# Comprehensive Technology Exploitation Using System Dynamics

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***Abstract*--Extensive exploitation of technology is strategically planned so far only in very few research institutions and companies. Thereby a great technological as well as economic potential remains untapped. A major reason for the neglect of the exploitation potential is that a situational assessment of exploitation opportunities throughout the entire technology life cycle has not yet been systematically explored. Although individual aspects of the problem were treated, a comprehensive model considering all relevant variables, such as the technology to be exploited, the specific objectives of the research and development project and the relevant factors of the environment of the exploitation situation, has not yet been developed. In addition, the change of these factors should be taken into account throughout the technology life cycle. In order to achieve this goal all relevant variables for the exploitation decision have to be described in sub-models and later combined in a multi-attribute decision model.**

**Based on a first framework presented prior by the authors, the intended contribution of the present paper is to develop a deeper understanding of the interdependencies between the key influential factors of the exploitation situation as well as the considered sub-models. Thereby the expected developments of the sub-models for the used System Dynamics model can be modeled.**

## I. INTRODUCTION

The lack of a missing methodology for the exploitation of technologies is seen both in development projects of research institutions as well as in the industrial practice [1]. Researchers and developers face many problems how to exploit newly developed technologies (both product and production technologies) to the maximum. Often technologies are researched and developed to application readiness without analyzing and planning their comprehensive subsequent exploitation by various strategic options in advance [2, 3]. Although the ever-increasing number of annual patent applications shows which technological potential is created each year by research projects [4], this is currently used only by large, internationally active companies like Procter & Gamble and Texas Instruments [5, 6]. Fig. 1 shows exemplary the potential exploitation which frequently goes unused over the life cycle of a technology used exclusively by the organization which developed it. Collaborative ventures, licensing or sale of the technology are examples of different means of exploiting technologies profitably. This permits a significantly higher return on the very high research and development investment.

The main reason for ignoring the potential is that up until now there has been a lack of a methodology capable of steering the selection of options relating to the exploitation of a given technology over its entire life cycle. Especially the complexity of the interactions among the factors which influence the decision regarding best possible utilization has not yet been investigated. Hence, the objective of the paper is the elaboration of a methodology for planning technology exploitation over the whole technology life cycle. Therefore, an overall framework as well as the distinct models needed, will be developed.

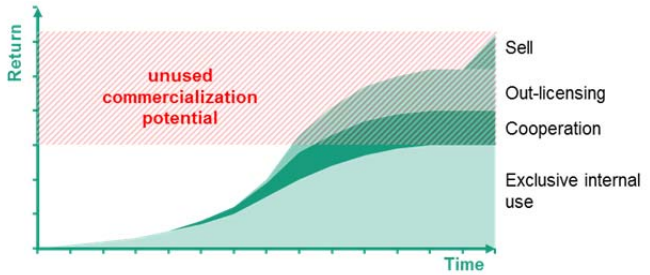


Figure 1: Unused potential when technologies are exclusively used in the foreseen domain

After an overview of the relevant literature concerning technology exploitations the concept of the methodology is explained and the different models are described. Furthermore, limitations in current research and open points for future research are discussed

## II. LITERATURE REVIEW

The problems surrounding inadequate exploitation of technologies were described scientifically more than three decades ago. The introduction of the term “technology marketing“ by Ford and Ryan in particular, aroused interest within industry in the subject of technology exploitation [7]. One of the fundamental principles underlying subsequent theoretical debate about the decision-making process relating to technology exploitation was likewise developed by Ford and Ryan in 1981 in their technology life cycle model. The reconciliation between the characteristics of individual life-cycle phases and the features of various options for exploitation was a major contribution at that time [8]. However, the model presented by Ford und Ryan is comparatively simplistic and does not do justice to the complexity of the decision-making process, because characteristic elements in the technology to be exploited are absent. In the following the main contributions to technology exploitations are highlighted briefly, a comprehensive review of the existing literature has already been made by Schuh and Bremer [9].

Mittag described in detail a process for marketing technology; however, he focusses on the practical implementation of out-licensing rather than on the selection of scenario-based options for exploitation [10]. Wolfrum as well as Boyens develop a more comprehensive approach to the problems relating to technology exploitation. But both consider only a

few factors which influence the complex decision-making situation [11] [12]. Sullivan approaches the subject of technology exploitation pragmatically and developes a decision tree for technology exploitation [13]. The approach provides good starting points for the research method although a number of factors which influence the decision and changes in the influencing factors over time are disregarded.

