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AN APPROACH FOR A RELEVANCE ANALYSIS OF NANOTECHNOLOGY

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ABSTRACT
Emerging technologies are being considered a driving force for innovation. Characteristics of such technologies concern close-to-science access to, and base of, technology, a broad range of expected, yet barely imaginable applications, and new challenges and approaches required to link technology push and market pull forces. For the 21st century, nanotechnology as an emerging technology field is being expected to become a key technology, and with impacts to be anticipated for nearly every industry, nanotechnology can be considered a cross section or enabling technology. Development in the field of nanotechnology is still driven more by technology and opportunity rather than by market requirements and needs of customers. Technical potentials of nanotechnology are yet to be tapped in both enterprises and within developers' and designers' communities, and with regard to inadequate transfer of nanotechnology in products and consumer benefits, a significant gap is to be recognised between the technological 'bank' of nanotechnologies and (prospective) application 'banks'.
Therefore, new management approaches are considered necessary, to get "access" to this mostly unknown field from a application perspective during the early phases of innovation processes and product design. An approach for a technology relevance analysis of nanotechnology in terms innovation potentials is presented which provides a structured access to the nano-domain and a procedure to identify relevant applications fields and corresponding solution by nanotechnology. The objective is to match the product functions with potential effects and properties designed and realised by nanomaterials, -structures, -surfaces, etc. to high-light feasible application fields.

Keywords: Technology Assessment, Nanotechnology, Technology Management, Innovation Process

1 INTRODUCTION

Emerging technologies are being considered a driving force for innovation. Leveraging their potential, new industries shall be set up as well as existing ones transformed, established technologies or product functionalities substituted or new markets opened. Thus emerging technologies establish a technological basis to hold or increase the company's competitive position and to assure the sustainability of the company [1-3]. Their impacts on markets can be both discontinuous, i. e. realised via radical innovations and new enterprises, as well as in more evolutionary ways by the convergence of science and application knowledge domains. Characteristics of emerging technologies concern close-to-science access to, and base of, technology with an expanding knowledge base, a broad range of expected, yet barely imaginable applications, and new challenges and approaches required to link technology push and market pull forces [4].
In order to benefit from the chances mentioned above, enterprises are challenged to identify relevant new technologies and future technology trends (e.g. what is called technology intelligence [5]) and to assess both their potential to improve current performance of products and processes and the (potential) threats, linked to their application, to eventually substitute current technologies and processes [6]. However, information and experiences required to identify and assess emergent technologies are so far missing or inadequate due to their dynamic technology developments, primarily science-based and partly interdisciplinary technology approaches, new working principles and a lack of competencies and know-how what a technology in focus may offer and how it could be used [7, 8].

2 NANOTECHNOLOGY AS AN EMERGING TECHNOLOGY

2.1 Basic principles of nanotechnology

Nanotechnology is neither a single scientific discipline nor a defined application area. Whereas 'nanoscience' is defined *"as the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale, 'nanotechnologies' are understood to be the design, characterisation, production and application of structures, devices and systems by controlling shape and size at the nanometre scale"* [9]. The new properties base on quantum mechanics, surface effects and molecular properties of materials over-ruling classic continuum physics and macroscopic effects. Physics, biology, chemistry and engineering converge providing the basis to functionalise, miniaturise or tailor materials, structures and surfaces [10, 11]. The great innovation potential of nanotechnology arises from the defined functionalities concerning the mechanical, electrical, magnetic, thermic/ thermodynamical, optical, chemical or biological properties of materials or surfaces (see e.g. [12]).

Basic nanomaterials are assigned to one of the following categories [13]: dot-shape materials (3-D nano-scaled structures, e.g. nanoparticles), line-shape materials (2-D nano-scaled tubes, e.g. carbon nanotubes CNT), sandwich or thin film structure with layer thickness of nm-scale (1-D nano-scaled layers, e.g. ultra thin coatings), porous structured materials (e.g. nanoporous materials) or complex structures like supramolecular 3D structures. Additionally, composite materials with nanoparticles incorporated are also considered nanomaterials.

Some nanomaterials utilised so far are nano-TiO_2 (UV-absorber in sunscreen, photocatalytic coatings), Si-based organic-inorganic hybrid polymers (scratch resistant, (super-)hydrophobic or antimicrobial transparent coatings), carbon nanotubes (tennis racket), nanoceramics (corrosion prevention lacquer), indium-tin-oxide (ITO, antistatic coating) or nanofibres for membranes (filtering processes). The short list depicts the wide range of potential applications in terms of product functionality as well as industries already. Thus nanotechnology is very likely to penetrate and influence almost every branch of industry like the application sectors precision engineering/ optics/ analytics, chemistry/ materials, energy/ environmental technology, medicine/ life science, car manufacturing, electronics/ IT or building industry [9, 14, 15]. The worldwide market volume in 2006 is about 100 billion Euros [16]. In 2014, global manufactured goods with nanotechnology incorporated will have a market volume of 2,6 bill. US$ that equals about 15% of total output [17].

Research and application of nanotechnology regards both materials and systems. A third category could be nano-tools which allow to examine and probe atoms and molecules. Systems running in future with nanotechnology are e.g. chips, sensor systems or drug delivery systems. Materials would have broader and more unspecific application areas: technical improvements, new functionalities on surfaces, improved material properties or integration of different functions are in principle of interest for nearly every product system.

2.2 Nanotechnology in the light of technology management

Nanotechnology is still at the beginning of development [11, 18, 19]. With impacts to be anticipated for nearly every industry, nanotechnology can be considered cross section or 'enabling technology' [7, 13], potentially providing substitutional, optimising, complementary or completely new functionalities [1, 20]. Progress in applications influences and results from developments in nanotechnological areas [7]. Regardless of their potential, some constraints to bring nanotechnology in marketable products continue to persist. Development in nanotechnology is still mostly technology or opportunity driven rather than by market requirements and (perceived) needs of customers (see [10, 15, 21, 22]). Still a gap between basic research and application exists in many areas. Furthermore, the technical potentials of nanotechnology are yet to be discovered in enterprises as well as with developers' and designers' communities.

