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SCENARIOS FOR THE STRATEGIC PLANNING OF TECHNOLOGIES

Technology Scenarios at the Early Stages of the Management of Technologies[1]

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Abstract

Manufacturing based corporations often find themselves confronted with complexities of increased pressures to innovate in order to ensure their comparative market positions. In order to react to various exogenous changes corporations need to develop strategies that match their manufacturing resources as well as products with the markets requirements. Technology scenarios represent a holistic approach for managing innovation processes and technologies efficiently. A multidimensional requirement catalogue for specific product- market- combinations represents the fundamental building block for the ranking of particular material- components and technologies. The following analysis through evolutionary algorithms for compatibility between and amongst them provides the necessary information about their suitability. The resulting scenarios and roadmap and a regular monitoring process are prerequisite for the managerial decision making process and the implementation technology strategies.

Key words: Technology Scenarios, technological innovation, technology combinations, material component, evolutionary algorithms, technological maturity, weak signals, life cycle approach, product- market- combinations, monitoring

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Introduction

The early recognition and visionary anticipation of technological potentials as well as the combination of technologies and materials plays a vital role in a globalising world that is characterised by the dynamics of increasing competitive pressure (Geschka et al., 2002).

Various empirical studies have shown a correlation between the success of corporations and their efforts to enhance innovation (Berth, 2003; Domsch et al., 1994; Harhoff et al., 2001; Panenbäcker, 2001).

It has further been recognised that technological advancement significantly influences the innovation of processes and products (Gerpott, 1999). However, these opportunities also bear risks that decisively impact the subsistence of corporations (Geschka, 2002). In order to strengthen and augment profitability and competitiveness of corporations it is important to creatively coordinate the dynamic interaction of corporate strategy, products and technologies (Itami and Numagami, 1992).

Coping with present and future challenges requires targeted coordination of numerous present technologies as well as the search for new technologies through the process of strategic technological management. In this sense technological management systematically analyses these potentials. However, in order to determine the success of particular technologies the analysis has to focus upon the interacting forces and effects of the technological and the social environment. Naturally, this enquiry is often based upon contemporary expertise. With the lack of knowledge about technological developments that lie ahead it should be our primary aim to minimize the factor of uncertainty within the technological development process (Zahn and Braun, 1992). The Scenario-Method can thereby make a valuable contribution to the strategic planning of technologies (Geschka,1994).

This paper is primarily focusing on technologies in the manufacturing and assembly industry.

Definition and Purpose of Technology-Scenarios

Present literature outlines various definitions for the term Technology- Scenario (Gausemeier et al, 1996; Geschka, 2002; Paul, 1996). For the remainder of this paper the following definition of the term will be used:

"Generated Technology Scenarios comprise coherent combinations of material components and technologies, whilst simultaneously satisfying all conditional constraints (requirements and rules). " (Grienitz, 2003)

Technology Scenarios thus represent Process Chains (PC), that allow the creation of specific product-market-combinations. Figure 1 illustrates the structure of a Technology Scenario.

The framework of a Technology Scenario incorporates Process Chain Segments (PCS) of material components and technologies that represent the overarching structure of the Process Chain (PC). The specific attributes (e.g. glue, punch riveting etc. for the assembly process) are referred to as a Process-Chain-Segment-Attribute (PCSA).

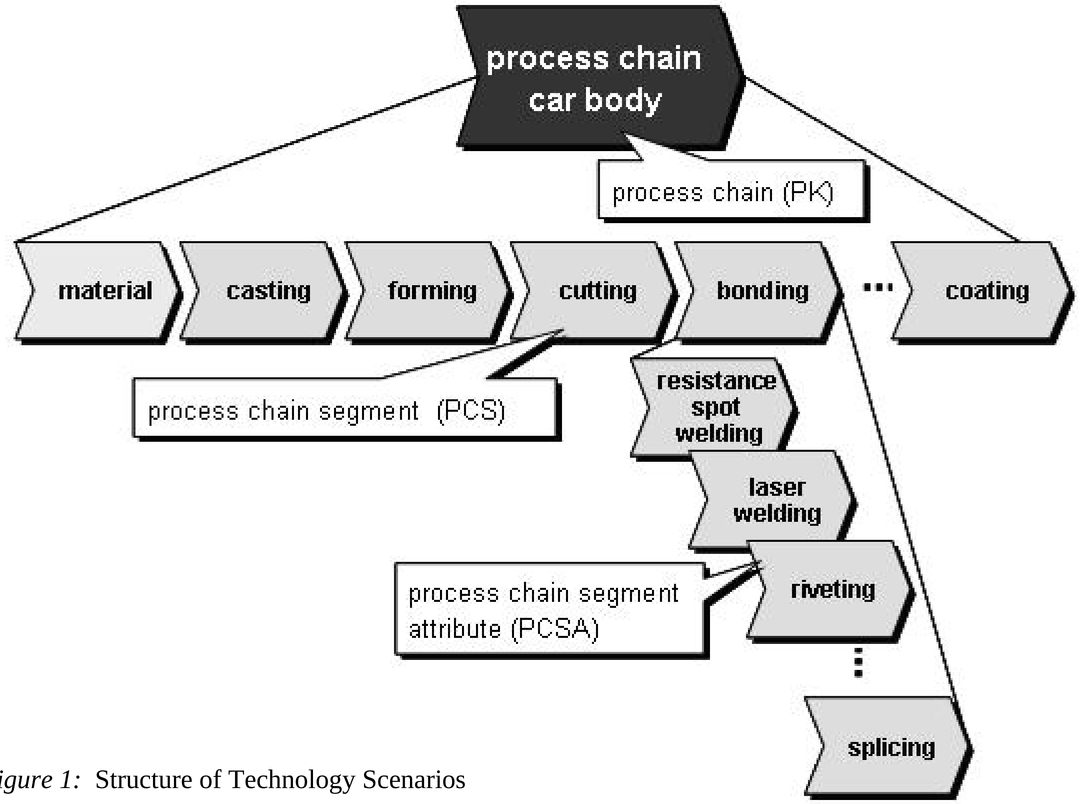

Figure 1: Structure of Technology Scenarios

With abstract reference to ANSOFF's (1957) Product-Market-Growth-Matrix and as a result of the level of awareness for material components and technologies, we can identify four archetypes of Technology Scenarios that suggest a particular need course of action.

