [49]. To be able to conduct successful fundamental research and get in contact with possible cooperation and support partners, know how about public funding and support mechanisms needs to be available [54]. In the discovery phase, the focus within **resources and infrastructure** lies in experimentation labs and the availability of scientists in special technological fields [44]. The **financial requirements** are comparably low with a reliance on public scientific funding bodies (e.g., specialized ministries, European funds) and the government as sponsor of successful technological creation [22,44]. Following the information outlined, the **actors in focus** within the discovery phase are universities, research centers as well as industry labs with a huge financial contribution of governments. Industrial actors play a minor role as the application in a real production environment is not in focus yet and the possibly generatable insights and contributions are small [28,44].

Development of Deep Tech Innovations

Within the development phase, the **focus** lies in the creation of a market-oriented technological application based on the fundamental patent and concept created initially [45,22,50]. In addition, the IP-related options need to be assessed [44]. The **target state** is a first prototype proving initial technological validation and giving parties of interest possibility for visualization and discussion [45,49,44]. Furthermore, a business model draft for the innovation including a defined value proposition needs to be achieved [45,49,50]. The **knowledge** required for such achievements base on operational technological understanding including (agile) prototyping [49]. Furthermore, business competencies in form of IP and business development need to be pushed [54]. The main **resources and infrastructure** are comparable to the discovery phase including scientists and labs which ensure prototyping activities and are extended with the involvement of technology transfer offices, supporting projects with business and IP-know-how [44]. The **financial requirements** change as fundamental scientific research is no longer in focus but initial steps into private funding are performed. Semi-public funds (e.g., *High-Tech-Gründerfonds*, *European-Investment-Fund*) do exist to support this phase [55]. Additionally, angel investors or high-risk venture capital funds play a stronger role [45,22]. Following these aspects, the **actors in focus** are founded start-ups or spin-offs developing and pushing the Deep Tech innovations [44]. Additionally, accelerators and incubators can form a fruitful environment for this development phase. On top, industrial players conduct deeper involvement as the prototypes have a stronger connection to industrial application [44].

Valley of Death for Deep Tech Innovations

Within the phase of the VoD within Deep Tech innovations, the **focus** lies in a market-oriented product and business development around the Deep Tech concept [45,22,50]. As **target state** a successfully engineered, scalable and market-ready product is given. Furthermore, the environment of this product is a mature company with a valid product-market-fit [44,50]. Multiple required types of **knowledge** result out of this focus and target state: first, a business adhesion and competencies for business model development need to be present [49,50]. Additionally, the agility to set-up and refine a MVP needs to be given [49], leading to the requirement of strong interaction between engineering and market development. Furthermore, competence within industrialization needs to be brought into the project to ensure producibility and scalability of the Deep Tech [50]. As the VoD is highly critical when it comes to liquidity of spin-offs, detailed knowledge about existing financing opportunities is required. The most important **resources and infrastructure** – in addition to the ones within the development-phase – are pilot facilities through which producibility can be validated [56]. Besides that, acquisition of technical as well as business personnel plays a major role. As mentioned before, the **financial requirements** in the VoD-phase are high, making venture capital funds with a Deep Tech focus highly relevant [45,22]. Public funding is scarce within this phase. Nevertheless, concepts of partly public VCs supporting high-risk Deep Tech projects do exist [22]. By applying the concept of acquisitions, industrial actors play an additional role in financing. Since they are naturally risk-averse, the financing tickets are comparably low in this still critical phase [57]. In summary, the **actors in focus** within the phase VoD of Deep Tech Innovations are industrial corporations, technology transfer offices, boutique VCs as well as the team scaling the Deep Tech in form of start-ups or spin-offs.

Industrialization of Deep Tech Innovations

The industrialization-phase formulates the last one within the technology transfer process for Deep Tech. The **focus** lies on the ramp-up of production processes, a broad market launch and ongoing technology and product optimizations [49,22,44,50]. With these elements successfully implemented, the **target state** consists of an ecosystem-readiness of the Deep Tech [49] including a broad usage in different industries leading to the effect of spillovers [36]. To ensure such ecosystem-readiness, **knowledge** in multiple areas needs to be applied. Overall, scale-up know-how in the fields of business as well as production is required [50]. Especially production scale up in Deep Tech is accompanied with high trial-and-error-costs.

Furthermore, the organization does grow significantly within this phase. Professional organizational structures including general management capabilities need to be implemented [49]. These organizational changes come amongst others along with a need for production facilities, sales networks, mature HR teams as well as supply chain managers in the field of **resources and infrastructure** [55]. In this last phase, the **financial requirement** is extremely high. All common mechanisms of the financial market can be applied (e.g., stock market, private equity, corporate venture funds, commercial dept, M&A) [45,22,44]. Therefore, the **actors** of the financing market play an important role within the industrialization phase. Furthermore, industrial partners have a strong influence and need to ensure the fit of Deep Tech into existing production mechanisms and supply chains.