The reasons for that is among others an unspecific access to nanotechnology in terms of a structured understanding of the nano-domain. There is a nescience about the basics, working principles and enterprise-specific innovation potentials of nanotechnology as well as lacks in procedures to manage such emerging technologies from firms' perspectives [3, 23]. Between the technological 'bank' of nanotechnologies and (prospective) application 'banks', a significant gap is to be recognised, materialising in inadequate transfer of nanotechnologies in products and consumer benefit (see e.g. [22]). Practical knowledge and competencies about scientific background and functionalities is mostly restricted to experts in the nanotechnology-related domains. However, precise applications of nanotechnology can only be identified by combining both market pull and technology push [24, 25]. The technological performance of nanotechnology and their physical forms (in terms of materials, structures, coatings, etc.) have to be presented in a 'comprehensible' way mediating the technology push. Simultaneously, enterprises have to sense the requirements of customers regarding products and their properties in very early stages to stimulate market pull, eventually. This requires to develop a systemic framework as a kind of well-specified blue-print to transfer knowledge between the disciplines and to share knowledge about nanotechnological feasibility and useful applications [8].

A 'comprehensible' systemic frame would have to deal with the complexity within nanotechnology:

- Functionalities feasible under the 'umbrella' of nanotechnology are quite different and various, be they 'new', help to optimise known functionalities, integrate them in existing systems (e.g. surface gets a function) etc.
- Functionalities can be applied to product-related problems, e.g. cooling or cleaning. Cleaning of surfaces of organic matters, drop fringes, liquids etc can be solved by (or a combination of them) 'superhydrophobic', 'photocatalytic', 'antimicrobial' features—depending on the system.
- Functionality can be provided by application of different nanomaterials, e.g. nano-ZnO , nano-Ag, nano-TiO_2 or preserving agents. Other nanomaterials have again different properties depending on molecular geometries (e.g. CNTs have excellent properties like tensile strength, transparency, ferromagnetism, electric and thermal conductivity, actuating elements or sensors).

To account for above, new management approaches are considered necessary to cope with the complexity and uncertainty of knowledge in nanotechnology during the early phases of innovation processes and product design. The main question is how enterprises and designers can be enabled to adapt nanotechnology in terms of fast and efficient problem solving alternatives, and to analyse the relevance of nanotechnology-based functionalities for their products and customer solutions.

3 ANALYSING AND ASSESSING TECHNOLOGIES FOR INNOVATIONS

Technologies can be scored and assessed comparatively with regard to their potential for commercial success and technical innovations. Many methods and process models are provided in literature to deal with the respective tasks.

Innovation process models are aimed at standardising and structuring procedures to develop product innovations. Well-known process models are the 'Stage-Gate-Process' by Cooper and Kleinschmidt [26] or the 'New Product Development' (NPD) process by Khurana and Rosenthal [27, 28]. The first model puts emphasis on the sequential phases of innovation process to systematize and control the different tasks by stages with concrete recommendations and gates with 'go/no-go'-decisions based on 'must meet' and 'should meet' criteria. The NPD-approach highlights the 'fuzzy front end' of product development.

However there are some obstacles concerning implementation of above in practical case considering innovations via emerging technologies. One is that process models in literature assume, that the underlying technology already exists [29]. A general differentiation between product and technology innovation processes can be observed, which necessitates integrating both technology innovation process and product innovation process. Sequential process models and innovation schemata emphasise upon step-by-step procedure with invention, innovation and diffusion. Considering emerging technologies—and especially nanotechnology [7]—science, technique and economics interact and interfere with each other. Thus feedback procedure schemata like the Chain-Linked-Modell by Kline and Rosenberg seem to represent a more fittable and realistic approach [23, 30], adding the elements 'knowledge' and 'research' to the innovation process. Concrete schemes how science and technology and innovation process could merge, are however missing [31-33].

Furthermore, innovation process models do at least partly neglect the task 'problem identification'. Tools for problems solving are applied successfully but how to identify a problem and define it is only rarely imparted in detail [34]. Obviously, the main difficulties to find new ideas are related to problems' and functionalities' identification [35, 36]. These first steps of 'idea search' at the beginning of an innovation process are not only essential and crucial since they may span a solution space and provide the opportunity to search for solutions outside the enterprise core competencies. The identification of new ideas to account for issues in focus should be approached in structured ways also to identify problems where nanotechnology might (or not) provide with solution opportunities. What is necessary is a kind of 'nano-polarising lenses' to detect for which purposes nanotechnology can be applied, be it to finish surfaces, combine different functionalities in a lacquer, integrate new functionalities in a surface, optimise the mechanical properties of a material etc. In this sense, the cross-sectional or 'enabling' character of nanotechnologies would require a context and enterprise specific analysis and evaluation. Universal phrases like "nanotechnology is important for our business" are way too unspecific – they apply to nearly every enterprise and do not suffice for strategy or technology assessment exercises [23], as it does not specify much needed details such as *where?* (product and requirement), *what*? (functionality) and *how?* (nanomaterial and application).

4 AN APPROACH FOR THE TECHNOLOGY RELEVANCE ANALYSIS

The remarks in chapter 2 and 3 evidence the need for an adapted approach to analyse and assess nanotechnology and their potential for innovations. It is necessary to provide a more detailed view on nanotechnology to come to be able to state specifically how it can be applied in a company.