The Archetypes are differentiated as follows:

- *Market penetration:* Technology Scenarios that are based upon established material components with mastered technologies require increases in efficiency.
- *Material Development:* Technology Scenarios that are based upon new, unknown material components with proficient technologies that indicate significant innovation with respect to material components. In this case the analysis should focus on potential substitution effects for alternative materials. A simultaneous analysis should also concentrate on new technological potential with existing material components.
- *Technological Development:* Technology Scenarios that are based upon established material components with un-mastered technologies indicate significant technological innovation. The potential of new technologies could lead to substitution of established technologies or open up new aspects for product development.
- *Diversification:* Technology Scenarios that are based upon unknown material components with un-mastered technologies open up new avenues for potential operational areas. This approach offers significant chances but also bears an additional risk that needs to be backed up with substantial investment. Dependent on the degree of advancement of the respective material component and technology, it is often the case that this form of Technology Scenario indicates opportunities for primary research areas or differentiation within the market.

Future products in specific market segments (known as Product-Market Combinations) should be implemented via Technology Scenarios. The sophisticated application of Technology Scenarios has become increasingly more company specific with regards to the corporation's requirements. On one hand, particular know-how with respect to material components may be considered, on the other strategic constraints and the ambition of technological market leadership may need to be factored in the Scenario.

Moreover it is to conclude that the fundamental tenor for the development of Scenarios is system thinking (Gausemeier et al., 2001) that equally focuses on socio-economic and political factors as well as technological components. This holistic interdependence is vital.

Literature overview and methodologies

The literature identifies several approaches to generate technology combinations. Gausemeier et al. (1999) defines technology scenarios for the external factors and interprets then only form the technological perspective. The identified technologies are then tested and ranked for their potentials and future suitability throught influence and consistency analysis.
Paul et al. (1996) uses a three-level enquiry to Scenarios regarding the external environment-, products-, technology scenarios. He construct Product scenarios and combines them with technologies according to the product structure. A continuous comparison through cross impact analysis - and consistency- analysis of the product- and environment scenarios leads to technology scenarios. Technologies are thereby not directly limited to product- or manufacturing technologies and therefore often lead to imprecise outcomes.
Fink’s et al. (2001) technology scenarios consist of technological development within the market- and product-environment. They start of with the development of technology scenarios. The second step focuses on the creation of process chains which represent combinations of manufacturing process. However the process creating of the combinations is not explained in great detail and thus remains unclear.
Geschka (1994) develops external environment scenarios that are aligned through technological developments. The applied method of consistency analysis thus focuses within the scenarios on the accounting of external factors with specific technological trends and developments.
Zwicky (1989) morphological matrix analysis consists of a combination of criteria and characteristics without the use of a consistency analysis. The method can be used for multiple applications since the attributes are fexible in their combination.
Ullmann’s (1995) scenario approach start of with setting the characteristic of the product such as the geometry of the process requirements. The second step analyses the various manufacturing process on the suitability, disregarding the product or the component that is meat to be produced. The third step combinations of the manufacturing process are weighted against the product requirements. Due to the complexity of this method it is possible that the best combinations remain unidentified. However the component specific combination of processes, multi- levelled grading of the assessment criteria for benchmarking and selection of process combinations is particularly useful for technical investment decisions, especially for diffuse fuzzy set oriented combination of technologies.
Fallböhmer et al. (2000) combines technologies with manufacturing processes with a specific focus on the a manufacturing task. Technologies weighted and stored neutrally in a database. Qualitative judgements are made about manufacturing materials and production costs. The focal point this approach is set on the potentials shortening the development of technology combinations through substituting manufacturing task or process. However the creation of technology scorecards is not transparent enough and lacks considerations of the market requirements. A combination based on the technology data model (TDM) and the technology information model (TIM) is applied.
Klocke (2001) creates technology scenarios through the comparison on manufacturing sequences. The ranking and prioritisation of technologies set through technical as well a economic characteristics through a multi criteria decision making process with fuzzy based AHP Algorithms. Since the sequences are at large determined by the transport and handing conditions the methods only allows a limited scope for the consideration of strategic aspects.

The literature identifies several approaches to generate technology combinations. However the herein given definition of Technology Scenarios can not be applied to all of them.
“Generated Technology Scenarios comprise coherent combinations of material components and technologies, whilst simultaneously satisfying all conditional constraints (requirements and rules). “ The comparison of the various approaches should nevertheless indicate their resemblance in order to foster and identify new approaches.

Strategic Planning of Technologies as a framework for Technology Scenarios

The strategic planning of technologies is a systematic approach, that utilises the potential opportunities arising from competition, market situation, technologies and material components to the advantage of corporations. This process can be broken down into six phases; Corporate Analysis, Market Analysis, Technological Projection/Prognosis, Strategy Development, Strategy Implementation and Strategy- Controlling. The initial focal point thereby rest upon an overall corporate »Analysis«. The results from this Controlling Process (Analysis) serve the purpose for determining the progressive structure of the individual phases.

The first phase comprises the recognition and determination of the strategic objectives and the respective positioning of the corporation. The subsequent step focuses on the identification of key competences. This phase of corporate analysis is then coined with the identification of the operational processes (framework). In other words a descriptive structure serves the purpose to set firm cornerstones for the planned course of action.

The goals obtained form this process therefore define the path of implementation for the strategic planning of technologies. It is thereby vital that definition of these goals have to be aligned with the overall corporate strategy. This postulates that future technological strategies must be consistent with the strategic plan in order to minimize potential interferences.

The second and third phase focuses on the strategic foresight, firstly from the market perspective and secondly from the technology perspective. The market analysis serves the strategic foresight and the development of scenarios in order to determine the external environment and to identify potential future markets. Simultaneous coupled with this process is the formulation of future product scenarios (Gausemeier et al., 1996). The scenarios thus represent the composition of technological and economic factors from the consumer perspective. The incorporation of market- and product- scenarios consolidations and specifies the operational field for the technology scenarios. For further analysis one or a few of the identified relationships resulting from the Product-Market combination, are going to be verified for future analysis.