The overall findings and therewith the completed reference phase model for Deep Tech are presented in Figure 6. Therein, the descriptive characteristics as well as the requirement categories identified within literature are mapped to the respective phases following the derived reference model structure.

		DISCOVERY	DEEP TECH DEVELOPMENT	VALLEY OF DEATH	INDUSTRIALIZATION
DESCRIPTIVE CHARACTERISTICS	**TRL**	▪ 1-3	▪ 4-5	▪ 6-7	▪ 8-9
	FOCUS	▪ Fundamental technology research	▪ Market-oriented technological application ▪ Access to the IP-related options	▪ Market focused product and business development	▪ Start of production ▪ Market launch ▪ Technology and product Optimization
	TARGET STATE	▪ Proof of concept in form of a patent ▪ Defined core team	▪ Technology validation with early Prototype ▪ Defined value proposition and initial business model	▪ Saleable product ready for series production ▪ Mature company with product market fit	▪ Ecosystem readiness of the Deep Tech
REQUIREMENT CATEGORIES	**KNOWLEDGE**	▪ Scientific knowledge ▪ Understanding of potential markets and of business and technical needs ▪ Know how on public funding and support mechanisms	▪ Operational technological understanding ▪ (Agile) prototyping capabilities ▪ Competencies in the areas of IP and business development	▪ Business adhesion and business model development ▪ Agility to set-up and refine MVP ▪ Industrialization competencies ▪ Knowledge about financing opportunities	▪ Readiness of the corporate organization and structure ▪ Scale-up expertise in business and production ▪ General Management capabilities
	RESOURCES AND INFRA-STRUCTURE	▪ Experimentation labs ▪ Scientists	▪ Experimentation labs ▪ Scientists ▪ Technology-transfer offices ▪ Intellectual property ▪ Prototyping facilities	▪ Technology-transfer offices ▪ Pilot facilities ▪ Technical and business personnel ▪ Offices	▪ Management team ▪ Production facilities ▪ Sales networks ▪ HR teams ▪ Supply chain managers
	FINANCIAL REQUIREMENTS	▪ Public scientific funding bodies based on scientific knowledge ▪ Governments	▪ Semi-public funds ▪ Angel investors ▪ High-risk venture capital funds	▪ Boutique venture capital funds with a focus on Deep Tech ▪ Partly public venture capital funds ▪ Acquisitions	▪ Private equity ▪ Public shares ▪ Corporate venture funds ▪ Commercial dept ▪ Mergers and acquisitions
	ACTORS IN FOCUS	▪ Universities ▪ Research center ▪ Industry Labs	▪ Deep Tech start-ups ▪ Academic and industry spin-offs ▪ Angel investors ▪ Venture capitalists ▪ Accelerators and incubators	▪ Corporations ▪ Technology-transfer offices ▪ (Boutique) venture capitalists ▪ Development Team of start-ups and spin-offs	▪ Corporations ▪ Actors on the financial market (venture capitalists, banks, …) ▪ Deep Tech start-ups

Figure 6: Descriptive characteristics and requirement categories along the four stages of the reference model defined

5. Conclusion and Future Research

The present contribution shows that Deep Tech-specific technology transfer strongly differs from common technology transfer processes. In particular, the phenomenon of the VoD is highly relevant for Deep Tech innovations and therefore of importance when defining reference phases. Furthermore, the complex value chains and ecosystems within Deep Tech development and industrialization have strong influence on the phases. Taking the Deep Tech characteristics into account, four reference phases were set up and described along three descriptive characteristics (TRL, focus, target state) and four requirement categories (knowledge, resources and infrastructure, financial requirements, actors in focus). The analysis and synthesis show that the requirements within the single phases do highly change due to an adapted focus and target state over the technology transfer process. The reference phase model for Deep Tech transfer developed in this paper represents an important step for the derivation of governmental support option for specific Deep Tech initiatives. When it comes to supporting Deep Tech during the transfer process, it is important to take the different situations and characteristics identified within this paper into account.

Although the model developed is based on existing technology development concepts and definitions, it requires a practical application validation following phase V of the reference process from SCHÜTTE. The validation of the reference phase model can be carried out by conducting a retrospective case study analyzing successfully developed Deep Tech. Furthermore, an interview study with several researchers and founders over various TRLs can be set up to validate the findings. As the presented work is part of a doctoral thesis, the phase-specific derivation of governmental support options for the transfer of Deep Tech will be further elaborated. The reference phase model presented within this paper will function as important guideline for future research and application.

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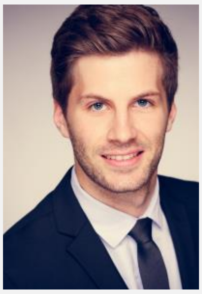

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