4.1 Relevance of nanotechnology

The relevance of nanotechnology results from the combination of a problem and a technical solution. The problem represents an application field in a product caused by internal or external drivers like market or customer requirements, need for improvement of quality, costs or environmental behaviour of the product, demands for new technological paradigms, etc, whose problem solving has a benefit for the enterprise. The solution represents the solving capability of a nanomaterial and its properties, which fit to the problem. Therefore the relevance of nanotechnology and thus its innovation potential can be assessed as relevant means-end-combinations (see [1]). The benefit of the problem solving could refer to attractiveness for customers (e.g. 'expected' requirements, 'faster is better' requirements, 'exciting' requirements by Kano [37]), level of innovation (new to market, new paradigm, etc.), market size or volume of sales of the new product, portability of the problem to other products, product groups or components or consistency with objectives and strategic measures.

4.2 An access to nanotechnology (materials)

As mentioned above, an assessment of nanotechnology has to handle with complexity and novelty—leading to uncertainty—of the technology (see chapter 2.2). To cope with it, a systematic 'understanding' of nanotechnology has to be modelled guiding the analysis of relevance and making different solutions comparable. Design science offer a helpful approach to structure the domain nanotechnology (see in detail [38-40]). The following characterisation is proposed according to the VDI guideline 2221: Systematic approach to the development and design of technical systems and products [41] (see Table 1).

Table 1. Characterisation of nanotechnology

Characterisation element	Specification in Nanotechnology	Example
Working Principle (WP)	General mechanism, how nanotechnological effect could act (see chapter 2.1)	(see step 2 in chapter 4.4)
Working Structure (WS) (corresp. Effect Carrier)	Nanotechnological structure (nanomaterial or nano-structure), which carries the specific function(s) as a applicable system	CNTs, metal-oxides, silver-nanoparticle
Function (FU)	Specific function, based on nanotechnological effects of nanomaterials	Photocatalytic, scratch resistant, UV protection
Problem Idea (PI)	Application field in a product, whereas nanotechnology could principally provide a solution	prevention of bacteria growth
Solution Principle (SP)	Combination of function and working structure	Photocatalytic by TiO_2-nano-particles
Solution Idea (SI)	Solution principle, extended by type of application (coating, process) and requirements/ restrictions (solution idea)	Photocatalytic by TiO_2: UV-light+H_2O+O_2 required
Innovation Potential (IP)	Relevance of the combination of problem idea and solution idea	prevention of bacteria growth by photo-catalytic TiO_2

4.3 A process model for the relevance analysis

The developed process model for the relevance analysis is based on the process model for product planning given by the VDI guideline 2220: Product Planning – Flow, Terms and Organisation [42]. The guideline emphasises structuring and a consistent terminology. The task ‘product search’ within the guideline gives the base steps for the proposed procedure. The following figure (Figure 1) shows the single steps, tasks and elements of the approach. Each step with tasks, applied methods and the integration of the nano-domain is detailed in chapter 4.4. The abbreviations in Figure1 (two-digit alpha numeric) are explained in Table 1.

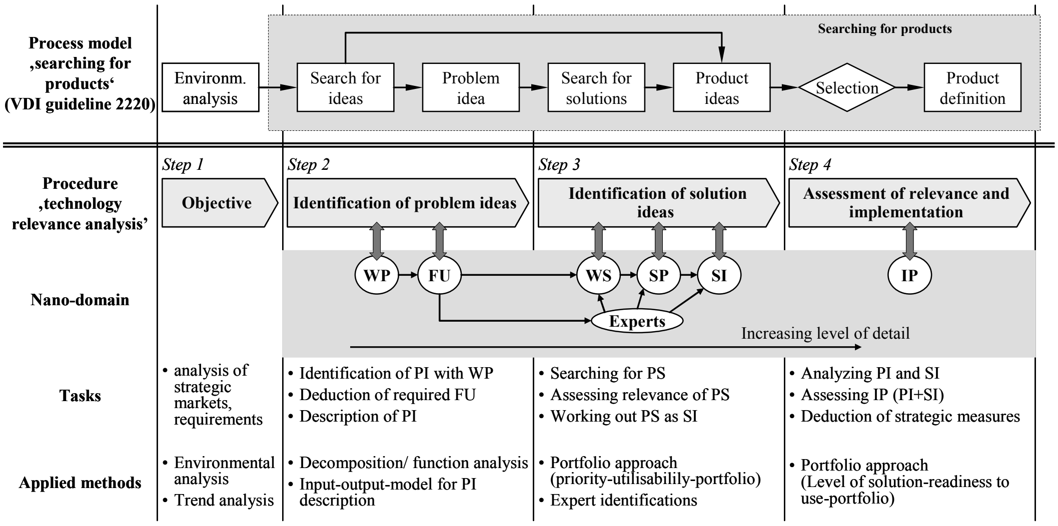


Figure 1. Process model for the relevance analysis of nanotechnology (WP = working principle, WS = working structure, FU = function, PI = problem idea, PS = solution principle, SI = solution idea, IP = innovation potential)

4.4 Procedure of the relevance analysis

In the following paragraphs, the different steps of the process model for the relevance analysis of nanotechnology will be explained.

Step 1: Objectives

First, the ‘object for analysis’ has to be defined. This could be a strategic business, technology or product segment, a single product, an assembly or component part or even a virtual visualized product—provided that the object for analysis can be decomposed in functional and structural units.
An environmental analysis of e.g.—potentially new—strategic market fields, internal and external requirements or product optimisation provides the potential demand for new functionalities and a basis for the definition of assessment criteria. Assessment criteria can refer to common objectives of technology strategy (e.g. technological leader), specific objectives (e.g. higher quality) and KO-criteria (‘killer’ or no-go criteria) or requirements to the solution (e.g. design, function, application).