Phase three illustrates the generated technology prognosis (generated by the Technology projection) comprise coherent and compatible combinations of material components and technologies, whilst simultaneously satisfying all conditional constraints (requirements and rules) for the implementation and compliance resulting from the Market- Product Combinations.

Phase four constitutes the formulation of Technology Strategies. It describes the key attributes and functions of the technologies and material components that determine the future success. The derived strategic focus describes the implementation of the goals within a clearly structured process. The strategy thus entails the path to success (Gausemeier and Fink, 1999). The implementation of the strategy is on one hand determined through the market segment the corporation would like to compete in and on the other hand determined by the key competences with which the organisation would like to operate.

The technological strategy should thus answer the following fundamental question:

“**Which technology, from which source, should at what point in time, at which proficiency level be utilised for what particular purpose?”** (Wolfrum, 1991)

Technological Strategies can be determined for the corporation as a whole as well as for single business units. In any case it is important not to significantly divert from the overall technological orientation and corporate strategy of the organisation. The decision to engage or not to engage in specific technologies is fundamentally determined by the respective field of a particular technology.

Phase 5: Strategy implementation – How do we accomplish the plan?

Phase five emphasises the changes in corporations through the implementation of strategy. The strategic goals are broken down into subordinate goals within the overall transition process. Hence the consequences and procedures are derived accordingly. The implementation is controlled and monitored through a performance measurement system that guides the overall procedure (accomplishment control). The operationalisation of particular goals can be carried out through Balanced Scorecard (Kaplan and Norton, 1997) or Value Based Management (Brunner, 1999).

Phase 6: Strategy controlling – How to implement an early warning system?

Phase six describes the process of Strategy controlling. The technology scenario is not a one-off exercise. Technologies, material components, as well as market-, technology- and external- environment scenarios require continuous monitoring framework. Seeming peripheral issues or weak signals indicating serious alterations to the business environment require an early recognition and interpretation. This can be operationalised through the implementation of a strategic early warning system that sensitises the observational awareness in the relevant field (scenarios, materials, technologies). Employees in respective operational key positions (so-called Scanners) or external remedial advisors can enhance this process. A centrally controlled early warning system will enable the collection, assessment and reporting of signals.

Strategy Controlling is thus a continuous exercise. Out of this monitoring process emerges, dependent on the respective signals, a new process that taps into the current phase within the development cycle of the strategic planning of technologies.

The super-ordinate cycle of the strategic planning of technologies shows, that intermediate results are partly processed numerous times. This is particularly the case when cycles are encountered in regular intervals. Essentially it is important to monitor as many processes and phases whereby past experience has shown that the greatest benefit arises form the documentation as part of strategic controlling process. For storing and managing this information, computer based models (based on the Technology Score Card Method) are necessary to effectively assess and manage results.

The utilisation of Technology-Scorecards in the strategic planning of technologies incorporates personnel at all levels of the corporation during the initial planning process. This process not only involves fully qualified business people that shed light on the economic factors of technologies and materials but also engineers that focus on the technological possibilities of products. This integrated process allows the judgement and amalgamation of various perspectives, regarding the technologies and material components in form of a Balance Score Card (Horvath & Partner, 2001) – e.g. finances, employees, strategy, time, maturity.

New methodology for the creation of technology scenarios

A comparison of the outlined approaches suggests a particular need for action for a new methodological focus in the strategic planning process of technologies and scenarios.
The approaches in present literature seem unsatisfactory when they are examined for their adaptability to complex change and dynamics as well as their flexibility to react to the naturally occurring changes in the external environment. The above outlined methods are only partially applicable for the development of future Technology Scenarios since their core focus tends to be the scheduling of machines and processing sequences. It is exactly at here where the present literature is lacking the strategic point of reference necessary for planning technologies in the long run.

None the outlined methodological approaches has yet managed to incorporate holistically the social, political and technological factors that are indispensable for the creation of material component- and technology- scenarios. Having outlined the methodological gaps in the present literature it is the aim of this paper to close these gaps and thus provides a coherent solution for the realisation of Technological Scenarios.

The following section develops the methodology for the strategic planning of technologies through a structured life cycle approach illustrated by the means of an example from the automotive chassis manufacturing industry. This approach rests upon an integrated and intuitive discourse that is supported through a software based application.

