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FRAMEWORK FOR SUSTAINABLE ORIENTED TECHNOLOGY DEVELOPMENT

Kurt Gaubinger[1], Fiona Schweitzer[2], Rahel Zweimüller[3]

University of Applied Sciences Upper Austria, School of Engineering and Environmental Sciences, Stelzhamerstrasse 23, A-4600 Wels, Austria
Email: [1]kurt.gaubinger@fh-wels.at; [2]fiona.schweitzer@fh-wels.at; [3]rahel.zweimueller@fh-wels.at

Abstract. This paper shows that companies can increase the effectiveness and efficiency of development activities by using process models that integrate sustainable orientation during all phases of technology development projects. An explorative research design was chosen to first define successful process structures and appropriate management tools for technology management, followed by a quantitative pilot study to identify key success factors for technology development projects with a particular focus on sustainable aspects. These data and the theoretical insights form the basis for the conception of a sustainable-oriented technology development framework, which demonstrates how a technology development process should be typically structured and how management tools should be adapted in the particular process steps to enhance sustainable orientation of the technology development activities.

Keywords: innovation management; technology development; sustainability, process orientation.

Jel classification: O32

1. Introduction

Technological innovations are increasingly significant for the sustainable success and livelihood of firms (Schuh *et al.* 2010). However, in times of steadily growing global competition and rapid technological change it becomes more and more difficult to create technological innovations and successfully bring them to market (Ahmed, Shepherd 2010). Moreover global problems, for instance environmental pollution, climate change and shortage of resources aggravate this situation. If a company wishes to ensure and enhance the sustainable orientation of research and development activities, process-related planning and the implementation of sustainable aspects take on an increasingly important role in addition to the systematic and strategy-orientated development of technology.

A number of books and articles, dealing with the topic of technology development (TD) have been published in recent years, but a systematic and process-immanent consideration of sustainable concerns at an early stage have hardly been considered (Cooper, Edgett 2007; Cooper 2006; Strebel 2003; Specht *et al.* 2002).

Against this background the aim of this paper is to establish a sustainable oriented technology development framework, which integrates specific activities in the early stages of the technological development process to increase the sustainability of technology development projects. Because of the high economic importance of the automotive supply industry in Europe (Eurostat 2006), the conceived framework specifically targets the particularities of this industry.

In order to reach the research objective a two step approach was choosen. First an explorative study was conducted to define successful process structures and appropriate management tools for technology management. This explorative study was realised by qualitative research using a semi-structured questionnaire. Based on a two-step probability sampling process, 14 persons from companies with outstanding records in technology development were selected for face-to-face semi structured interviews guided by open-ended questions. In a second step a quantitative pilot study was carried out to identify key success factors for TD activities with a particular focus on sustainable aspects. The basis of this study was a standardised online survey with 120 individual questions (N: 360; response rate: 12 %). The results of these studies and the theoretical insights form the basis for the conception of a sustainable-oriented TD-framework , which demonstrates how a TD process should be typically structured and how management tools should be adapted in the particular process steps to enhance sustainable orientation of the TD activities

2. Theoretical background

2.1. Process oriented technology development

In many cases the outcome of TD projects exhibits new correlation effects between the natural sciences and technical advancement (Strebel 2003) and therefore TD projects are often undirected, unfocused and more indistinctly defined than are product development projects (Cooper *et al.* 2002; Vahs, Burmester 2005). Some authors sub-divide the TD activities into the actual technology development process ("applied research") and into so-called advanced development (Specht *et al.* 2002). In principle advance development is responsible for application-oriented further development of new technologies with regard to products and processes of the next or next-but-one generation and in many cases the outcome of these activities are related prototypes (Diehlmann 1998).