Brockhoff states that the decisions involved in technology procurement are too complex to be replicated fully in straightforward technology portfolios [14]. It is likely that this also applies to the exploitation decision. Brockhoff also shows that standard methods currently used, are unsuitable for the applications for which they are required and that market-oriented criteria should be adopted in the decision-making models in addition to the frequently technological criteria [15]. Teece suggests a process for deciding on the type of technology exploitation to be pursued using a flow chart to extrapolate recommendations for exploitation as a function of defined influencing factors [16]. Ford and Saren replicate the decision situation in the exploitation, thereby making a contribution to the theoretical description of technology exploitation. However the model does not do justice to the complexity of the decision [17]. Arora et al. restrict their observations to licensing as a means of technology transfer. However the arguments in favor of strategic orientation of companies in order to capitalize more on technology potential by licensing can be addressed within the research method [18]. Birkenmeier draws up a further frame of reference for the exploitation decision by describing the technology, the customers and company characteristics and goals in detail, as factors which influence the decision-making process. He restricts his view to external technology exploitation as an independent option for action, thereby leaving the interrelationships between various exploitation options such as joint-venture, spin-off, licensing or sale unresolved [1]. Lichtenthaler reinforced the relevance in practice of the subject of technology exploitation in an empirical investigation of 154 companies [19]. He develops a theoretical management concept for external technology exploitation. Anokhin et al. develop a model for the classification of unused technologies in the technological environment of a company. They differentiate between the four exploitation options of internal use, collaboration, spin-off or sale [20].

The author himself has already contributed publications to the topic of technology exploitation. Relevant influential factors on the exploitation situation were identified and a decision making model was designed on the basis of the AHP (analytical hierarchy process) was presented. Nevertheless, the extension of this model towards a dynamic approach taking into account the constant change of influencing parameters over the life-cycle of the exploited technologies has not yet been developed [21] [22] [23].

Other authors have addressed the exploitation of technologies, yet every one of them has examined one option for exploitation in isolation e.g. licensing [24] or has analyzed only a very limited number of factors which influence the decision as to whether or how to exploit a technology [25] [26] [27] [28]. Methods of evaluating the benefits of different technology exploitation options such as internal use, collaboration, licensing, spin-off have been marginalized in all previous publications [1] [16].

All major works relating to the research method outlined here are listed in Fig. 2, classified according to their research focus. The treatment of subjects within the categories "object of exploitation", "process description" and "user group" (subject) was evaluated. The technology-exploitation decision-making process which will be developed has not previously been described in any detail either. Although individual aspects have been investigated by various authors, there has, to date, been no holistic approach. The on-going lack of an integrated approach is particularly clear at subject level.

Although there have been some tentative approaches to developing a systematic methodology of evaluating technology exploitation options, there has not yet been a comprehensive methodology to support the exploitation decision-making process. The existing approaches do not do justice to the complexity of the exploitation decision but nevertheless can be refined and integrated within a holistic problem solving approach. The decision models developed by Ford, Teece, Sullivan, Boyens and Wolfrum in particular, offer concrete starting points for structuring the investigated topic.

## III. DESCRIPTION OF THE MODEL CONCEPT

### *A. Objective of the paper*

A scenario-based methodology for planning a technology exploitation strategy is aspired in order to address the described shortcoming. The goal underlying the development of this methodology is to support users of a technology in such a way as to provide them with a tool which will permit them to recognize the full potential of a technology and to exploit it systematically. The methodology will consider both internal and external influences on the decision-making process as well as the goals of the decision-making authority. Changes in the related fields of target markets, technological properties and characteristics of the exploiter will be taken into account and integrated accordingly in the model.

It is anticipated that the methodology will support research facilities and technology-oriented companies in the drive to exploit newly developed technologies systematically and more thoroughly than has previously been the case. The goal is to ensure that not only are these technologies deployed in the primary area of application for which they were intended but that they are also accessible to as many different stakeholders as possible. Companies can apply the methodology in order to increase the profitability of high-cost development methods or even to help to finance them in the first place.

### *B. Concept for the method developed*

The model theory, supported by the systems engineering process in generating models, has proved to be a useful tool