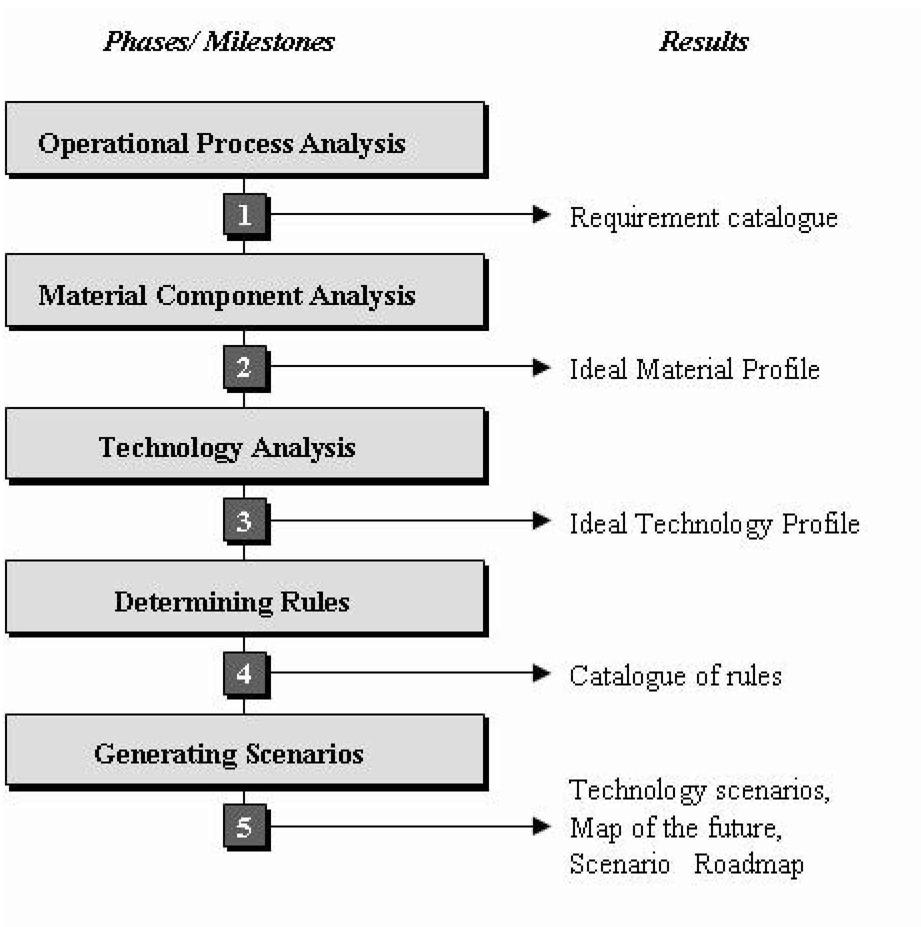

Figure 2: Phased model for the creation of Technology Scenarios

The process of Technology Scenarios is structured into the following five phases (Figure 2):

- *Operational Process Analysis:* The operational process analysis represents the foundation for the combination of material components and technologies. Firstly, a requirement catalogue (key criteria) is produced to compile future product-market- combinations that in return allow the characterisation of the various perspectives. The subsequent steps focus on the selection of a particular combination in order to agree specific requirement criteria (Ideal- Profile) that will constitute the basis for all further considerations. Once having shed light on a particular combination a benchmarking exercise will determine the identification of requirements and their respective magnitude. The operational process analysis is structured into five separate segments and represents the overarching framework for Technology Scenarios.
- *Determining Rules:* These rules set out the requirements for the assembly process for the Technology Scenarios. More specifically these detailed rules represent an assessment of material components, technologies and auxiliary conditions that result from the documentation and their technological interconnections.
- *Material Component Analysis:* The Material Component Analysis is of vital importance in the field of strategic technological planning since the selection of materials determines the results and the construction of the end product (Fischer, 1994). Following the structuring process (e.g. material/ substance groupings (Warnecke and Westkämper, 1998) a further analysis matches the relative level of 'fit' of the requirement profile with Ideal Profile. The result of the material component analysis is a detailed documentation of substances and material components.
- *Technology Analysis:* The methodology of the Technology analysis is similar to the above described material component analysis. After the structuring process of the technologies, considerations focus on the identification and applications of existing and potential new technologies. These are then structured in a process chain. The Ideal Profile is then again set into direct comparison with the requirement profile. The result of the Technology Analysis thus provides a detailed documentation of all technological aspects.
- *Generating Scenarios:* The scenario generation phase merges all the information that has resulted for the documentation of materials and technologies as well their interdependencies set out under the rule framework. The generated scenarios are illustrated graphically in order to ensure a clear and functional communication of the findings. Additional roadmaps will simultaneously support the various perspectives for the potential development.

The following sections will discuss in further detail the creation of technology scenarios. Starting of with an outline of how to set out rules, we will then continue to address the construction of the requirements of the product-market-combinations and the surrounding feature that are necessary to carry out the technology scenario.

Determining rules

This section depicts the setting of rules, considering all boundary conditions that enable, assume or eliminate the use of technologies and materials. It is therefore necessary to view these conditions for the creation of technology scenarios as a parameter of the overall optimization process. The application of a holistic requirement catalogue involves economic, social as well as technical aspects. However numerous rules, when applied simultaneously create asymmetries within the framework that interfere with the overall outcome. Given the resulting complexity, the principle of Occam's razor, popularised by the English philosopher William of Occam, describes a fundamental criterion that aids the process when it comes to determining the rule framework. One should thereby not increase the number of entities (rules) required to explain a given phenomenon beyond what is necessary. The consideration of this aspect has been key in the choice of the structure optimization process.

In order to develop Technology Scenarios these detailed rules need to be documented and catalogued. This catalogue is specified through six key segments:

- The structure represents the construction and sequence of the Technology scenarios. It is determined and constrained through the operational field.
- The requirement profile (specification catalogue) defines key attributes and specifications that determine the ideal- profile. With this in place, direct comparisons of compatibility can be made between the material components- and technology-analysis and the Ideal Profile.
- The material- technology- ranking analyses the parallel applications of a scenario.
- The ranking and analysis of technological interactions indicates the potential requirements for a collective application of technologies.

- The ranking and analysis of material component indicates possible requirements for a collective application of materials.
- Further rules emerge from the occurrence of substituting technologies and their consequential requirements and conditions.

  It should however be kept in mind that with the exception of the first two rules (requirement profile, structure) that particular cases offer or require the expansion as well as the possibility of not applying or substituting one or more of the remaining four rules. Generally speaking, leading on from Occam's razor, the principle that should apply, when determining the rule framework, is to maximise the benefit of the Technology Scenarios with a minimum amount of rules in order to allow sufficient and efficient scope for the scale of innovation (Schwefel, 1977).

Operational Process Analysis

The balanced scorecard method considers various perspectives and respective attributes. Every perspective thereby indicates technical, economic, ecological and ergonomic requirements (Breiing and Knosala, 1997; Brose, 1982; Zahn and Braun, 1992).

The assessment of each and every perspective should be carried out very meticulously. The selection of attributes and the level of details have to be considering under the constraints of limited resources (time, finances, labour). The effort of obtaining this information needs to be examined and reasonable balance with the quality of the final outcome (marginal benefit that arises from additional research) (Breiing and Knosala, 1997).

The allocation of the identified characteristic and attributes of the perspective should be viewed as a support mechanism rather than a conclusive answer. Given the complexity of the issues it is inevitable that the identified characteristics can have explanatory power for a diverse range of outcomes. But what is import here, is the recognition of these variables and not the allocation.

A neutral and balanced focus regarding the list of attributes should be treated with high priority. This means that a lot of ground has to be covered to integrate and account for all explanatory variables. Identified product-market-combinations (from the initial assessment phase of the external situation) can aid the search for appropriate characteristic or indicate alternative attributes. Generally it should be the aim to match the list of attributes with the requirements of the product-market-combinations.