Although TD projects represent a small proportion of typical company's development activities, they are often vital to the company's growth and survival. Therefore TD projects have to be selected and managed in a systematic and focused manner throughout a well-defined process model (Cooper 2006). One of the principal objectives of process models is to structure typical tasks in the corresponding field to ensure the targeted application of work techniques, methods and tools (Gaubinger 2009). A well-defined process is transparent for all departments and a common understanding can be developed, which eases communication within the company. Empirical studies (Cooper 2001) show that companies using a well-executed development process are more successful than companies which lack such a systematic approach.

Because TD projects are quite different in terms of risk, uncertainty, scope and cost of typical new product development (NPD) projects (Specht *et al.* 2002; Cooper 2009), these processes have to be different from traditional NPD processes.

There exist a vast number of models which describe the "ideal" product development process (Cooper 1988; Thom 1980; Geschka 1993; Pleschak, Sabisch 1996; Vahs, Burmester 2005; Gaubinger 2009). They vary with regard to the degree of detail. However Cooper is the only author who expanded his product development process model to the so-called front end of innovation (Cooper 2008). Consequently Cooper extended his scope to a systematic TD, which "feeds the NPD process" (Cooper 2009). He developed the "Stage-Gate TD process" which starts with a promising idea and consists of three stages - Project Scoping, Technical Assessment and Detailed Investigation - and four gates that are the Go/Kill decision points (Cooper 2006). Cooper points out in his current publications that the TD process should be iterative and features loops within stages and potentially to previous stages (Cooper 2009).

2.2. Sustainability and innovation

Besides the ongoing trend towards aggravated global competition, environmental and social challenges are increasingly affecting businesses in many industries. Due to this, the desire/need to develop sustainable products is one of the key challenges facing companies in the 21st century (Maxwell, Van der Vorst 2003). Corporate sustainability can be defined as meeting the needs of firm´s present and future stakeholders, such as shareholders, employees, clients, pressure groups etc. (Dyllick, Hockerts 2002). Towards this goal, focusing on short-term profits is not enough to survive in this challenging environment, because stakeholders expect firms to create economic, environmental and social value. Elkington (1997) emphasizes, that these three dimensions are interrelated and they may influence each other in multiple ways. There is wide agreement that the challenges of sustainability conceals risks, but also offers a significant potential for innovations and related business opportunities (Hansen *et al.* 2009). Therefore sustainability aspects must be considered systematically at all stages of the innovation management process, and particularly in the early stages of the process, the so-called "front end of innovation". To structure and asses the sustainability effects of innovations and therefore to better inform management about the search focus for sustainable motivated innovation activities, Hansen *et al.* (2009) have conceptualized a model termed the "Sustainable Innovation Cube" (SIC), which identifies 27 individual areas in which sustainability effects may occur and which can be regarded as targets to be addressed by innovation management. Additionally, the SIC model implies the assignment of sustainability assessment methods to the 27 SIC areas, which guide companies to the right choice of assessment tools (Hansen *et al.* 2009).

The authors of this article assert that only companies, which define sustainability as a main strategic goal, will gain a competitive advantage; however, not without difficulty. Nidumolu *et al.* (2009) points out that most companies go through five stages on the path to becoming sustainable. At each stage companies face different challenges and must develop new competencies to exploit the stage-specific innovation opportunities (Nidumolu *et al.* 2009). The range reaches from the awareness that environmental regulations and norms become an opportunity for innovations via a stronger awareness of efficiency-aspects throughout the value chain and via the development of sustainable products and services to the development of new business models. Stage five goes even further and tend to create “next-practice-platforms” which change existing paradigms.

3. Research questions and methodology

To establish a sustainable-oriented technology development framework for automotive suppliers, the following questions have to be answered: Which steps are crucial to the process of sustainability-oriented technology development in firms of the supply industry, and what tools and methods should be applied to the individual process steps in a sustainably-orientated technology development process?

To answer the research questions, two studies were carried out. First, an explorative research design was used to ascertain successful process structures and suitable management tools for technology management (study 1). Afterwards a pilot study was carried out to identify key success factors for the TD with a particular focus on sustainable aspects (study 2).