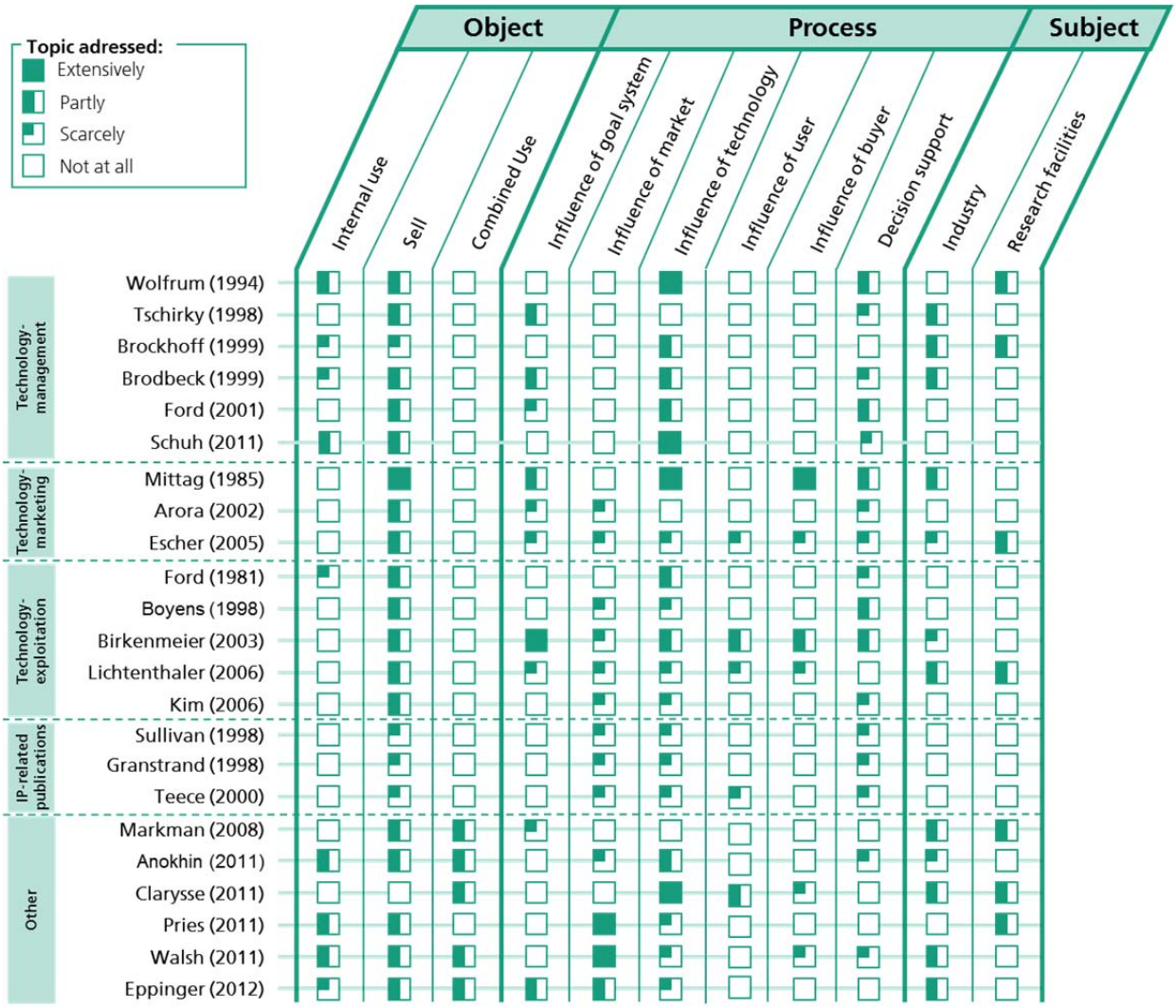


Figure 2: Evaluation of the different approaches described in the literature

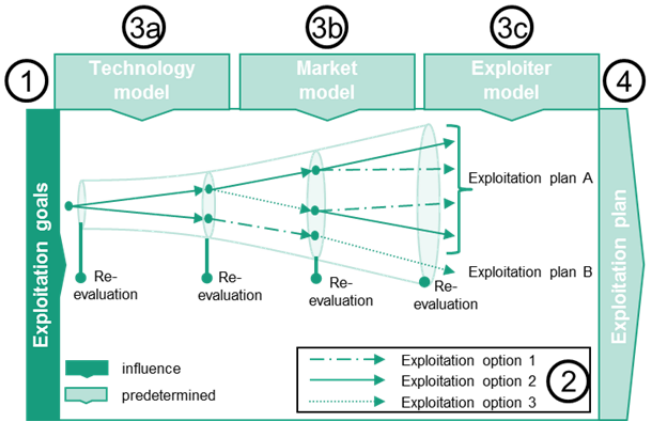


Figure 3: Scheme of the exploitation situation

in replicating complex sets of facts in scientific practice [29] [30] [31] [32] [33]. It is anticipated that due to the complexity of the initial situation, detailed models of the key influential factors are crucial for the accuracy of the method presented. Therefore, the dependency of the models describing the technology, the markets and the exploiting organization will have to be identified and taken into account in this model. In addition, a system of goals developed by the exploiter must be incorporated in the decision process. Since the methodology to be developed is intended to take account of future contextual developments in evaluating the options for exploitation, a facility for the simulation of these developments over a specific period of time, will be included in the model.

The basic exploitation situation can be divided into four modules as illustrated in Fig. 3. The starting point in the first module is a system of the exploiter's goals. This model includes generic goals relating to technology exploitation which can be weighted in accordance with the initial situation or point of departure, in the form of a description model. In the second module, the individual exploitation options, some of which have previously been investigated scientifically, will be compared and contrasted in a description model. In the

third module, the technology exploitation situation will be characterized via a technology model, a market model and an exploiter model, taking account of developments over time. Interactions between the three sub-models in the third module will then be systematically explored and described. The fourth module, the exploitation plan, will be the outcome of a decision model which sets the three previously described modules in context to one another, permitting various exploitation scenarios to be evaluated in terms of the specific exploitation objectives.

**Module 1: Exploitation goals**

The generic system of goals is intended to include goals defined specially for the exploitation decision as well as related and higher-level strategic goals drawn up by the exploiting organization so that the options for exploitation can be evaluated within the context of the general goals of the research facility or company concerned. The related and higher-level goals might include goals relating to specialist areas bordering on R&D such as Production, Marketing, Sales and Procurement as well as farther-reaching goals and objectives. Different approaches to the development of a system of goals are described in the various areas of specialist literature. [1] [10] [15] [34] [35] [36]. Examples for those goals are the establishment of a technology leadership, the minimization of risk and expenditure when exploiting technologies or the maximization of net returns realized with the exploitation (compare Fig. 4). Since all options for exploitation will be evaluated in terms of the contribution they make towards achieving certain goals or targets, it is essential to ensure that there are no goals which are surplus to requirements.