- *»Market and Competition«* – Critical Success Factors are to be addressed in the context of the »Markets and Competition«. These factors are vital for the success of an organisation (Gausemeier et al., 1996). An example of a critical success factor could be the level of market penetrations resulting from research activities.
- The aspect of *»Costs and Finances«* is primarily to be considered in the context of financial aspects (products, production, organisational structure or necessary investments) for potential Product Market combinations.
- *»Strategy«* – The analytical perspective of cyclical developments identifies the super-ordinate Corporate Strategy (positioning and key competences). The strategy phase thus sets out the super-ordinate direction of a corporation for specific product market combinations. (Entrepreneur, early followers, imitator (followers) etc.), competitive Strategy, (cost leadership, technology leadership, expert knowledge etc.) research and development strategy (preceding research, cross licensing etc.), (Seibert, 1998) or market-positioning with Reference to ANSOFF (market penetration, differentiation etc. (Gausemeier and Fink, 1999).
- The perspective of *» time and maturity «* describes the receptiveness of new products within markets and their respective environment. Even though an innovation is ground-breaking, the customer might not directly be prepared to invest in them. The levels of maturity of markets or products are thereby described through the life- cycle analysis.
- *»Opportunities and risks«* – On the contrary to the key success factors (addressed in 'markets and competition') opportunities and risks are the driving factors behind the developments in the future production. The operational structure is consequentially aligned to the identified success factors. After the documentation of the driving factors light is shed upon the evaluation of product market combinations.
- On one hand the phase of *»functions and constructions«* describes the functional abstractions of product market combinations. On the other hand, the lists of different construction possibilities are to be cross checked with the opportunities for product- market-combinations. In this step it is useful to refer to the morphological thinking described by Zwicky (1989). The questions one should ask is: Which functions does the customer regard as important and which are to be neglected?
- The perspective *»processes«* looks at all the value added that arises, ranging from the initial developments stages, the production process to the final point sale. The related question or

requirement are for example documented in form of perspectives: "Which production method (frequency and repetition of capacity), which chain of production (spatial arrangement) or which manufacturing structure (sequence of processes) should be used?" (Eversheim and Schuh, 1999). The process of reparations should also be considered within. This process could for example include criteria such as the capacity of repair or effort of repair.

- *»Employees«* – Bullinger and Lott, (1997) note that the employee is the central, pivoting point of success for a corporation. The perspective employees describe the required skills as well as the prerequisites for high motivation and quality.
- The perspective *»ecology«* describes the product as a whole with reference to the characteristics of its environment. This involves a holistic view on the life-cycle (extraction, application and utilisation). It is essential to amalgamate and recognise the interaction of ecological and economic factors already in the very early stages of the product development.
- *»Regulations«* – The documentation of conceptually influencing factors such as legislative restrictions, rules and regulations as well as guidelines (internal/ external) are summarised in the form of a constraint list (Eversheim and Schuh, 1999).

For the purpose of defining the key attributes, we identify those characteristics that have the best fit with the market product combinations.
The ideal-profile of requirements is almost identical to the list of constraints for a new product (Breiing and Knosala, 1997). It also acts as an identification of conceptual, determining parameters (Rasenack, 1998). The description of requirements sketches the expected performance of a product correspondingly with the rules, regulations and specifications (Breiing and Knosala, 1997).

Generating Scenarios

Technology scenarios are created through the combinations of material components and technologies. In this step ancillary conditions laid out in the requirement profile have to be considered. One will soon realise that the divergence of objectives doesn't always make it easy to directly derive an optimal solution.

This section outlines the process of reasoning for the selection of the optimisation process. Chapter 4 introduced the various methods and approaches for the development develop of Technological Scenarios. However with reference to their methodological requirements it was illustrated that existing algorithms are not appropriate.

Since the amount of auxiliary conditions can be numerous and since the optimisation of local goals of optimisation can not necessarily be accounted for as the total maximum or minimum it proves difficult to define an overall global optima's (solutions that meet all predefined requirements). Thus it is more important to have a solution driven strategy that focuses on the local optima from which specific Technology Scenarios can be defined and selected (Rasenack, 1998).

The search for a solution is determined through a complete calculation of all aggregated combinations. This means that only six Process Chain Segments (PCS) with 10 process chains characteristics (PCC) result in 60.466.176 batches that have to be evaluated and audited. The level of complexity and the associated effort for the evaluations does not make this approach very practical.

The commonly applied Consistency- Analysis or Cross Impact Analysis can also not be drawn upon for the creation of technology scenarios as these methods only consider future projections pair wise (Gausemeier et al., 1996). The paired results are insufficient since they do not satisfy auxiliary conditions Schwefel (1977), Nissen (1994, 1997, 1998)) and respectively Propach (2002) who introduce a wide ranging catalogue of solution strategies based on several optimisation tasks. Having compared all present strategies with respect to their likelihood of convergence (referring to the local optima) the selection points towards the Evolutionary Strategies (ES). Other processes of optimisation, show advantages with respect to the initial research time, however their likelihood of convergence is rather weak.

In the framework of this work, a further description of the solution process will be paramount (Rasenack, 1998), thus the remainder of this section will develop evolutionary strategies. With the application of ES it is possible to overcome numerous of auxiliary conditions and whilst being able to deliver a product-technology-bundle in the optimisation process. These requirements are best meet through natural analogical processes.

For the purpose of hereafter used annotations and terminologies refer in the table, "Terminology of Evolutionary Strategies (Basic principles)" by Nissen (1998).