Step 2: Identification of problem ideas

In the second step, ‘problem ideas’ are identified. ‘Problem ideas’ describe an application in a product where nanotechnology can possibly support optimising the product performance, incorporating new, or integrating different functions.
Their identification is guided by a model of functional principles provided by nanotechnology. These principles define the decomposition of the object for analysis in such a way as to match nanotechnology-related with product-related views. As mentioned above (chapter 2.1), nanomaterials and nano-structures apply their functionality in compounds (this means e.g. a composite material, polymer or solution) and on surfaces. The functionalities refer to mechanical, electrical, magnetic, thermic/ thermodynamical, optical, chemical or biological properties. These properties can be classified—regarding principle interactions—in the two types ‘field interaction’ (electric field, magnetic field, thermodynamic, optic field) and ‘interface interaction’ (mechanical, chemical or

biological interaction on surfaces). Thus, by the combination of ‘interaction type’ and ‘application place’, four working principles can be deduced:

- Interaction of a (electric, magnetic, thermic, optic) field in (compound) material
- Interaction of a (electric, magnetic, thermic, optic) field on a surface
- Interaction of a interface (mechanical, chemical, biological kind) in a material
- Interaction of a interface (mechanical, chemical, biological kind) art on a surface

This categorisation of working principles attempts to abstract the various functional capabilities of nanotechnology—with respect for the ongoing research and development in nanoscience.

The working principles guide the identification of problem ideas. According to this, problem ideas are such a kind, where the problem bases on a field or interface interaction and where the problem refers to a surface or a material of the object for analysis. Therefore, the object for analysis has to be decomposed in a functional model as well as in an object model (this means surfaces and physical, constructional elements of the analysed object), based on the approach of decomposition and function analysis [43-45]. The results are two models each with a hierarchical tree of function or object elements. These elements represent a product-specific part, where nanotechnology can be applied to optimise, substitute or invent a function. The next step is to identify problem ideas. For any element questions about required improvements or potential modifications are asked. These questions aim at the innovation potential of nanotechnology:

- *Optimisation* of elements’ properties.
- *Substitution* of elements’ properties.
- *New application/ functional principle* of properties.
- *Integration or combination* of functions of one or more elements by nanotechnology.
- *Substitution* of an applied material by a new Working Structure (WS).
- Application of a *New Working Structure (WS)* substitution current elements’ structure.

Problem ideas can base on precise problems regarding quality, functionality or cost, or on a wish to redesign functions or materials. The identification of problem ideas in this stage is independent of real solution capabilities by nanotechnology. As a kind of a creative process, the intention is to gather a multiplicity of different problem ideas, where nanotechnology could principally provide technological solutions.

Finally, the problem ideas are described with the required function for which new solution within nanotechnology has to be searched. An example for such a problem idea is a *scratch on a mechanical part due to mechanical stress* (interface interaction). The respective object element is the *surface of the mechanical part*. The required function is *scratch resistance*.

Step 3: Identification of solution ideas

The task of step 3 is to search and analyse ‘solution ideas’. Solution ideas are understood to be technological concepts enabled by nanotechnology, composed of a combination of nanomaterial and function (e.g. ‘antimicrobial surface’ by ‘nano-silver’) and additional parameter that deliver a principal contribution to a required property (problem idea). The search relates to experts with nanotechnology knowledge to acquire ‘solution principles’ and ‘solution ideas’ (see Figure 1). Solution principles are specified as solution ideas, if they show a general utilisability and the priority of the underlying problem idea, respectively.

Starting step 3, ‘solution principles’ are searched that correspond with the required function of the problem idea. *Cooling by carbon nanotubes* is an example for a solution principle. Different solution principles can fit to the required functions (see listing in chapter 2.2). The aim is to obtain combinations of ‘function’ and ‘working structure’ as a potential solution of the problem idea. Sources of information are documents or expert knowledge in particular. The knowledge of nanotechnology experts can be acquired by individual interviews, a Delphi study or a workshop to identify ‘solution principles’ and—later—‘solution ideas’. The description of the solution principles regard the key factors functionality, underlying working structure and any restrictions for application concerning the KO-criteria (step 1), that may lead to a rejection of the solution principle. The pre-selection of problem ideas and solution principles is based on the criteria ‘general utilisability’ of the solution principle and ‘priority of the underlying problem idea’. The general utilisability depends on the level of performance of the selected function-working structure-combination:

- Is the principle utilization given?
- Can the required function be realised by the solution principle?
- Is the principle feasibility for the enterprise given?

The prioritisation of problem ideas selects those promising the highest benefit for the enterprise. Criteria are strategic application benefit (comparable to Kano [37]), market potential, broadness of technology and accordance with objectives. By this, the number of problem ideas for the assessment procedure is limited to those, which provide from the market view the most benefit. If the combination of solution principle and problem idea has a medium to great priority and utilisability—meaning that nanotechnology offers a solution principle—the combination is selected for detailing and relevance assessing in step 4 (see specification criteria e.g. in [34, 46, 47]).

Step 4: Assessment of relevance and implementation

In the last step the relevance of the solution ideas is assessed in a portfolio approach to identify nanotechnological applications with a high problem solving potential. Assessment factors are the degree of performance (application view) and readiness of usage (developmental view). Strategic guidelines to adapt the nanotechnological concepts are being derived from the portfolio.

The assessment of each solution idea is based on the requirements of the corresponding problem idea. Such criteria are general criteria (from step 1) as well as problem specific requirements concerning e.g. function, application, design, environmental or implementation aspects (see step 3). For each requirement a target value (quantitative or qualitative) is determined. The degree of performance of the solution ideas is assessed in a value benefit analysis for each problem idea. Solution ideas not meeting the KO-criteria do not fulfil the desired performance. The description of solution ideas, their performance rating and the estimation of readiness of usage has to be made together with the experts. The results are transferred into a portfolio to indicate the technology relevance and corresponding strategic measures (see Figure 2).

The technology relevance is 'high' to 'very high', if the performance is fulfilled, otherwise the technology relevance is 'low' to 'very low', if the requirements are only poorly or not fulfilled. The high relevance of the application was yet assessed in step 3.