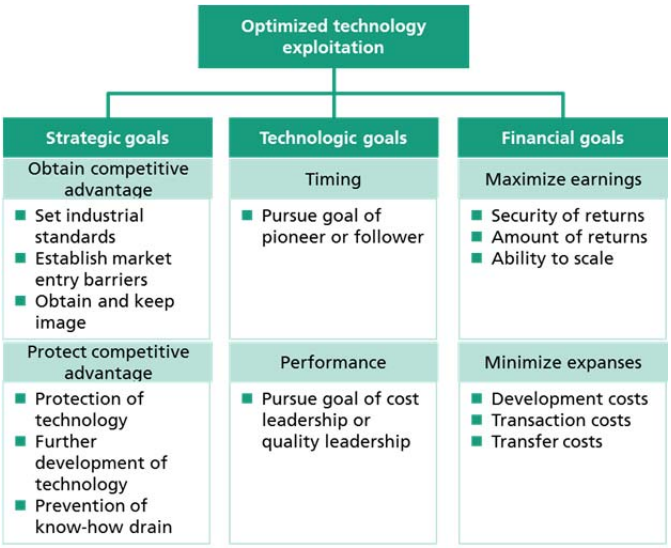


Fig.4: Goals of the optimized technology exploitation

**Module 2: Exploitation options**

The exploitation options available to the organization will be identified, structured and evaluated in terms of the strengths, weaknesses, opportunities and risks in this module. The resultant description model will therefore encompass the area in which the solution to the exploitation issue is to be found. A profile will be drawn up of the specific strengths and weaknesses of each exploitation option. This will be done via a SWOT (strengths, weaknesses, opportunities risks) analysis and will create a basis on which the various options for exploitation can be evaluated in terms of the technology, market and exploiter-specific influence they exert and in terms of the contribution they make towards achieving the goals of the organization.

On the first level, a distinction can be drawn between internal and external forms of exploitation. Internal technology exploitation relates to the use of the existing technologies in a production environment within the organization which developed them. Within the framework of the strategy model, it will be important to investigate whether further distinctions can be drawn between various options for internal exploitation. In contrast, external technology exploitation describes the commercialization of technologies outside the boundaries of the research facility or of the company. There are various approaches in the literature, which can serve as a structure for the research method proposed here. The majority of the authors classify options under the headings shared use, licensing and technology sale. The last two external options for exploitation are independent exploitation evaluations which probably require no further subdivision. Shared use, however, is a group of exploitation options which can be further subdivided into joint-venture, strategic alliance, R&D collaboration and, in some cases, franchising. It will also be important to consider the possibility that it may make good sense strategically, not to initiate any exploitation for a while in order to revisit the decision regarding exploitation at a later date under different boundary conditions.

The outcomes of the exploitation options sub-model are diverse internal and external options for technology exploitation which can be selected in the course of technology commercialization. The possible exploitation options are illustrated in Fig.5. The specific characteristics of the exploitation options must be described in order to be in a position to evaluate the influence exerted by various contextual factors in subsequent modules. Moreover the options must be characterized so that the benefit contributed by each of the exploitation options to individual goals within the system of goals can be identified.

Modeling the interactions between the different forms of exploitation will be particularly challenging. It is vital that these are modeled since the goal of the research method is to develop a methodology for the creation of a long-term exploitation plan. Consequently, it is essential to take account of the outcomes of simultaneous, parallel or purely sequential use of several exploitation options.

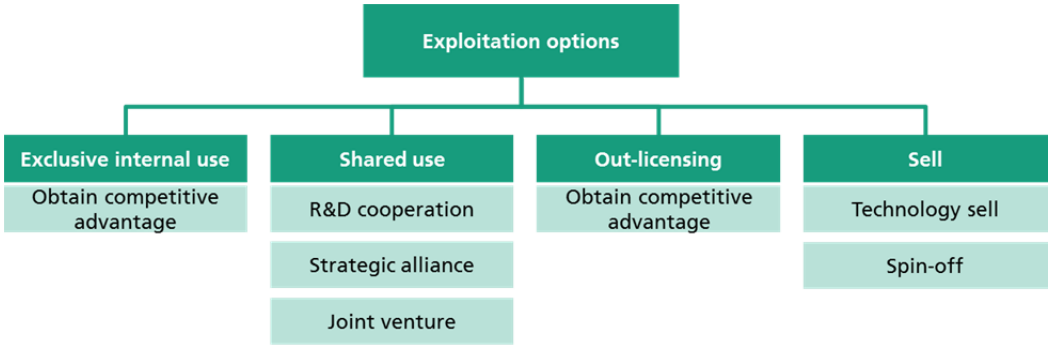


Fig.5: Possible Exploitation Options

**Module 3: Context model**

The context model consists of technology, market and exploiter models. The contextual factors can be regarded as the moderators of exploitation planning which influence the evaluation of the contribution made by the exploitation options to achieving the goals of the organization concerned. The description of the interdependencies assumes a particularly important role due to the complexity of the sub-models and of the likely interactions between them. It can be assumed that the three sub-models identified are interwoven with one another in a range of diverse ways. However, before an explanatory model of these interactions can be designed in the form of a model which simulates interdependencies, it will be essential to develop each sub-model individually as a description model.