Terminology of Evolutionary Strategies- Basic principles (Nissen, 1998)

Meaning	*Relevance of Evolutionary Strategies*	*Technology scenario*
Individuals	Structure (entails the relevant elements that constitute the solution)	Process- Chain- Segments (PCS)
Population (of Individuals)	Number of structures (Solution alternatives)	Number of Process- Chains (PC)
Parents (μ)	Selected individuals for the reproduction	For the selected reproduction PC
Parent	One reproductive individual	One reproduction –PC
Fitness	Quality of solutions with regards the target criteria	Value of the Fitness-function, determined by the set of rules
Offspring, Children (λ)	Individual that stem from the parent	PC generated from the Parents
Generation	Process-Iteration	
Mutation	Search function that modifies an individual	Operator, modifying the characteristic of a Process Chain Segment
Recombination / Crossover	Search- operator that mixes all elements of the individuals.	Operator that mixes several PC with one another

Since the 1960s researchers have tried to solve problems through the use of natural analogies whereby they attempt to replicate biological paradigms. Evolution has shown that the living species of today, that emerged from a "long term experiment" (3 Billion years) (Rechenberg, 1973) have optimally adopted to the give environmental factors whereby less adaptable ones have been eliminated. Evolutionary theory has shown that the constant struggle and competition of species for resources and space has been the driving force for the changes and improvements of species and the populations. The results and knowledge derived from evolution, is the focal point of Bionics (Rechenberg, 1973).

Along side the research field of bionics is that of evolutionary techniques or respectively- Evolutionary Algorithms (EA's). EA's are used in particular for the identification and optimisation of particular processes (Nissen, 1994). However both fields of research follow a common goal. They attempt to simulate the principles of evolution and apply its logic in an abstract way to complex problems of optimisation (Propach, 2002).

Evolutionary algorithms imitate the primary principles of evolution: Multiplication (replication), alteration (variation) and choice (selection) on an abstract level (Nissen, 1994). Evolutionary algorithms (EA's) differentiate themselves from conventional search- and optimisation methods through their close adaptation of natural terminologies. Thus they focus on the natural evolution process that is particularly advantageous for optimisations. The difference of deterministic and evolutionary algorithms is highlighted by the characteristics that the latter is simply based on chance and can be applied without any kind of constraints. In theory it is possible to use EA's universally (Weicker, 2002).

The challenge of creating technology scenarios will be outlined in the remainder of this section through the application of Evolutionary Strategies (ES) that have been derived from the EA's. Rechenberg (1973) defines evolutionary strategies as multi-applicable process of optimisation. They simulate strategies on an abstract scale, whereby the level of relative adaptation to the given environment determines their survival. The process and function is illustrated in a rather abstract way in Figure 4

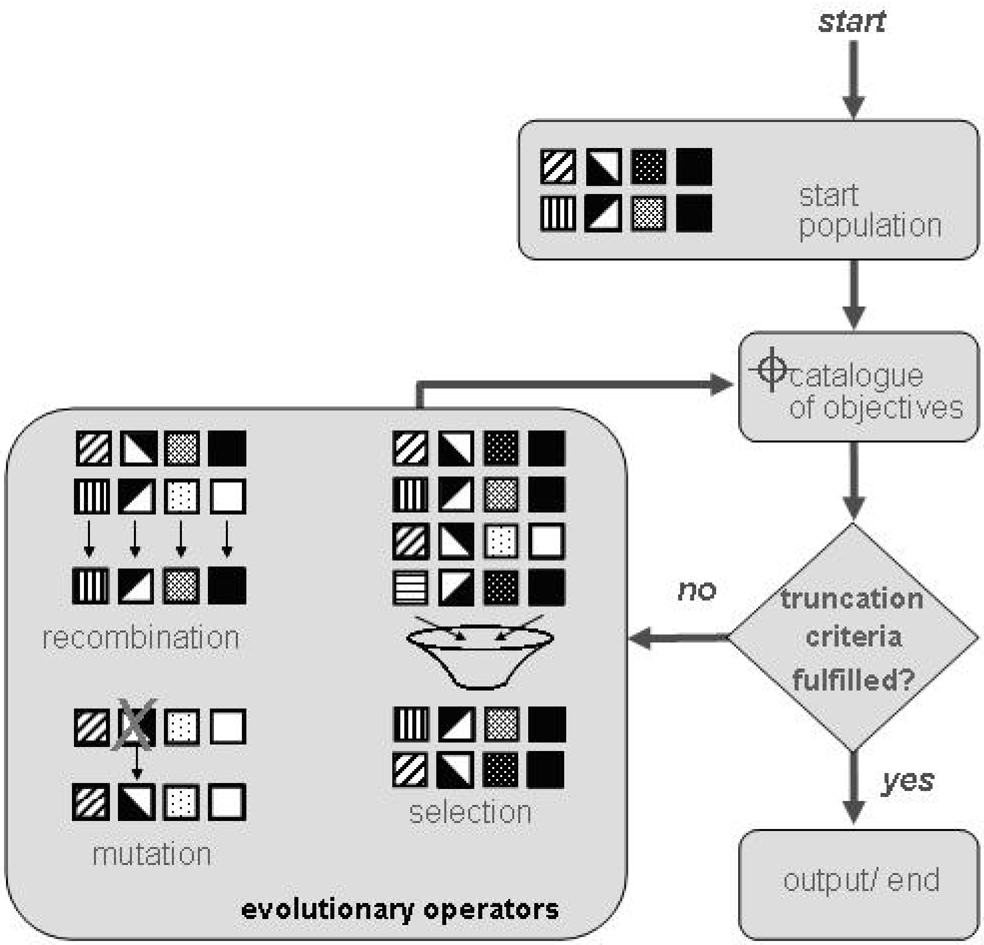

Figure 3: Process of Evolutionary Strategies

Nissen (1998) describes the process as followed:
"One starts of with a frequent stochastically generated initial population of possible alternative solutions that are ranked to their 'level of fit' accordingly. An interactive cycle generates repeatedly modified new suggestions for the old solutions. [...] In the process of creating offspring the information (solutions) from the parent generation is copied (replicated) and applied to several other outcomes such as mutations or crossovers that could determine solutions. The resulting offspring from this process is then given values and selected so that a new population is generated (selection for survival). It is thereby possible, that the parent generation could rival with their progeny for survival."

Following the rational of the Evolutionary Strategy, the creation of product component and technology bundles "select and drop" (whilst considering the sequence) are comparable. According to the evolutionary strategy and the notation from Figure 3, parents (m) and children (l) represent the outcome of the optimisation cycle (generations). Children and parents represent intermediate solutions- so called product component and technology bundles.