3.1. Research design of Study 1

The first study focused on identifying the structures and contexts of technology development activities within companies in the supply industry. As empirical studies on this subject are scarce, an explorative research design was chosen, realized by a qualitative research using a semi-structured questionnaire. The questionnaire comprises five sections: generating ideas, technology development, market-orientation, process-controlling, and organizational context. The sample was drawn in two steps. First, Upper Austrian companies of the auotomotive supply industry with outstanding records in technology development were selected according to a set of criteria (e.g. awards, number of patents). In a second step, people in charge of technology development and pre-development in these companies were identified and approached (e.g. head of R&D, managing director, project team manager). This sampling procedure was chosen to keep the number of blank interviews low and to gather meaningful information (Patton 2002). In total, 14 respondents from 11 companies (8 medium sized and 3 large scaled automotive suppliers) were interviewed in spring 2010. Double-Interviews in a company were used to reduce informant bias (Rudek 2008; Homburg 2007). All interviews were recorded with prior permission and analyzed using the four-step procedure suggested by Lamnek (2005).

3.2. Findings of Study 1

Our exploratory analysis revealed the following four main areas which are crucial for successful technology development activities: (1) strategic Planning, (2) idea management, (3) technology development and (4) commercialization.

Regarding the *strategic planning* it can be noted that in conjunction with the reevaluation and reorientation of the innovation strategy an *annual or semi-annual strategy meeting* is anchored in most companies surveyed. Consistent with the literature the planning activities of the large companies are broader than those of the medium-sized companies. This can be seen from the ways in which information is gathered and, in particular, prepared and the strategic planning instruments, such as technology and innovation portfolios, scenario techniques, technology issue analysis, etc. However, medium sized companies also carry out strategic situational analysis by using analyzing tools like *SWOT analyses*, trend analyses and competitive analyses, although to a lesser extent than the large firms surveyed. In the view of the interviewees these top-down activities are important, to take into account a strategy focused generation of ideas.

In the field of *idea management* it was generally observed that innovative suppliers work not only with internal but particularly with a wide range of external sources of information and ideas. Consistent with Cooper`s research results, *qualitative criteria* are employed at the beginning of TD projects to evaluate technology ideas in interdisciplinary teams. *Checklists*, which enable a systematic approach to idea evaluation, were primarily used as assessment tools. In contrast, decision matrices and purely verbal assessments of technology ideas were seldom used. Differences in assessment also became visible by the numbers of assessment levels, which are undertaken, before ideas were turned into concrete development projects. The empirical research indicates that a two-step evaluation procedure is most popular, where the technology ideas are first assessed by an interdisciplinary team (prioritization), and those ideas that pass the first step are further assessed by the management that makes a selection decision (choice).

According to the research results, it has become evident that during the actual *technology development* a *systematic planning and implementation* of development activities is of major importance for both the reduction in development time and speed up rapid pace of the introductory phase. The findings show that the logic of the Stage-Gate process with fuzzy gates (Cooper 2007) dominates in order to systematize the development activities (n=8). However, three companies surveyed use classical project structure plans for project planning and control, which are similar to Stage-Gate processes again. As a result of the specific characteristics of enterprises the structure of the TD processes provides varied differences. Firstly these distinctions relate to the *number* of process stages, which range from 3 to 13 phases and secondly, they are based on whether a difference was made between TD and NPD projects, or whether the development activities are combined into a single innovation process. In this context nearly all respondents (n=10) share the opinion that a partial systematization of the so-called "fuzzy front end" of innovation is wise in order to give the uncertain innovation contents a higher (rate of) predictability. Despite the individual business differences in TD structures, a *fundamental process structure* for TD could be identified by analyzing the similarities of the companies' development activities. Based on the decision to follow up a technology idea, the steps of TD comprise a *rough project planning* on the part of the interdisciplinary team, a *concept phase* including technical research followed by the phase of *technology development* where tests are carried out. The new technology knowledge is then integrated in *new technology applications*. Output of this phase is a *customized prototype* that builds the fundament for the further production development.