To achieve this, all of the exploitation options will have to be evaluated on the basis of the influencing factors identified, in terms of the contribution they make to achieve the goals of the exploiting organization. Only partial evaluation of the diverse options for exploitation in a situational context can be extrapolated from the literature. It will therefore be essential to conduct case studies showing the conditions under which decisions relating to exploitation were made in the past and how these decisions would be evaluated retrospectively. It is anticipated that the findings will subsequently be verified in discussions among experts.

The sub-models must describe the characteristics of the technology, the markets and the exploiters over the entire period of time under consideration. This is of vital importance in view of the need to plan exploitation options over the entire life cycle of the technology. Special consideration must be given to uncertainties and dynamic developments.

**Module 3a: Technology Model**

The goal of this model is to identify the principal technological factors which influence the exploitation planning process. There are several approaches in the literature, to which reference can be made in the course of the research method, e.g. [1] [11] [39] [40].

The overview in Fig. 6 shows that there is a diverse range of technological characteristics which can influence the exploitation decision. On completion of the search for technological influencing variables it will be necessary to analyze the relevance of each one to the decision-making situation in hand. As in the case of the other models, the challenge here is to design to model so as to ensure that it is sufficiently detailed yet practical.

**Module 3b: Market model**

The market model undergoes a multi-stage definition, description and classification process. The area of the market under scrutiny for the technology, on which the methodology is focused, will be defined beginning with the definition of the markets in question. The objective is to define the markets in which the technologies are to be marketed and to use the decision-making model to select a suitable exploitation option for them.

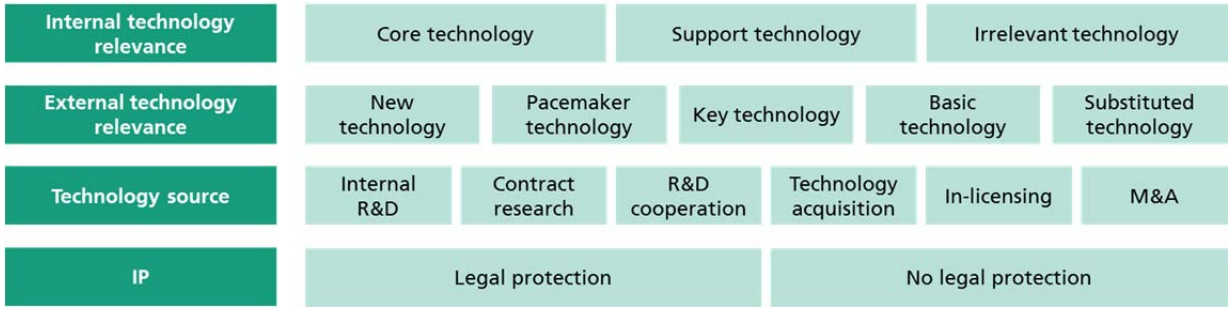


Fig 6: Characteristics for the classification of technologies

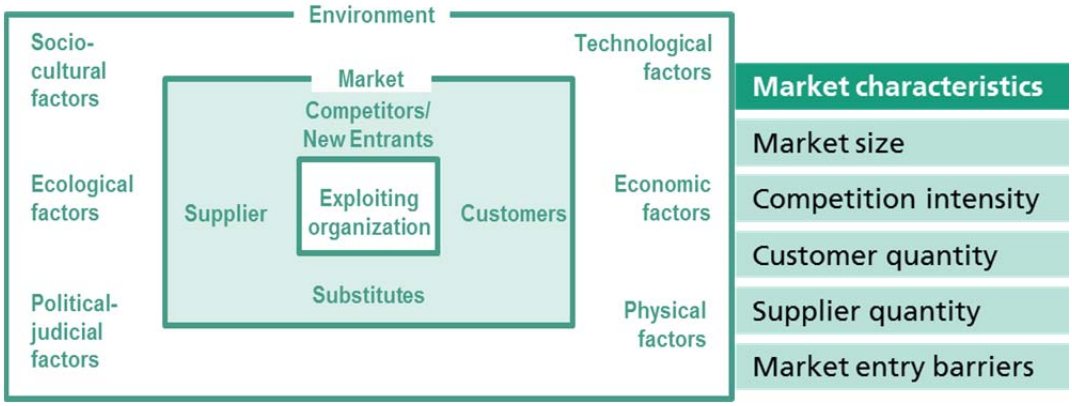


Fig.7: Elements in the immediate and wider environment of the exploiting organization [38]

As soon as the market-related scope of consideration has been clearly defined, it will be characterized using appropriate attributes. There are already a number of approaches to defining and characterizing markets in the literature. Their suitability will be investigated prior to incorporating them in the market model if they are found to be useful [1] [18] [19] [41]. An overview of factors and moderators from both the wider environment and the provisional target market which are of relevance to the exploiting organization is presented in Fig. 7.