Depending on the position of the innovation potential in the portfolio (Figure 2), for each respective solution idea strategies can be deduced, based on possible strategic measures especially for emerging technologies [6]. Three strategies are proposed to deal with the different relevance of specific solutions and their readiness for usage:

- *Strategy A 'Reject'* (Portfolio field A): Reject the solution idea, as the performance is not or poorly fulfilled, independent of the readiness of usage.
- *Strategy B 'Watch'* (Portfolio field B): Follow up or watch the development of solution idea—as passive or active part— as the performance is only partially fulfilled, but the application is still in the research stage.
- Strategy C 'Realise' (Portfolio field C): Realise the solution idea, as the performance shows (partial) fulfillment, and the application is foreseeable or an application already exists.

4.5 Case study

This approach was developed and evaluated in a research project, funded by the German federal state of Baden-Württemberg. The objective was to identify relevant nanotechnological applications with a positive environmental impact. The application cases were provided by enterprises from the sectors 'cleaning' (enterprise A and B), 'cleaning equipment and systems' (enterprise C), 'filling and packing machines' (enterprise D) and 'kitchen and bath fittings' (enterprise E). All enterprises had the handling with liquids in technical systems in common.

With enterprise D, an enterprise of the engineering industry, the approach and the results of each step of the relevance analysis of nanotechnology are exemplary explained.

Step 1: Objectives

First, a standard filling and packing machine composed of all standard processes like washing, unpacking, sterilisation, filling, labelling, packing and pipes / tanks was selected. Requirements like over all objectives ("accordance with the technology leader strategy") or KO-criteria (filling machines for medical sector: "conformance with FDA-guidelines") were defined.

Step 2: Identification of problem ideas

After that, problem ideas were identified by the decomposition as described above. A function and a object model was generated, decomposing the filling and packing machine in its single omponents. Figure 2 shows exemplary the simplified object model.

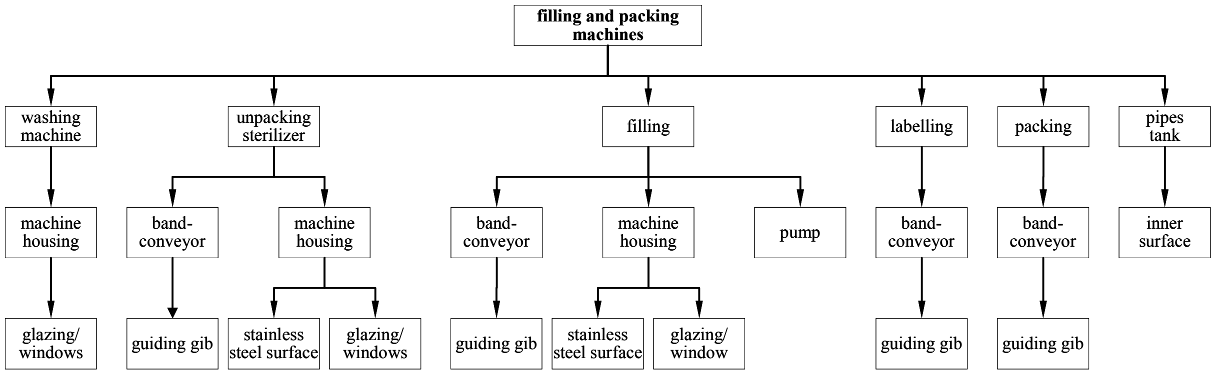


Figure 2. Object model of the decomposed filling and packing machines

Each element in the bottom line of the model was analysed if one of working principles corresponds to a problem, optimisation potential or a function of the element. If one or more working principles showed relevance for the element, the underlying problem or desired modification (e.g. optimisation or substitution of elements' properties, new application, substitution of an applied material by a new working structure (WS), etc.) was specified as a problem idea with the functional requirement. Table 2 shows in the left column examples of identified problem ideas.

Step 3: Identification of solution ideas

With the functional requirements, experts in the field of nanotechnology were searched in order to obtain information about suitable solution principles in the nanotechnology. The requirement was to select experts with a more overview like knowledge to get rather a general view about potential solution principles and working structure than a deep insight in single solutions. Experts from companies Henkel, Degussa, Bayer MaterialScience and researchers from Fraunhofer Gesellschaft were interviewed. The following Table 2 shows a selection of the identified problem ideas, the corresponding function by nanotechnology and the solution principles.

Table 2. Selection of problem ideas, functions and solution principles for a filling and packing machine manufacturer

Problem idea (PI)	Function (FU)	Solution principle (SP)
Reduction of liquid residua in tanks, pipes and pumps [PI1]	Hydrophobic or oleophobic	• Wax storage layer (regenerative lotus-effect) [SP1] • Hybrid polymer with hydrophobic and oleo-phobic functional groups [SP2]
Prevention of bacteria growth on surfaces of machine housings [PI2]	Antimicrobial	• Nano-silver [SP3] • Antiseptic ZnO nano-particle [SP4] • Photocatalytic TiO_2 nano-particle [SP5] • Hybrid polymer with preserving agents [SP6]
Prevention of electrostatic charge at the guiding gib [PI3]	Antistatic	• Antistatic zinc-oxide layer [SP7] • Antistatic antimony-tin-oxide layer [SP8] • Antistatic Indium-tin-oxide (ITO) layer [SP9]
Sterilisation of bins after the unpacking process from the outer package [PI4]	Sterilization, antimicrobial	• Nano-silver [SP3] • Antispetic ZnO nano-particle [SP4] • Photocatalytic TiO_2 nano-particle [SP5] • Hybrid polymer with preserving agents [SP6]
Prevention of fogging of housing glazing [PI5]	Anti-Fog, (super)hydrophobic or hydrophilic	• Hybrid polymer with (super)hydrophobic functional groups [SP2] • Hybrid polymer with hydrophilic functional groups [SP10] • Wax storage layer (regenerative lotus-effect) [SP1]

Different suitable solution principles were found by literature study and expert interviews. The collected solution principles for one problem idea partly based one quite different nano-effects. Whereas e.g. nano-silver inhibits enzymes of microorganisms, the photocatalytic effect of TiO_2 is used to generate hydrogen peroxide and hydroxyl radicals by presence of UV-light and water. Hydrogen peroxide and hydroxyl radicals are an oxidation agent, causing great stress to cells. Both the enzyme inhibition by nano-silver and the oxidative effects on the microorganisms by hydrogen peroxide leads to a die-off of mircoorganismen, TiO_2 even destructs organic matter.

