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Potential-based Technology Planning for Production Companies

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Abstract

Strategic technology planning is a key challenge for manufacturing companies in order to stay innovative and succeed in the dynamic international competition. State of the art approaches are mostly based on technology evaluations that focus on present technology readiness and maturity or qualitative potential assessments. These approaches lack of a quantitative consideration of future development potentials of new or immature technologies. The presented approach includes technology potentials in the strategic technology planning and therefore introduces a concept for the quantitative and comparable evaluation of technology potentials. Based on this evaluation, a technology roadmap can be developed to support strategic technology planning.

Keywords: Technology Planning, Technology Potential, Technology Management, Innovation Management

1. Introduction

Global competition and the associated dynamic market environment with customers demanding more and more customized products have become a main driver for manufacturing companies to drastically shorten their innovation and development cycles [1–3]. New challenges for producing companies also arise with stricter law enforcement regulations to tackle global warming and environmental pollution [4], while new technological challenges and opportunities arise with digitalization and "Industrie 4.0" that radically change processes and disrupt whole industries. Therefore, an effective technology- and innovation management has become a core skill to stay competitive [5,6].

1.1. State of the art

Most approaches in production technology management employ the technology maturity as a main indicator for the economic and technical performance of manufacturing technologies [7–9]. However, only few approaches take into account the companies' individual technology strategy for the evaluation of production technologies [10,11]. Thus, established approaches focus on the technical and economic status quo of a regarded technology but lack of an estimation of its future potential and development possibilities [12]. Especially technology potential plays a significant role when decisions on strategic investments into new technologies are to be made [13]. From a technical point of view, technology potential describes the property of a technology to create value added in future by new or better technical features [8]. From a strategic point of view, technology potential is described by the opportunities a company can generate based on its knowledge and skills in production, processes and materials [14,13]. For this work, technology potential is defined by the value added, a technology can create for a company based on its future development possibilities from an economic, technical and strategic perspective.

The consideration of technology potentials however could help to estimate the technology's technical and economic performance and strategic fit for the time of implementation

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and actual operation period instead of a static review at an earlier point of time.

So far, the evaluation of technology potential mainly focuses on isolated perspectives, such as economic [13] or technical [8] aspects. An economic description and analysis of technologies mostly focuses on modeling cash-flow or net-present-value generated by the utilization of a technology [15,13]. Mainly technically focused approaches aim to evaluate the technologies performance driving key parameters like process stability, quality or material flexibility and estimate their development in the future [8]. Strategy focused approaches aim to evaluate the strategic fit of a technology and the company's strategy environment. The strategy environment can for example comprise human capital and skills, strategic sustainability targets or the aspiration of technological leadership in the market [16–19]. Strategy based evaluation approaches mostly focus on single facets of the strategic fit.

Yet, a comprehensive approach to cover the whole picture from technical, economic, and strategic perspective in depth is missing. To our knowledge, there is no substantiated framework and set of parameters to describe the potential of manufacturing technologies and no dedicated method to identify and evaluate these parameters.

In industrial practice, typically, technology suppliers elaborate potential analysis studies to highlight the technology's advantages from an economic and technical point of view (cf. [20,21]). These studies are highly diverse in the structure of analysis and emphasize different aspects of a technology. An analysis of 50 studies revealed only 8% of the studies structurally classify parameters. Less common are potential analysis studies by industry associations or federal agencies which not only analyze advantages and chances but also disadvantages and risks of a technology from various views (cf. [22,23]). Considering the different approaches of describing and analyzing a technology's potential, there is no methodological framework which defines a transparent and comparable structure with tangible evaluation parameters.

1.2. Objectives and structure of the paper

Hence, the objective of this paper is to present a methodological framework for the evaluation of technology potentials based on predefined evaluation parameters. In detail, this entails the description of a main model for the description of technology potentials comprising three sub-models. Furthermore, a detailed description of each sub-model—economic, technical and strategic—and an exemplary analysis of the set of evaluation parameters from a technical perspective should be given.

Based on the Design Research Methodology (DRM) introduced by Blessing [24] the paper is structured as follows: In the first section, technology management and its relevance have been introduce, the state of the art was analyzed and research gaps were identified. Subsequently, the objectives of the paper were formulated. Section 2 describes the DRM-based research approach which leads to the Technology Potential Framework in section 3. In section 4 the methodological approach is evaluated for the technology potential based design of a next generation all-solid-state battery (ASSB) production.

2. Approach and Methods

The presented research approach is based on the DRM framework which serves the step-by-step development of the Technology Potential Framework presented in section 3.

2.1. Literature research on technology evaluation

In order to find the basic structure for the Technology Potential Framework, a comprehensive literature review of existing methods for technology evaluation was conducted. The review revealed three main perspectives on technology potential, which are economic, technical and strategic (see section 3). Based on this tripartite structure, a two-step research approach was used to identify an appropriate set of parameters describing each of the three main perspectives.