**Module 3c: Exploiter model**

The exploiter model describes the specific exploiter characteristics which are relevant to the evaluation of the different options for exploitation. There is a wide range of approaches to characterizing companies or research facilities as the exploiters of a technology. As is the case with other sub-models, however, the question arises as to which influencing factors actually influence the exploitation decision. It is therefore essential, as in the case of the market and technology models, to first identify possible characteristics and then condense them down until only those which exert influence on the exploitation decision are left. There are only a few references in the literature relating to technology exploitation and the related disciplines to the influence exerted by the characteristics of the exploiting organization on exploitation planning [1] [16] [37] [38]. Possible Characteristics of the exploiting organization are illustrated in Figure 8.

The structural presence of the exploiting organization in the markets in which they operate, their financial resources or their industrial contacts are among the examples of variables which would influence the form that the exploitation of a technology might take. In cases where production is on-going within a selected geographical sphere of interest, it might be assumed, for example, that internal exploitation of the technologies can be more easily accomplished than in cases in which there is no production structure in the selected area of interest. This thesis will be among those formulated and tested on the basis of case studies and in discussions with experts.

**Module 4: Exploitation plan via System Dynamics and Scenario Technique**

The decision model for the selection of suitable options for exploitation is at the core of the exploitation model outlined. Once all factors which influence the exploitation decision have been modeled, it is vital to analyze interdependencies among the sub-models and then transfer the individual models to a holistic decision model. The model should take account of the exploiter-specific goal system as well as the contextual factors as moderators.

It can be assumed that the chronology of the context model and the goal model will seldom be static. In order to take account of this, it will be important to ensure that the moderators of the exploitation situation defined in the context model are designed to be variable. When these moderators are varied over the course of the planning period, changes may arise in the suitability of various options for exploitation. It is anticipated that the prognoses for the context factors will form a basis which will permit exploitation plans covering the entire life cycle of a technology to be developed.

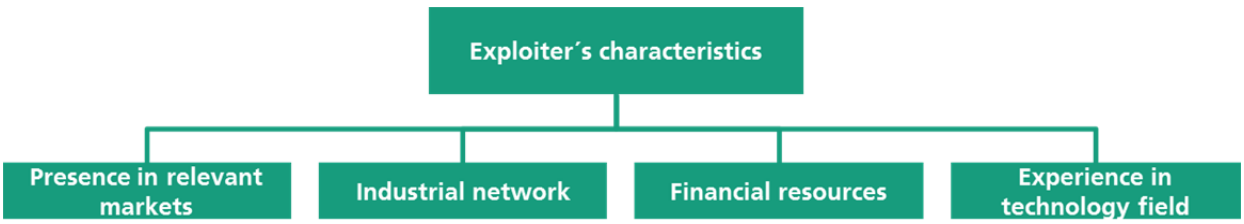


Fig.8: Characteristics of the exploiting organization

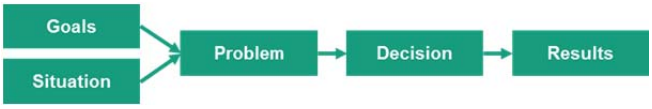


Fig. 9: Linear view of the world [45]

For the described purpose, the System Dynamics approach has proven to be suitable since it supports the assessment of decision options in dynamic surroundings [44]. The approach widens the linear view of the world as presented in Fig. 9 towards a more extensive, holistic model of the decision situation. The main feature of the System Dynamics approach is the consideration of the initial situation not as an unchangeable status but as a changing, interactive environment. This is represented by the several feedback loops between the decisions to be taken and the environment shown in Fig. 10 [45].

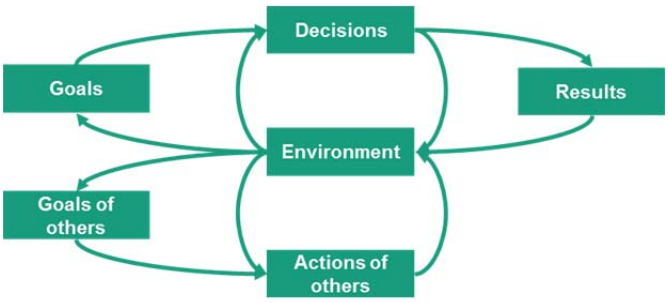


Fig. 10: Feedback view of the world [45]

The System Dynamics Approach consists of three process steps [44]:

- Design of cause and effect relations
- Transfer to a flowchart
- Formulation of a system of equations

The cause and effect relations have to be deducted from interrelations between the individual models described before. It was mentioned that the dynamic environment is crucial in the simulation of the benefit generated by the various possibilities of technology exploitation. Hence, the dynamics is the central element connecting the sub-models. The generic System Dynamics approach can be adopted in the elements of goals, decisions and results. The goals correspond to the exploiter-specific goal system of module 1, the decisions are the exploitation options of module 2 and the environment consists of the three sub-models of module 3. Finally, the desired optimized exploitation path as objective of this research is the result of the model. As shown in Fig. 8, the environment of the original System Dynamics model has to be divided into the three sub-models of technology, exploiter and market with the market being influenced by the actions and goals of competitors.