All combinations of problem idea and solution principle were assessed in a portfolio approach according to their benefit and the principle practicability in order to identify and select the relevant ones for the detailed specification and analysis. Combinations that didn't meet the KO-criteria were rejected. The solution principle 'wax storage layer (regenerative lotus-effect) [SP1]' to reduce liquid residua in tanks, pipes and pumps [PI1] e.g. were rejected, as wax particles could diffuse in the liquids, which is for some application not allowed. Other solution principles like 'antimicrobial nano-silver' [SP3], 'antistatic zinc-oxide layer' [SP7] or 'antistatic antimony-tin-oxide layer' [SP8] were also rejected due to failure of performance/ KO-criteria. By this preselection, the number of to be specified and assessed combinations was reduced.

The following combinations of problem idea and solution idea were selected to assess their innovation potential:

- Innovation potential [IP1]: Reduction of liquid residua in tanks, pipes and pumps [PI1] by hybrid polymer with hydrophobic and oleo-phobic functional groups [SI2]
- Innovation potential [IP2]: Prevention of bacteria growth on surfaces of machine housings [PI2] by antiseptic ZnO nano-particle [SP4]
- Innovation potential [IP3]: Prevention of bacteria growth on surfaces of machine housings [PI2] by photocatalytic TiO_2 nano-particle [SP5]
- Innovation potential [IP4]: Prevention of bacteria growth on surfaces of machine housings [PI2] by hybrid polymer with preserving agents [SI6]
- Innovation potential [IP5]: Prevention of electrostatic charge at the guiding gib [PI3] by antistatic indium-tin-oxide (ITO) layer [SI9]
- Innovation potential [IP6]: Sterilisation of bins after the unpacking process from the outer package [PI4] by photocatalytic TiO_2 nano-particle [SI5]
- Innovation potential [IP7]: Prevention of fogging of housing glazing [PI5] by hybrid polymer with hydrophilic functional groups [SP10]

Step 4: Assessment of relevance and implementation

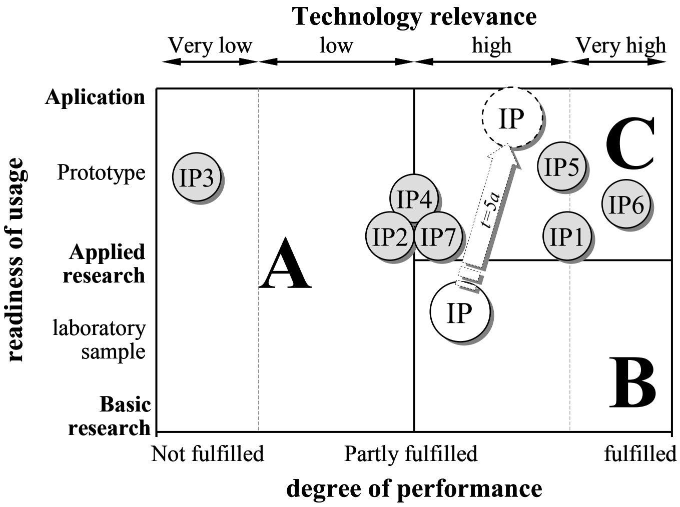
The problem ideas and the solution ideas of each combination were detailed by key parameter like performance parameters, applied coating technology, environmental aspects, design, environmental conditions of application or test and quality standards to broaden the information basis on the application and nanotechnology side. Criteria were e.g. resistance against treatment with detergents and chemicals, transparent application, durability or temperature conditions of the application. The key parameters were to allow a rough estimation whether the solution idea could fulfil the requirements or not. The assessment was performed in a benefit analysis wit an ABC-scale.

Again, nanotechnology experts were integrated in the analysing and assessment procedure. Workshops with experts from Bayer MaterialScience, Degussa and Fraunhofer Institute were conducted for each defined innovation potential. Experts with an expertise for single solution ideas (e.g. hybrid polymers with functional groups) and access to R&D capabilities were acquired in order to get access to the implicit knowledge within the nano-domain as well as to research infrastructure to assign feasibility studies. Additionally, bringing together the enterprise with the nanotechnology experts the enterprise could expand its expert network.

Within the workshops, each innovation potential was assessed regarding its degree of performance and readiness of usage. The degree of performance based on the key parameter consolidated from both problem idea specific constraints and conditions (requirements of the potential application) and solution idea related parameter. About ten key parameters per innovation potential were used.

Each innovation potential was put in the assessment portfolio to get an overview about degree of performance, its readiness of usage and the expected development. For every innovation potential a standard strategy was derived from placement in the portfolio.

Figure 3 shows the assessment portfolio. The circle represents an innovation potential. The dashed arrow and circle gives a suggestion of the expected development in e.g. the next 5 years (“Will the solution idea than be ready for usage?”, “Will the solution idea than meet the desired performance?”). The grey circles named IP1 to IP7 in the portfolio represent the innovation potentials of the case study (see chapter 4.5 and Table 2). As no innovation potentials were on basics research level, an estimation of the expected development in the next 5 years was not necessary.