Concerning the *commercialization of new technologies* it can be stated that a clear structuring of commercial activities throughout the development process was rare (n=2). Nevertheless by comparing the survey results a non-formalized, three-step approach was identified. The first step can be denoted as "*strategic market planning*", where all activities are subsumed which aim to assess and specify potential promising markets and the applications of new technologies. After the new technological know-how has been accumulated within the company, the technology is presented to a selection of (innovative) customers, with the aim of starting pilot projects. This activity constitutes the crucial core of the second step "*customer integration"*. Once the functionality of the technology has been demonstrated in form of physical prototypes, other potential customers are contacted through various communication channels in order to increase the awareness level of the new technology in the target market. These activities we subsume under the term "*broad marketing*" which constitutes the third step of the identified commercialization activities.

3.3. Research design of Study 2

The process structures for technology management that were identified in study 1 were used as a basis for the development of an analysis framework for a quantitative pilot study. We developed a survey with 120 individual questions that respondents answered to assess the different input and output dimensions of the technology development framework (the total list of items can be obtained from the correspondent author upon request). All variables were measured using a five-item scale. We used the CMD database to select companies from three relevant industries („automotive supply industry", "machinery engineering" and "manufacture of other transport equipment"). Geographically we concentrated on three Austrian regions (Upper Austria, Salzburg, and Styria) and medium and large sized companies (number of employees > 50). This led us to a total population consisting of 359 companies. A pre-tested standardized online survey and reminders were sent to relevant managers in winter 2010. 44 respondents participated, accounting for a response rate of 12 %. As the total number of participants is low, the Kruskal-Wallis test for three and more unrelated samples (KW) was used for analyses in which case a sample size of 30 and less is sufficient for statistical testing (Ilozor 2009). While representative conclusions can hardly be drawn from this sample size, we understand the study as a pilot for a subsequent larger quantitative study, and its aim is to look for tendencies and first indications in the sample. Our intention was to assess the impact of different technology management variables on technology innovativeness by the KW. For technology innovativeness, we adapted the items used by Gemünden *et al.* (2007) and calculated the overall mean of this items to divide our sample into three groups; „top performers", were the 15% of the sample with the highest scores on technology innovativeness, "low performers" were those 15% who had the lowest scores, and the remaining companies were grouped into the "middle performers" class. In the following exemplary analysis the results of the pilot study are shown. In particular, sustainable aspects of TD are focused and their impact on the success of suppliers is analyzed.

3.4. Findings of Study 2

A data analysis relating to the respondents revealed that 22.7 % were managing directors, 22.7 % were heads of technical department, 31.8 % heads of R&D department, 9.2 % executives from the pre-development department and 13,6 % were executives from Sales and Marketing.

Besides that, 31 % were associated with the automotive industry, 42.9 % operated in the fields of mechanical and electrical engineering, 16.6 % in the field of metal production and metal processing and 9.5 % resided in other industries. Companies of all sizes were included in the sample: 45 % employed no more than 250 employees, 32.5 % have no more than 1000 staff and 22.5 % employed more than 1000 employees.

Table 1. Exemplary analysis results from the Kruskal-Wallis Test for ranked data

	χ^2	p
technology strategy		
existence of a recorded technology strategy	6.383	0.041*
anchoring of sustainability	2.859	0.061⁺
strategic foresight		
analysis of competitors	6.463	0.040*
analysis of customers	6.098	0.047*
analysis of suppliers	5.831	0.054⁺
idea management		
integration of employees	6.370	0.041*
integration of customers	7.643	0.002*
integration of particularly innovative customers	7.672	0.022*
assessment of all the technology ideas by interdisciplinary teams	9.943	0.007*
technology development (TD)		
building an interdisciplinary team for each planned project	14.888	0.001*
joint definition of project-specific targets	10.758	0.005*
clearly defined technology specification sheet	8.816	0.012*
dealing with substances and energy as effectively as possible	6.334	0.042*