The first step involves the identification of universal populations of technologies and materials whereby first bundles are created following the scenario structure. This process is repeated until at least two material- technology-combinations (starting population) are generated.

The whole solution space is derived through the potential amount of possible combinations of materials and technologies. It is assumed that all technologies are compatible with one another and that material-technology-bundles begin with one material component. The reality however shows that it is difficult to combine fundamental technologies. Additionally it should be kept in mind that previous parents or children narrow the space even though the production of children indirectly contains the universal population of material components and technologies. This means that no child can be identical to one particular parent or other child.

Once the starting population is identified, the repetition of the three fundamental steps is carried out as follows:

- *Replication, Recombination and Mutations:* The parents are copied. Through the process of recombination or mutation new children are created (Nissen, 1998).
- *Ranking of a bundle (offspring):* Parents and children each represent bundles. These are evaluated and ranked according to their level of fitness.
- *Selection:* The level of fitness is key to the selection of parents and children. The section determines which bundles will be kept for the next population (survival of the fittest). Parents and children are equitable (hold the same level of importance) when comes to the selection process. The new population then triggers the next step of iteration (Nissen, 1998).

Iterations, the creation of solutions (generations of parents and children) are carried out until the changes in the target function are minimized. The target function is measure through a value of fitness which determines how good the derived solutions fit the respective requirements. The value of the target function is iterated until the threshold of a particular amount of generations (50 to 200) has been generated. The adept variations of the evolutionary operators should indicate whether or not the solution is based on a local maximum. Once the two indicators, one being the value of the target function and the other being a large number of generations, the search for a solution is completed. For the further processing or interpretation the children that have generated in the final round are to be use for visualisation and Roadmapping.

In order to communicate and present the technology scenarios, especially to people that where not involved at the stage of the development process, a map (visualisation) of the future as a result form the Multi-Dimensional Scaling (MDS) illustrates the separation of the scenarios form one another.

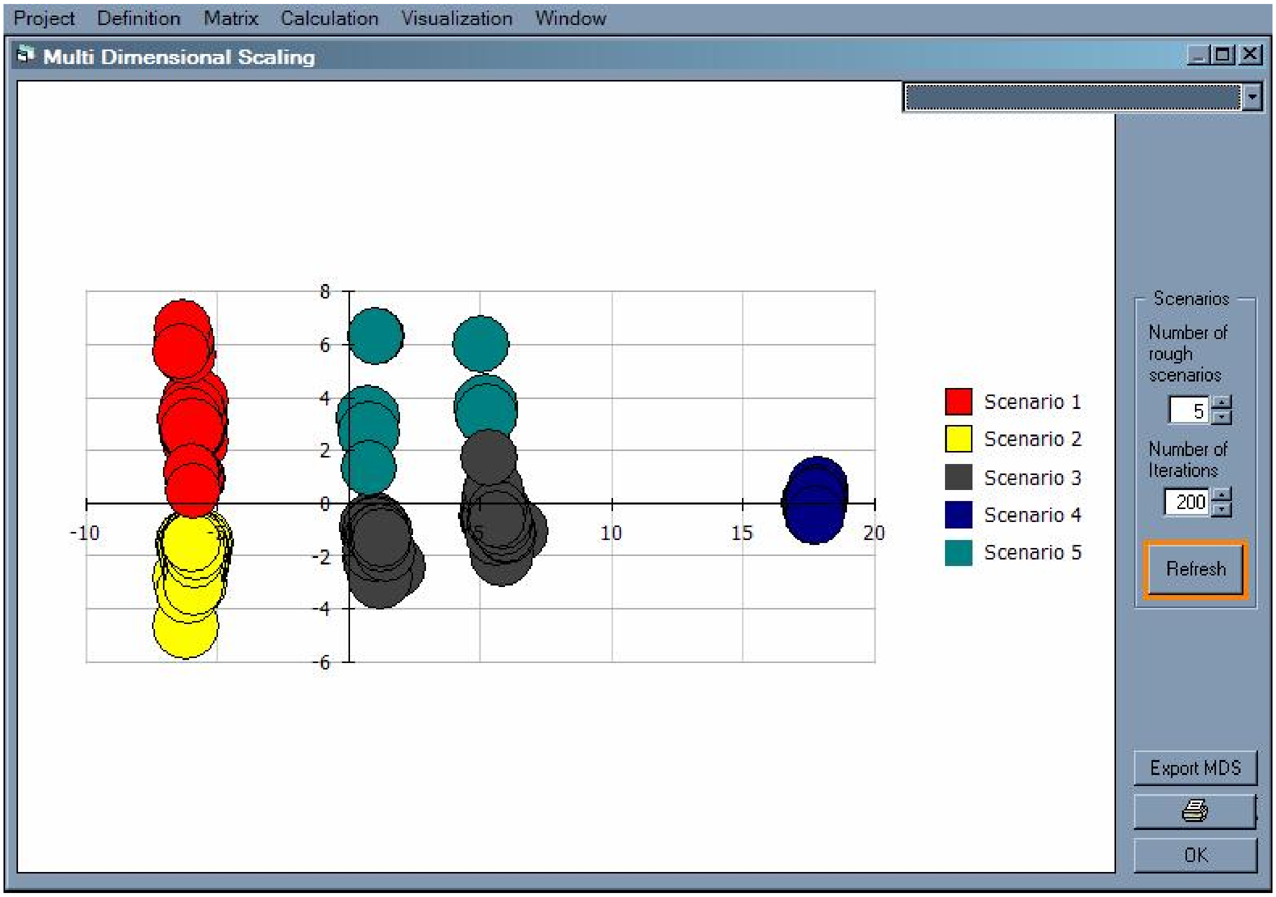

Figure 4: Visualization of Scenarios in the Map of the Future

Each bubble represents one possible material-technology-bundle whereby each cluster outlines one technology scenario. Through the list of characteristics and attributes additional key aspects can be highlighted and added to the map.

Scenario roadmapping aid the Scenario Controlling Process. The requirements catalogue contains the perspective »Time and Maturity«. The aggregation of technologies and material components with respect to their availability and maturity allows the positioning of the scenarios the scenario roadmap. The map illustrates the possible paths of development for technology and material components.