In a first step, potential analysis studies from technology suppliers, industry associations and federal agencies were analyzed to find similarities in structure and specifically used evaluation parameters. Based on this analysis a first set of evaluation parameters was derived. In the second step, the existing set of evaluation parameters was extended by the analysis of basic literature for production technology, technology management and corporate strategy. Thus, the parameter set derived from a comprehensive analysis of best practices in industry was completed by parameters derived from basic literature as theoretical input.

2.2. Analysis of technology potential analysis studies

In the first step 50 potential analysis studies about specific production technologies were examined. Single factors that influence the potential of production technologies were identified (such as surface quality, connection strength, material flexibility, process temperatures, tightness, degree of automation, sustainability, etc.) and associated with the literature based categories (economic, technical, and strategic). Thereby the basic tripartite structure was evaluated, and the main categories were verified by a distinct allocation of parameters to main perspectives.

On the other hand, a first specific set of parameters was derived by the systematic analysis of potential analysis studies. The individual influencing factors described for a certain technology were abstracted to a general term that is relevant for production technologies in general. For instance, most potential analysis studies include factors that describe the error rate of the production processes. These can be summarized in the context of process stability respectively process availability. This factor in particular can be assigned to the category technological potential. The 50 examined studies comprise different technology fields, which ensures a universal validity of the derived generalized factors derived from technology specific factors described in the studies. Since the number of 50 studies provides only a limited number of different technology fields, the derived general factors must also be validated to revise their universal applicability to production technologies. Due to the high specificity of production technologies and their area of application, some specific potential factors are just relevant for very restricted products or processes and not relevant for a general description of technology potential.

In summary, the first step was to derive specific potential factors that can be assigned to the technological, economic or strategic category. However, these identified factors only represent an incomplete collection of potential analysis studies which show divergent structures and argumentations. Nevertheless, this first input is suitable for developing first concepts for sub-models of the presented main perspectives.

2.3. Analysis of basic literature

In a second step, basic literature on production, business and strategy was analyzed to evaluate and complement the first set of parameters and their allocation to main perspectives. The specific approach to analyze the literature differs depending on the main perspectives since economic, technical and strategic influences need to be modelled fundamentally differently. In the following, the technical sub-model will exemplarily be discussed more in detail to demonstrate the approach.

The review of the 50 potential analysis studies shows that there is no generic structuring of factors influencing the technical potential of production technologies. However, the studies define specific parameters describing a production technology and its technical performance. Those parameters were listed and consolidated. In basic production literature (cf. [25–27]), different production technologies are described and compared. From the comparison and the emphasized advantages and disadvantages of each production technology, general influencing parameters (like process accuracy, process speed, etc.) and technology specific factors (like the quality of the micro-structure of a joining, etc.) can be extracted and assigned to the main categories.

3. Technology Potential Framework

The developed framework follows a tripartite structure (see Fig. 1), where the overall technology potential consists of three sub-models (economic, technical and strategic). Accordingly, technologies can generally be evaluated from an economic, technical and strategic point of view.

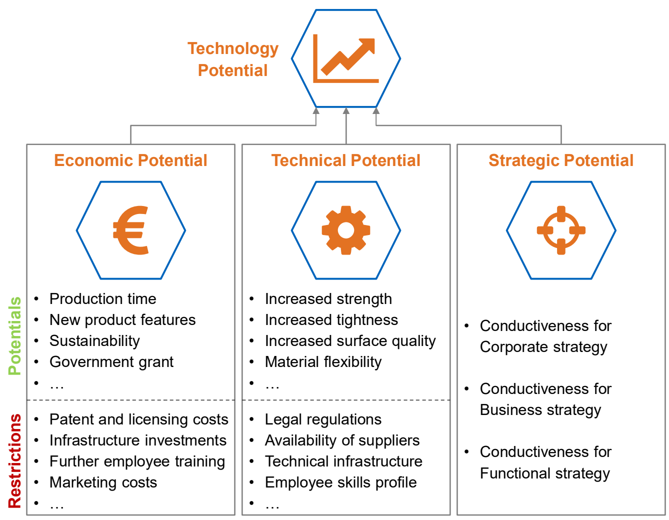

Fig. 1. Structure of the Technology Potential Framework.

The economic and technologic sub-models consist of potentials and restrictions whereas the strategic sub-model is structured by the different strategy levels (see section 3.1). In order to describe and evaluate a technology's potential as a whole, all of the introduced perspectives need to be considered in one framework and need to be connected.