* p < 0,05 (significant); ⁺ p < 0,1 (weakly significant)

Table 1 shows the main results. Based on the chi-squared values of the KW test and the significance level there is a difference in the mean ranking of technology strategy behavior among high and low performers. Our results show a significant association between the existence of a recorded technology strategy and corporate performance as well as a correlation between the anchoring of sustainability in a firm`s technology strategy and its performance.The findings validate the literature discussion above, which points out, that strategy-driven planning of TD activities is crucial to success. Furthermore the results indicate that the analysis of suppliers has a performance-enhancing effect and that the analyses of competitors and customers have a significant impact on corporate success. This is consistent to research findings, where competitive and customer orientation is success factors of innovation (Gaubinger *et al.* 2009; Corsi, Dulieu 2008; Gundlach, Stephan 2010). In addition, the study results show a significant correlation between the integration of staff members, customers as well as so called “Lead Users” in the process of creating new ideas and the corporate performance. This integration can lead to a higher employee motivation firstly (Thom 1983) and a greater acceptance of innovations through customers secondly (Larsen, Lewis 2007). In addition, firms who assess their technology ideas in interdisciplinary assessment teams and those who assemble an interdisciplinary team before the actual start of a concrete TD project are more successful than those who do not. Finally, the findings indicate that a joint definition of project-specific targets, a clearly defined technology specification sheet as well as dealing with substances and energy as effectively as possible during the TD project possesses a significant influence on corporate performance.

4. Development of the sustainability-oriented TD framework

While the findings of the first study present some clear indications, how successful companies within the supply industry structure their development activities and which tools are helpful to manage TD projects successfully, those of the second study provide ideas for the *appropriately* integration of sustainable aspects in the TD framework. These empirical findings build upon the theoretical insights to form the basis for the framework of a strategy-orientated TD process.

To embed this strategic and sustainable orientation in the development process holistically, a target-oriented use of methods and instruments is crucial for success, which is taken in consideration in a process attendant toolbox. In order to ensure the practicability of the toolbox a *manageable number* of phase-specific and *easily applicable* instruments have been integrated, which guarantee a sustainable-oriented and effective implementation of TD activities. Furthermore, the specificities of the supply industry must be considered, due to the complex interaction between and the individuality of products and services (Backhaus, Voeth 2007). As shown in Figure 1 the resulting framework of the sustainability-oriented TD process consists of three main phases: *preliminary phase*, *technology development* and *advanced development*. These overriding process steps are categorized in eight sub-phases and seven gates with appropriate tools.

4.1. Preliminary phase

The implementation of sustainability starts with the orientation of the TD activities towards *clearly defined corporate goals and R&D principles* that must include concrete statements on the ecological corporate target position and principles of stakeholder management. Based on the assessment of the internal technological corporate competence base, it is essential to search for weak signals systematically (Diller 2007). The *PESTEL analysis* (Hungenberg 2011), an *issue analysis* (Boutellier, Biedermann 2008) and an extensive *structural analysis of industry* (Porter 1980) are suitable for the holistic analysis of the macro and/or micro-environment. These analyses must take into account the three dimensions of sustainability in all areas. Moreover, a *strength-weakness analysis* must be made, the evaluation criteria of which comprise economic, environmental and social parameters, in order to analyze the firm's competence base. Finally, the *SWOT analysis* allows for the derivation of options for strategic action (Müller-Stewens, Lechner 2005), which determine concrete search fields for the following phase of idea generation.