All material components and technologies of a particular technology scenario are carried out in parallel. The respective timeframe for change from one maturity level to another determines the position in the roadmap . For technology scenarios an operational field can be derived.

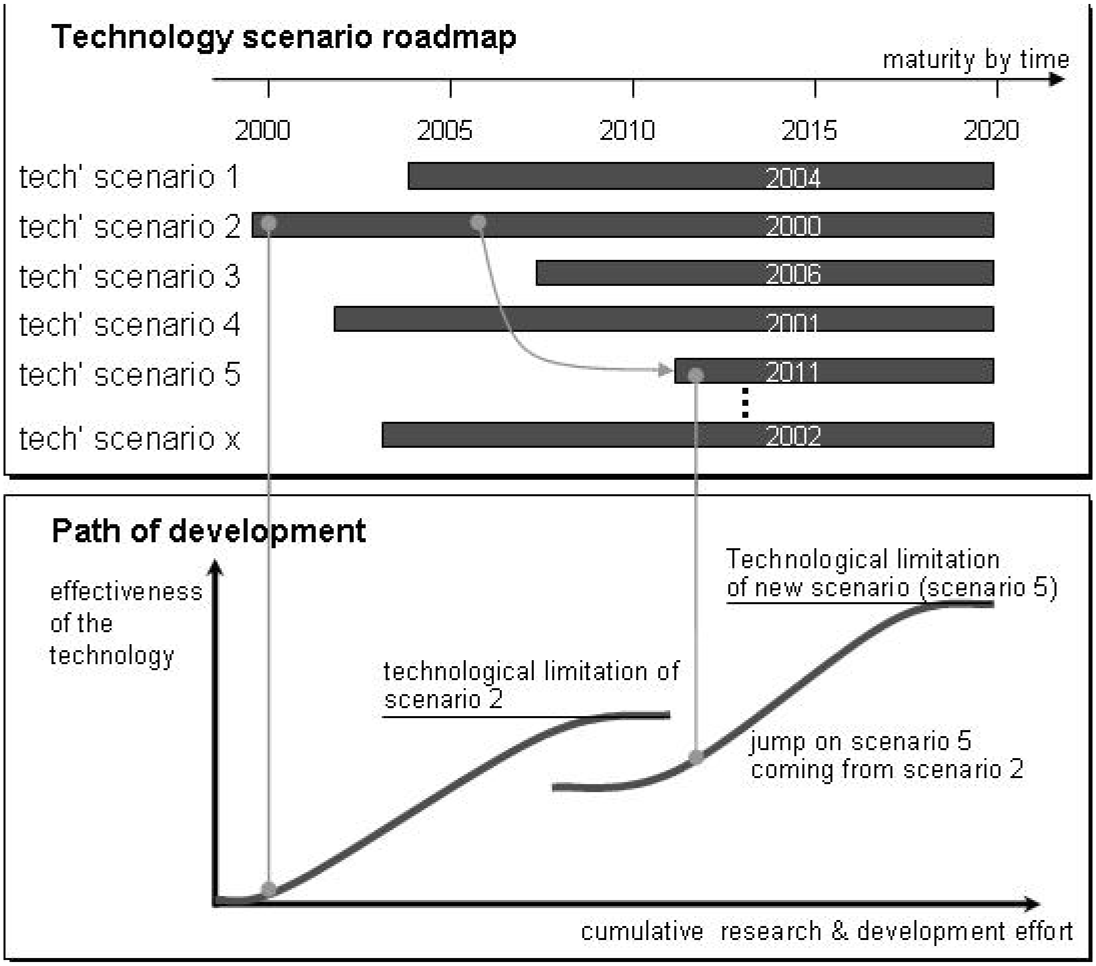

Figure 5: Technology scenario roadmap and the path of development

From the overarching road map for all technology scenarios (respectively materials and technologies), generally applicable development paths can be highlighted. Moreover, it is possible to identify stages of development for specific technologies or materials. This means that for example two scenarios use the same material component that in return can be treated with two different technologies. Consequentially it is the maturity of the technologies that highlights possibilities for technological advancement.

6 Conclusion

This work defines Technology scenarios as coherent combinations of material components and technologies that are strongly relevant for the creation of particular Product Market combinations.

Our initial analysis has shown that there is yet no coherent methodology that allows a complete integration of the cycle of strategic technological planning nor do any of the existing methods provides a holistic judgement of technologies and materials from an socio-economic, technical and ecological perspective.

The approach illustrated within can react to the changing requirement profiles that are developed in the technology scenarios whilst in return enabling the applicant to derive, implement and coordinate the technology strategies. The first step in this process begins with the collection of variable for a multidimensional catalogue that represents the requirements of selected products in specific markets (product- market- combinations). This requirement catalogue in return represents the fundamental building block for the ranking of material components and technologies, whereby the suitability is determined through the implementation of particular combinations. Moreover potentials for their compatibility and interlinking are analysed. The results of this evaluation and identification of constraints are coined in coherent Product- Technology- Combinations (Technology Scenarios) that are perfectly suited for the implementation of product- market- combinations.

The process of strategic technological planning is not a one-off analysis but should be undertaken regularly. The continuous observation of the environment will significantly support the results derived from the ranking (so called material technology characterisations). This characterisation represents an important tool for the early 'technological reconnaissance'.

Future research in the field should concentrate on the optimisation of the Algorithm that is use for the creation of the technology scenarios. Application of self adjusting strategy parameters could hereby accelerate the identification of the solution algorithm. A process of self optimisation could incorporate the changes that have emerged from the operators (recombination and mutation) in the evolution process automatically. The adjustments made for qualitatively high individuals are thereby stored so they can be used for further adaptations. Subjects are hereby the Strategy-parameters are subject to changes in the evolutionary operator. Such a procedure would give the opportunity for flexible and direct adjustments; however this can have the effect that control is loss through outside influences. (Weicker, 2002).

Fundamentally it is to say that this approach offers several opportunities for abstraction that can be integrated existing approaches well beyond the management of technologies. A vital importance is this context constitutes the early 'technological reconnaissance'.

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