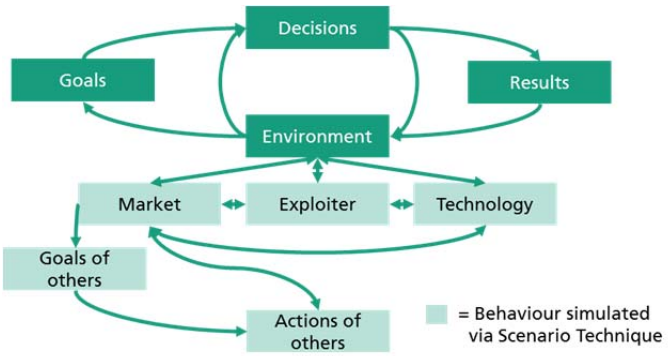


Fig. 11: System Dynamics adapted to the exploitation situation

The development of these influential factors has to be simulated. Scenario Technique has proven broadly accepted within the scientific community for the simulation of uncertainties and discontinuities in economic models [46]. In this model, a broad range of scenarios for the behavior of the key influencing variables and moderators as defined in module 3 has to be defined. Therefore, the process of scenario creation as defined by Gausemeier has to be carried out [47]. A long list for potential key influential factors for the market and technology model has been given in model 3a and 3b earlier in this chapter. Key influential factors for the exploiter have not yet been discussed extensively in literature and are the focus of further investigation. However, in model 3c there are given some possible key influential factors for the exploiter. The resulting scenarios, finally, will provide input in form of the environment for the System Dynamic model as shown in Fig. 11.

At this point, first the actual model will be further deepened, which is to be erected with the help of System Dynamics. The appropriate factors for market, exploiter and technology must be detailed in the next step. Figure 12 shows a detailed picture with exemplary elements and interdependencies. On the one hand there are the influence factors of the environment for the exploitation decision, which are already described in the models 3a, 3b and 3c.

On the other hand there are the factors which are getting influenced by the decision, i.e. the chosen exploitation option. This is considering the first feedback loop and is not necessarily targeting the same factors as mentioned in the first step. The third step is the development within the environment which results out of the changed factors after the chosen exploitation option.

**Step 1**: defining key factors (A) influencing the exploitation decision

**Step 2**: defining key factors (B) which are influenced by a chosen exploitation option

**Step 3**: influence of key factors (B) on key factors (A)

Step 1, the key factors which are influencing the exploitation selection, is already done and briefly explained in the models 3a, 3b and 3c. Step 2 is the next issue for future research. It is describing the impact assessment of a chosen

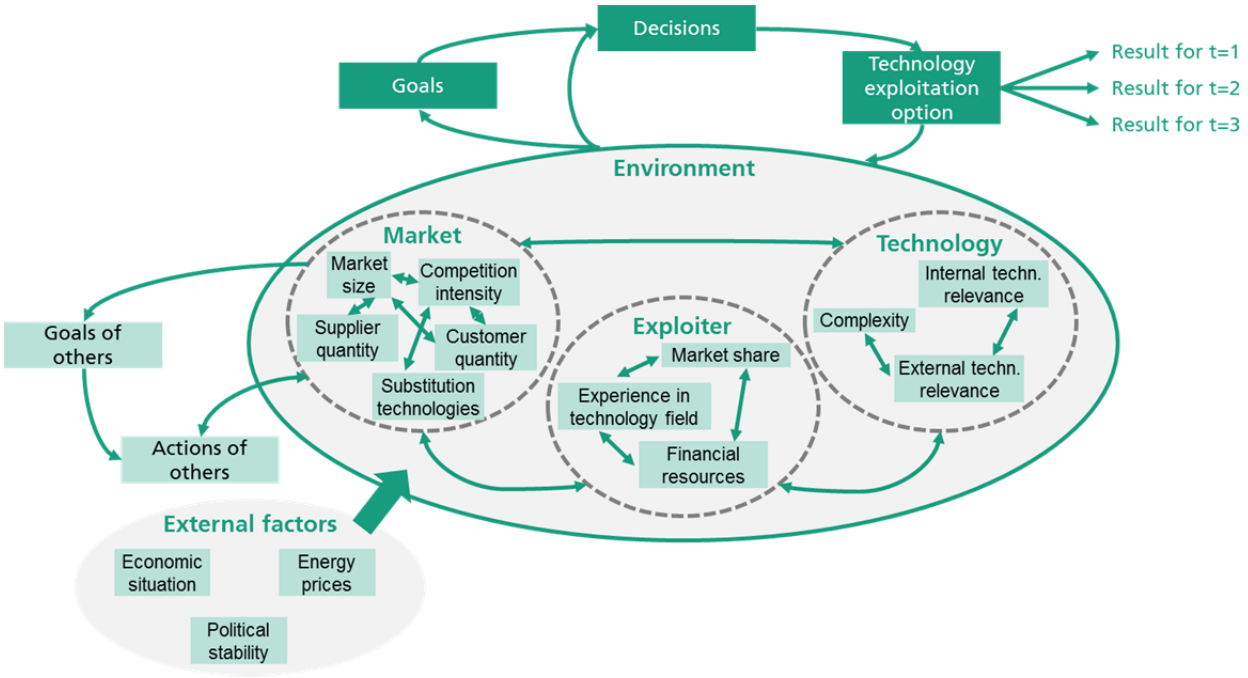


Fig. 12: System Dynamics adapted to the exploitation situation with exemplary influence factors