In the phase of idea generation many search field compliant technology ideas should be generated that take into account different internal and external sources of information. A structured *suggestion scheme* for ideas can provide both economic and social value. The latter stems primarily from involving employees in activity areas which are critical to corporate success and therefore increase employee motivation and commitment. The integration of *sustainably-minded lead experts (SLE)* and *sustainably-minded lead customers (SLU)* ensures the appropriate direction of the idea-finding process to sustainable-oriented needs. Finally, the alternative ideas for new technologies are evaluated in interdisciplinary teams by using *checklists* and *value benefit analyses*, which consider environmental and social aspects in addition to economic ones, which in turn allow technology to be assessed at an early stage. To estimate the potential of new technologies and the foundation of the Go/Kill decisions a *Delphi survey* can be used, that should involve SLE. In Gate 1, the decision is made to transfer a technology idea into a concrete TD project.

4.2 Technology development

In the phase of *project planning* (Stage 1) it is necessary for the whole development team to create a general state of knowledge (Slama *et al.* 2006). A *catalogue of clear objectives*, which defines both the efficiency of resources and eco-efficiency as stated goals of the TD project, is an important planning and controlling instrument during the entire process. Subsequently, an initial *project plan* is prepared, including a project structure plan, a schedule plan, a resource and cost plan, and an organizational plan. Since TD projects are usually based on a set of imperfect information at project start, the project planning must be specified with increasing level of information in the ongoing phases. Similarly, a process-integrated controlling must assess the development activities and results during the whole development project, including environmental and social parameters in addition to economic parameters. The resulting stakeholder analysis, generated during schedule planning, shows the relationship of the project to the relevant stakeholders and identifies potentials of conflicts and benefit potentials, as a basis for the successful management of relationship with stakeholders in order to guarantee socio-efficiency (Schwalbe 2007; Nguyen *et al.* 2009; Dyllick, Hockerts 2002). In the subsequent phase - the *technical concept* (Stage 2) - a technical assessment of the focused technology area is carried out and the possibilities of the TD are investigated in detail by a *technology assessment* (Ludwig 1997). In this context, possible opportunities and risks of the new technology will be acquired and evaluated, various solutions will be derived from the assessment and efforts are being made to assemble existing competences of different specialist departments (Heubach *et al.* 2008). The identification and specification of possible applications of the technology and the determination of promising target segments rank among the most important main activities of this phase. In the phase of *technology development* (Stage 3) the technology concept is realized successively and iteratively through tests and experiments.

Simulation tools can be useful for a resource-saving testing of technology`s functionalities at this early stage. Output from this stage is new technology knowledge.

Simultaneously, it is important to determine already identified or yet to be identified *sustainable-minded Lead Users* (SLU) of the target segment, who pursue a sustainable business strategy. Again, c*hecklists* and *value benefit analysis* are evaluation tools, which enable a systematically selection decision. Based on the SLU identification it is about winning a potential customer for a joint advanced development. In the course of these acquisition efforts, the existing simulation results can be useful, to demonstrate the new technology knowledge efficiently.