3.1. Potentials, Restrictions and Strategy Levels

Apart from the integration of economic, technical and strategic perspectives, a company's business environment and competencies to utilize a technology need to be considered. Thus, Technology Potentials objectively describe the influencing factors on the performance of a technology and their probable development over time. In order to utilize the full technology potential of a certain technology, several requirements need to be met by a company. Those requirements are defined as Technology Restrictions in this work. The idea is based on Schöning's [13] concept of objective technology potential and "lock-out" effects.

Exemplarily, a company needs financial resources, a certain amount of time and employees with a suitable skill set to exploit the full potential of a technology. In the case, some of the requirements are not fully met, restriction factors emerge which hamper the utilization of the technology.

3.2. Economic Sub-model

In literature there are different approaches to model a technology's economic potential as described in section 1. Each approach comes with advantages and disadvantages. The developed approach is based on the cash method of accounting which is similar to most cash-flow approaches. This method distinguishes between revenues and costs which define the overall profit by subtracting costs from revenues [26]. Consequently, an increase of profit can be generated by increasing revenues at constant costs, cutting costs at constant revenues or cutting costs and increasing revenues at the same time. The economic potential of a technology therefore is defined by its ability to increase profits in future. In detail, a cost cutting potential and a revenue increase potential can be described, which result in the potential of increasing profit.

Cost cutting potential might for example arise from automatization potentials, lower error rates or scale effects in production. The origin of cost cutting potentials and single influencing factors is diverse and often connected to other sub-models. Therefore, the classic accounting approach of cost center accounting is used to separate economic influences from their technical or strategic origin. This approach allows to identify changes in costs independently from their underlying cause.

The revenue in general can be defined as the product price multiplied with the quantity of sales. Consequently, a potential for increasing revenues arises from higher prices customers are prepared to pay or increased quantity of sales.

Economic restriction factors generally are based on insufficient financial resources for making investments in infrastructure, buildings, further training of employees or licensing costs for instance.

3.3. Technical Sub-model

For the technical sub-model, similar to the economic sub-model, literature provides different approaches to describe a technology. Most approaches focus on the characterization of a specific technology by its main performance drivers (cf. [8]). In order to provide a generic approach that is universally applicable to production technologies on the one hand, but creates a sufficient depth of research on the other hand, the technical potential is described on two levels. The first level comprises general technical potential factors that are relevant to all production technologies. Examples for universal technical parameters are production speed in product units per time, emissions or error rate in terms of technical availability or scrap rate. In the second level, a subdivision into the production technologies according to DIN 8580 [28] is carried out. Due to the fundamental technical differences between the technology fields defined in DIN 8580 [28], each field needs to be characterized by specific parameters in detail. This classification is completed by the classes "assembly technology" with a focus on handling and "logistics technology" with a focus on transport and storage. Each class consequently is described by a set of parameters which can be divided in product oriented and process oriented parameters.

For instance, one class of DIN 8580 [28] are joining technologies (cf. DIN 8593 [29]). Product oriented parameters, for instance, are strength of the connection, tightness, surface quality, added weight and material flexibility. Exemplary process oriented parameters are technical auxiliaries, necessary process preparations and technical process times like cool-down time. Hence, the total of all parameters describes the theoretical technical potential of the technology which is hampered by technical restrictions.

Technical restrictions mainly are based on a lack of competencies or resources for the optimal utilization of the technology's potential. In this perspective, restrictions can be classified as internally or externally caused. This classification gives indications for solution approaches. Internal restrictions exemplarily are described by the competencies of employees, their willingness to learn or technical indications on the technology chain that come with a technology change. External restrictions are defined by legal restrictions and regulations, patent restrictions or market limitations by technology suppliers.

3.4. Strategic Sub-model

The strategic sub-model aims to evaluate the strategic fit of a technology and its future viability for a company's strategic focus. Especially the long-term view completes the description of technology potential and enables companies to make sustainable technology decisions. In order to evaluate the strategic fit, a company's strategy needs to be described in detail to understand advantages and disadvantages of a technology referring to the strategy. Hence, a company's strategy is described and analyzed on different levels. The most abstract level is the corporate strategy which defines in what kinds of businesses the company wants to work in, how the business portfolio is set up and how resources are allocated [30]. The second level is the business strategy which defines the competitive strategy within the chosen markets [30]. The third level describes functional strategies which define the strategy of each business function such as production, finance or human resources.

To evaluate the strategic fit the company's strategy needs to be identified and analyzed. Subsequently, the key question that need to be answered is if the considered technology is beneficial, neutral or adverse with respect to the identified strategy. The strategic sub-model does not comprise Potentials and Restrictions since a company's strategy always respects individual strengths and weaknesses. Hence, the analysis of the strategic potential of a technology can never be company-independent.