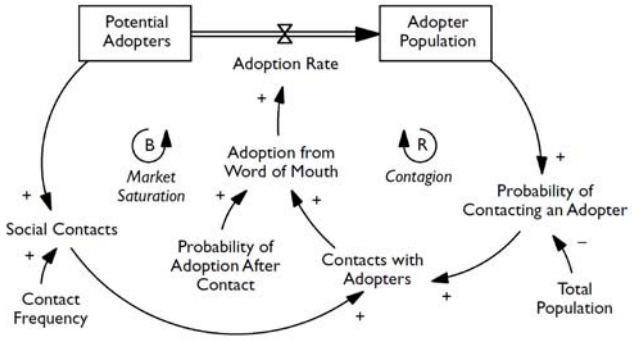


Fig. 13: Exemplary causal diagram showing Stock and Flow Structure [45]

exploitation option on the three context factors market, exploiter and technology, which are representing the environment of the System Dynamics model. As an example, the market model is to be considered more detailed. When the exploiting company has chosen an exploitation option using the decision making model, the decision re-influences the conditions of the different market elements. This could be e.g. the market size, the competition intensity, the quantity of suppliers and customers as well as the quantity and success of substitution technologies. Depending on whether the exploiter chooses an internal exploitation or licensing, it is conceivable, that e.g. substitution technologies develop in a different way. If the technology is licensed, it is more likely that other market player will use the same technology instead of developing an alternative one. Hence, the number of substitution technologies would decrease or at least remain constant. Step 3 considers the evolution and changes within the environment, i.e. within the market, the technology and the exploiter. Step 2 and step 3 have to be simulated with equations, which reflect the causal relationship between the factors.

Figure 13 shows an example, how Sterman illustrates a causal diagram. The arrows in the diagram indicate the causal relationships with the positive signs at the arrowheads indicating that the effect is positively related to the cause and the other way around [45]. These relationships can be constituted with model equations, which can later be implemented in an automated calculating tool. The equations for the exemplary causal diagram would be:

*Adoption Rate = Adoption from Word of Mouth [ + Adoption from Other Sources]*
*Adoption Word of Mouth = Contacts with Adapters X Probability of Adoption After Contact*
*Contacts with Adopters = Social Contacts X Probability of Contacting an Adopter*
*Probability of Contacting an Adopter = Adopters / Total Population*
*Social Contacts = Potential Adopters x Contact Frequency*

The next step of research is to define the factors inside the sub-models of the environment, market, exploiter and technology, and to form the equations similar as the example given. With the influences within the environment model given, the next decisions for exploitation options can be made.

In addition to the simulated influencing factors, it is important to take account of the fact that the chronology of the recommended options for exploitation must be included in

the model. This means that when the results of the model are simulated, account must be taken of the fact that the sale of a technology at an early stage rules out further exploitation, for example. Simulating these interactions is one of the challenges to be overcome in the feedback loops between decision, results and environment. There has been no previous input in the field of technology exploitation or in any related disciplines in relation to this problem. It will therefore be necessary to develop a suitable logic, deduct formulas and verify them with the help of experts.

The result of the exploitation model will be an exploitation plan as the outcome of a simulation of the exploitation situation. The exploitation plan shall contain detailed information on how to reasonably exploit one`s technologies in a changing surrounding. With the help of this plan the user will know how to act (which exploitation option) and when to act (which scenario promotes which way of exploitation). The exploitation plan will be optimized with regard to the individual goals of the user. Furthermore, the method will enable the user to test the robustness of his exploitation strategy against the occurrence of the scenarios designed in the model. To permit such a high level of detail, the presented model has to be expressed via formulas and a specific system of user goals has to be defined. These issues will be the topic of further research.

## IV. CONCLUSION

In order to deduct reasonable decisions for the exploitation of technologies over their lifecycle it is necessary to take into account a broad range of influential factors. The specific goal system of the exploiting organization, the characteristics of the technology, the market and the exploiter as well as the different possibilities of commercialization are the key elements in technology commercialization.

In this paper a method based on System Dynamics was presented in order to model the exploitation of technologies considering the whole technology lifecycle. Therefore, the state of the art in the field of technology exploitation was presented via a literature review. Based on the assumptions of past research, a framework for the modeling of commercialization situations of technologies was presented. Various expected interactions between influential variables of the exploiting entity, the market and the external environment on the benefit of different commercialization strategies were related to each other in this framework via the System Dynamics approach. Scenario Technique can help modeling the expected developments of the key influential factors for the System Dynamics model.

Anyways, the interdependencies between the key influential factors of the exploitation situation still have to be modeled in detail with help of the System Dynamics approach. The formulation of an equation system simulating those interdependencies is the subject of further research. Nevertheless, the combination of System Dynamics and Scenario Technique for the evaluation of the benefit created by different ways of technology exploitation over time looks promising to cope with the high level of uncertainty typical of the research topic.

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