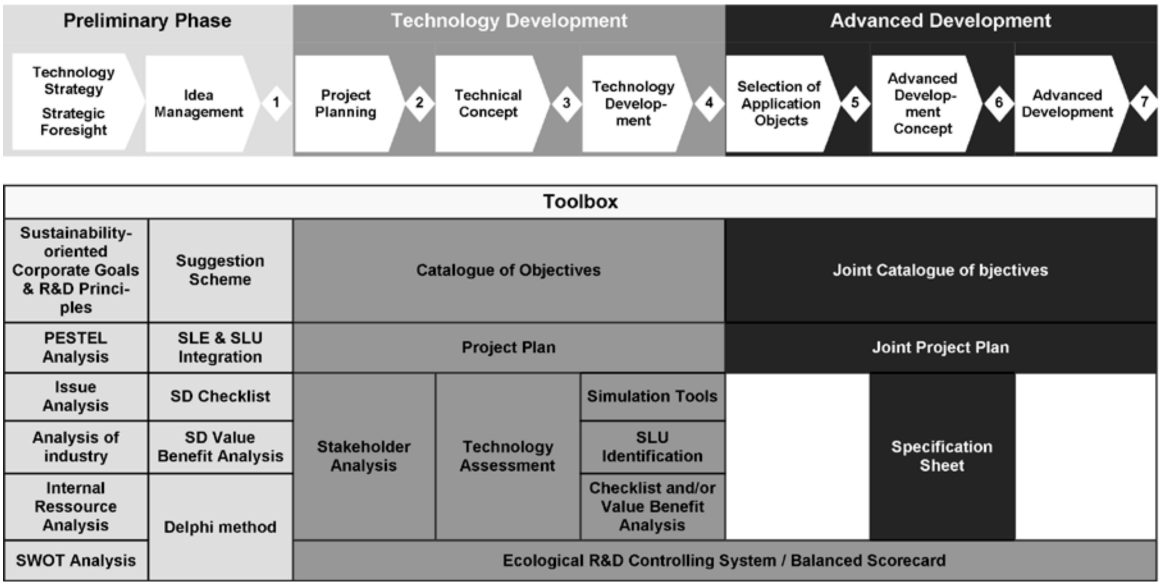

Fig. 1. Sustainability-oriented TD-Framework

4.3. Advanced development

In the phase „*selection of application object*" (Stage 4) a concrete application object is selected in a joint pilot project, where the technology will be used. In the phase of *advanced development* concept (Stage 5) the technology-specific requirements of the application object are defined according to the customer`s demand (Heubach *et al.* 2008) and then are transferred into a *specification sheet*. The predominant principle of customized solutions in the supply industry leads to the necessity for an application definition of the object, in which the technology will be later integrated, by the pilot customer. Based on the specification sheet, object-related feasibility studies are accomplished and a detailed product requirement definition is drawn up. In the field of advanced development care should be taken already during the concept phase to ensure a resource-efficient prototyping by using renewable resources and avoiding risks posed by the release of substances, according to the objectives of a *Cleaner Production* (Chiang, Tseng 2005; Vickers, Cordey-Hayes 1999). As early as during the TD, the predevelopment project also has to be planed and controlled by using sustainable-oriented project management tools. The development and construction of the application objects take place during the phase of *advanced development* (Stage 6). In parallel, the systematic planning of an *integrated concept of commercialization* is carried out for the future "broad commercialization" of the new technology and is aimed at establishing business relations with other potential customers. In this way, finally, the economic dimension of sustainability is taken into account.

5. Conclusions

Process models are useful for systematizing the „fuzzy front end" of innovation to give the uncertain contents of early innovation more stability and predictability. Thereby, the particularities of TD projects, which are characterized by a higher level of abstraction in comparison to new product development projects, must be taken into account. Against this background the developed framework may be understood as a *preliminary reference model,* which points out how a TD process can be structured and how tools and methods should be adapted and applied in the particular process steps to enhance a sustainable orientation of the TD activities on the other hand. Especially *firms in the supply-industry* will benefit from the established framework, because it includes a *manageable number of phase-specific practicable management tools* that can assist them in increasing the *effectiveness* of their TD activities ("doing the right things with respect to sustainability"). Furthermore, the implementation of the framework will enhance the *efficiency* of the TD activities ("doing the things right"), due to the strategy-orientated and systematic procedure, resulting in reduced time to market and a higher return on TD activities. Therefore, our research can serve as a practical guide for managers and development teams of medium-sized firms. The data collected during the two studies reported in this paper and the theoretical insights have formed the basis for this framework.

Nevertheless, we recognize several limitations that may be addressed in future research. First, our qualitative study is focused on companies within the automotive supply industry and therefore it only examines how firms within this industry structure their TD activities. Second, the quantitative study is limited to a small sample size, which only indicates trends in the sample, so that future studies should include a greater sample that aim to come to more representative conclusions by further statistical tests. Third, the findings of the two studies reflect the procedures and activities of technology management of Austrian firms. Thus, it would be worthwhile to expand the view to other countries. Further, it is acknowledged that the developed process model is an *initial* reference model that needs to be adapted and specified to the particularities of each firm and validated by implementing the process in a broader scope.

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