Strategies for implementation of the innovation potential against technology relevance and readiness for usage:

Portfolio field A (left half)
Strategy A: Reject the solution idea

Portfolio field B (quadrant down right)
Strategy B: Follow up the solution idea

Portfolio field C (quadrant top right)
Strategy C: Realise the solution idea

Figure 2. Assessment portfolio and deduction of strategic measures
Circles represent a innovation potential (combination of problem idea and solution idea), dashed circle represents the expected position in e.g. 5 years. The grey circles IP1 to IP9 represent concrete innovation potentials of the case study (see chapter 4.5 and Table 2)

Afterwards, detailed feasibility studies conducted by the experts were arranged for the innovation potentials in the portfolio field C (IP1, IP5, IP6 and IP7).

6 CONCLUSION

The presented approach offers a procedure to assess the potential of nanotechnology for an enterprise. In order to cope with the complexity und technological diversity of nanotechnologies, a procedure was developed analysing and assessing the relevance of nanotechnology in relation to product-related problem ideas. Problem ideas represent opportunities for innovations, either by optimising the product (higher customer benefit) or by using a new technical paradigm (technological progress) – or both. The approach given has been structured according to VDI guideline 2220: Product Planning in the way that it necessitates to structure the nano-domain to manage the identification and assessment process.

The approach given is considered a starting point to approach nanotechnology and to evaluate related potential for technical or commercial success. These issues form core tasks of both technology and innovation management. Functional utility of nanotechnology is a precondition for its application—with this in mind the approach may provide an entrance point to nanotechnology. Furthermore, issues like suitable production processes for nano-featured products, toxicological risk prevention during usage of nanomaterials or necessary competencies to research and develop nanotechnological materials or products remain to be clarified in more detail. The novelty of nanotechnology is posed by its rather special scientific base, rapid development of knowledge, and the ongoing convergence within related fields of e.g. physics, biology, chemistry and engineering science. These circumstances put high responsibilities on experts to play a crucial role in transferring knowledge from nanoscience and nanotechnology into applications and producing enterprises, respectively.

REFERENCES

[1] Bullinger, H.-J. *Einführung in das Technologiemanagement: Modelle, Methoden, Praxisbeispiele*. (Teubner Verlag, Stuttgart, 1994).

[2] Spath, D., Dill, C. and Scharer, M. *Vom Markt zum Markt: Produktentstehung als zyklischer Prozess*. (LOG_X, Stuttgart, 2001).

[3] Day, G., Schoemaker, P. and Gunther, R., eds. *Wharton on managing emerging technologies*. (John Wiley & Sons, New York, Chichester, 2000).
[4] Day, G. and Schoemaker, P. A Different Game. In Day, G. and Schoemaker, P., eds. *Wharton on managing emerging technologies* (John Wiley & Sons, New York, Chichester, 2000).
[5] Lichtenthaler, E. Technology intelligence proceses in leading European and North American multinationals. *R&D Management*, 2004, 34(2), 121-135.
[6] Doering, D. and Parayre, R. Identification and Assessment of Emerging Technologies. In Day, G. and Schoemaker, P., eds. *Wharton on managing emerging technologies* (John Wiley & Sons, New York, Chichester, 2000).
[7] Shea, C.M. Future management research directions in nanotechnology: A case study. *Journal of Engineering and Technology Management*, 2005, 22(3), 185-200.
[8] Christensen, J.F. Asset profiles for technological innovation. *Research Policy*, 1995, 24, 727-745.
[9] Royal Society, ed. *Nanoscience and nanotechnologies: opportunities and uncertainties*. (Royal Society und Royal Academy of Engineering, London, 2004).
[10] Bachmann, G. Innovationsschub aus dem Nanokosmos. (VDI Technologiezentrum, Abteilung Zukünftige Technologien, Düsseldorf, 1998).
[11] Bushan, B., ed. *Handbook of Nanotechnology*. (Springer Verlag, Berlin, Heidelberg, 2004).
[12] Schmidt, G., Decker, M., H. Ernst, H. Fuchs, W. Grünwald, A. Grunwald, H. Hofmann, M. Mayor, W. Rathgeber, U. Simon and Wyrwa, D. Small Dimensions and Material Properties - A Definition of Nanotechnology. (Europäische Akademie zur Erforschung von Folgen wissenschaftlich-technischer Entwicklungen, Bad Neuenahr-Ahrweiler, 2003).
[13] Paschen, H., Coenen, C., Fleischer, T., Grünwald, R., Oertel, D. and Revermann, C. *Nanotechnologie: Forschung, Entwicklung, Anwendung*. (Springer Verlag, Berlin, Heidelberg, 2004).
[14] BMBF, ed. *Nanotechnology Conquers Markets - German Innovation Initiative for Nanotechnology*. (Federal Ministry of Education and Research (BMBF), Bonn, Berlin, 2004).
[15] Heubach, D. and Beucker, S. Application of nanotechnology in environmental technology - innovation potentials for companies? Insights from two german surveys. In Chein, H., ed. *International Symposium on Environmental Nanotechnology (ISEN) 2004* (ITRI, Taipei (Taiwan), 2004).
[16] Luther, W., Malanowski, N., Bachmann, G., Hoffknecht, A., Holtmannspötter, D. and Zweck, A. Nanotechnologie als wirtschaftlicher Wachstumsmarkt: Innovations- und Technikanalyse. (Zukünftige Technologien Consulting (ZTC) des VDI Technologiezentrum GmbH, Düsseldorf, 2004).
[17] Lux Reserach. The Nanotech Report: Investment Overview and Market Research for Nanotechnology (4th Edition). (Lux Research Group, New York, 2006).
[18] Roco, M. and Bainbridge, W.S., eds. *Societal Implications of Nanoscience and Nanotechnology*. (Kluwer Academic Publishers, Dordrecht, 2001).
[19] de Vries, M.J. Analyzing the Complexity of Nanotechnology. *Techné: Journal of the Society for Philosophy and Technology*, 2005, 8(3), 62-75.
[20] Heubach, D., Beucker, S. and Lang-Koetz, C. Uses of Nanotechnology in Environmental Technology in Hessen - Innovation potentials for companies. (HA Hessen Agentur, Wiesbaden, 2007).
[21] Rieke, V. and Bachmann, G. German innovation initiative for nanotechnology. *Journal of Nanoparticle Research*, 2004, 6, 435–446.
[22] Hessen Agentur. Nanotechnologie in Hessen - Ein Bestandsaufnahme auf Basis von Unternehmensbefragungen. (Hesssiches Ministerium für Wirtschaft, Verkehr und Landesentwicklung (Hrsg.), Wiesbaden, 2005).
[23] Gerybadze, A. *Technologie- und Innovationsmanagement: Strategie, Organisation und Implementierung*. (Vahlen Verlag, München, 2004).
[24] Zweck, A. Technologiemanagement - Technologiefrüherkennung und Technikbewertung. In Schäppi, B., Andreasen, M., Kirchgeorg, M. and Radermacher, F.-J., eds. *Handbuch Produktentwicklung* (Hanser Verlag, München, Wien, 2005).
[25] Hauschildt, J. *Innovationsmanagement*. (Vahlen Verlag, München, 2004).
[26] Cooper, R. *Winning at new products: accelerating the process from idea to launch*. (Addison-Wesley Verlag, Massachusetts, 1993).
[27] Khurana, A. and Rosenthal, S. Towards holistic "front ends" in new product developement. *Journal of Product Innovation Management*, 1998, 15(1), 57-74.