4. Implementation and evaluation for ASSB's

As a use case scenario, the presented methodology was applied to the hypothetic production of ASSB's for electric vehicles. These batteries promise a higher safety combined with higher energy or power density, resulting in longer driving distance or faster charging of electric vehicles [31]. While promising results concerning the performance of ASSB have been achieved on the laboratory scale [32], the implementation of scalable processes for ASSB production is still in its infancy [33] and will potentially require innovative production technologies [34]. While the successful implementation of ASSB mass production promises a differentiation in an enormously growing market, the manufacturing cost will have to be competitive with the steadily sinking cost of the current lithium-ion battery technology [35]. Therefore, a strategic investment would come along with a high risk of failure.

Based on a scenario analysis, two different scenarios were selected and elicited by means of an expert workshop: The first scenario (A) describes an established lithium-ion cell manufacturer already producing electric vehicle battery cells in a large scale and trying to be the first one to fulfil the customers' future requirements (cf. [36]) with a new product. The second one (B) describes a newcomer (potentially a large first or second tier automotive supplier with little experience in battery production) that tries to enter the market as a technology follower. The core component of the ASSB is the so called solid electrolyte separator (SES) which needs to be fabricated as a homogeneous and thin layer (< 30 µm) with negligible porosity. From the large variety of possible layer fabrication technologies [33], the slot die coating and the aerosol deposition method were selected as examples. While slot die coating is a widely established technology in battery electrode processing [37], aerosol deposition is an emerging technology with low degree of maturity but promising results for the fabrication of high quality SES layers [38].

In order to make a strategic and potential based technology decision, the technologies were evaluated using the full parameter sets for economic, technical and strategic potentials. The preliminary evaluation approach was simplified and based on a qualitative assessment of the parameters comparing the considered technologies with current technologies. Therefore, a bipolar scale was established to evaluate the technology's potential from highly positive potential (+2) to highly negative potential (-2). Furthermore, the evaluation parameters needed to be weighted depending on their significance for the company which was established by a scale from 0 (not relevant) to 3 (highly relevant). Table 1 shows an excerpt of the evaluation for aerosol deposition in comparison to a conventional tape casting technology in companies with different strategies.

Table 1. Excerpt of evaluation parameters.

		Parameters (excerpt)	Company A			Company B		
			Weight	Evaluation	Weighted evaluation	Weight	Evaluation	Weighted evaluation
Technical sub-modell	Potential factors universal	Flexibility	1	+2	+2	2	+2	+4
		Process stability (Scrap rate)	3	-1	-3	3	-1	-3
		Emissions	1	+2	+2	2	+2	+4
	Potential factors Coating	Corrosion resistance	2	+2	+4	2	+2	+4
		Thickness of coating	3	+1	+3	3	+1	+3
		Quality of coating (bubbles, inclusions)	3	0	0	3	0	0
	Technical restriction factors	Patent restrictions	1	+2	+2	3	+2	+6
		Legal restrictions	1	+1	+1	3	+2	+6

As a result of the evaluation aerosol deposition has positive potential for Company B in all categories (see table 2). While for Company A the technology is not beneficial in all categories. From an economic point of view, the aerosol deposition has the potential to cut costs and increase revenues compared to the currently used technology. Regarding the company's strategy, the different market positions and strategic objectives differentiate the strategic potential.

5. Conclusion and Outlook

The presented framework constitutes the basis for a comprehensive evaluation approach for technology potentials. In contrast to previous works, this approach focusses on a parameter based evaluation to compare different technologies transparently and to enable companies to evaluate a technology's potential based on their specific requirements and characteristics. The framework uses three perspectives—economic, technical and strategic—to substantially describe a technology's potential.

As a result of the practical evaluation the dataset showed that the results highly dependent on the weighting of the parameters which projects the company's strategy and requirements. The evaluation of the parameters, on the other hand, is the same for all technical potentials, since these are technical characteristics that can be determined independently of the business environment. Economic and strategic

Table 2. Evaluation results for the potential of aerosol deposition.

		Company A weighted values	Company B weighted values
Technical sub-model	Potential factors Universal	-0,47	0,00
	Potential factors Coating	0,30	0,30
	Technical restriction factors	-0,60	1,07
Economic sub-model	Cost cutting potential	0,25	0,25
	Revenue increase potential	0,47	0,61
	Economic restriction factors	-0,73	0,40
Strategic sub-model	Corporate strategy fit	-2,00	-1,00
	Business strategy fit	-2,00	2,00
	Functional strategy fit	no assessment possible	no assessment possible

parameters have been evaluated based on the company's setting. In summary, however, it can be stated that the majority of the parameters determined in the context of this work are relevant to the potential of the investigated coating technology. Additionally, the differences between the two company perspectives became clearly visible.

Nevertheless, this approach is intended to build the basis for further research on technology potential and strategic technology planning. Especially the economic and strategic sub-models need to be detailed and a quantitative evaluation approach including the calculation of an overall potential indicator needs to be developed. In order to utilize the approach in industrial practice, a constitutive roadmapping approach needs to be elaborated.

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