[28] Khurana, A. and Rosenthal, S. Integrating the fuzzy front end of new product development. *Sloan Management Review*, 1997, Winter 1997, 103-120.
[29] Marxt, C., Hacklin, F., Röthlisberger, C. and Schaffner, T. End-to-End Innovation: Extending the Stage-Gate Model into a Sustainable Collaboration Framework. In Xie, M., Durrani, T.S. and Tang, H.K., eds. *IEEE International Engineering Management Conference: Innovation and Entrepreneurship for Sustainable Development*, pp. Volume 3, 963-967, (IEEE Engineering Management Society (EMS), Singapore, 2004).
[30] Kline, S.J. and Rosenberg, N. An Overview of Innovation. In Landau, R. and Rosenberg, N., eds. *The positive sum strategy* (National Academy Press, Washington D.C., 1986).
[31] Grupp, H. *Messung und Erklärung des technischen Wandels: Grundzüge einer empirischen Innovationsökonomik*. (Springer Verlag, Berlin, Heidelberg, 1997).
[32] Ajamian, G. and Koen, P. Technology Stage Gate: A Structured Process for Managing High Risk, New Technology Projects. In Belliveau, P., Griffin, A. and Somermeyer, S., eds. *PDMA Toolbook for New Product Development*, pp. 267-295 (John Wiley and Sons, New York, 2002).
[33] Durrani, T., Forbes, S., Broadfoot, C. and Carrie, A. Managing the technology acquisition process. *Technovation*, 1998, 18(8-9), 523-528.
[34] Patzak, G. *Systemtechnik - Planung komplexer innovativer Systeme: Grundlagen, Methoden, Techniken*. (Springer Verlag, Berlin, Heidelberg, New York, 1982).
[35] VDI, ed. *Systematische Produktplanung*. (VDI Verlag, Düsseldorf, 1983).
[36] Veryzer, R.W. Discontinuous Innovation and the New Product Development Process. *Journal of Product Innovation Management*, 1998, 15(4), 304-321.
[37] Kano, N., Seraku, N., Takahashi, F. and Tsuji, S.-i. Attractive Quality and Must-be Quality. *Hinshitsu: Journal of the Japanese Society for Quality Control*, 1984, 14(2), 39-48.
[38] Hubka, V. and Eder, E. *Einführung in die Konstruktionswissenschaft: Übersicht, Modell, Ableitungen*. (Springer Verlag, Berlin, 1992).
[39] Birkhofer, H. *Analyse und Synthese der Funktionen technischer Produkte (Fortschrittberichte der VDI Zeitschriften Nr. 70)*. (VDI Verlag, Düsseldorf, 1980).
[40] Pahl, G., Beitz, W., Feldhusen, J. and Grote, K.-H. *Konstruktionslehre: Grundlagen erfolgreicher Produktentwicklung - Methoden und Anwendungen*. (Springer Verlag, Berlin, Heidelberg, 2005).
[41] VDI-2221. *VDI-Richtlinie 2221: Methodik zum Entwickeln und Konstruieren technischer Systeme und Produkte*. (Beuth Verlag, Düsseldorf, 1993).
[42] VDI-2220. *VDI-Richtlinie 2220: Produktplanung - Ablauf, Begriffe und Organisation*. (Beuth Verlag, Düsseldorf, 1980).
[43] Akiyama, K. *Funktionsanalyse. Deutsche Übersetzung Marc Pauwels*. (Verlag Moderne Industrie, Landsberg/ Lech, 1994).
[44] Gausemeier, J., Ebbesmeyer, P. and Kallmeyer, F. *Produktinnovation - Strategische Planung und Entwicklung der Produkte von morgen*. (Hanser Verlag, München, Wien, 2001).
[45] VDI-2803. *VDI-Richtlinie 2803 Blatt 1: Funktionenanalyse - Grundlagen und Methoden*. (Beuth Verlag, Düsseldorf, 1996).
[46] Breiing, A. and Knosala, R. *Bewerten technischer Systeme: Theoretische und methodische Grundlagen bewertungstechnischer Entscheidungshilfen*. (Springer Verlag, Berlin, Heidelberg, 1997).
[47] O'Meara, J.T. Selecting Profitable Products. *Harvard Business Review*, 1961, 39(1), 83-89.

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