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Enhancing Creativity of Strategic Decision Processes by Technological Roadmapping and Foresight

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Abstract—**The quality of a company's strategic planning is a key factor influencing its competitiveness and development prospects. We will demonstrate how an appropriate choice of user interfaces, knowledge acquisition tools and analytic decision support methods can stimulate the creativity of the strategic planners taking part in technological roadmapping. With strategic planning formalized as a multicriteria decision problem, the usual process of debating and brainstorming is better focused on reaching a consensus solution in an efficient way. An intelligent roadmapping support tool and publicly available technological foresight results assure a high quality of data gathering and interaction of experts with stakeholders. Real options are used to evaluate the opportunities, threats, challenges, and flexibility during the planning period. The above approach has been implemented as an intranet application and used to apply information technology (IT) foresight outcomes to establish IT investment plans in innovative companies that develop new products and launch them on the market.**

Keywords—Strategic planning; roadmapping; creativity; multicriteria decision making; IT foresight

I. INTRODUCTION

Creative decision making at all management levels is a condition for success in business. Strategic planning in companies exploits OR-based methods to support the decision-making process such as decision trees, influence diagrams, multi-criteria analysis [1], analysis of key technologies and factors, SWOTC analysis (extended SWOT with ***C****hallenges* and dynamic assessments) [2], etc. These methods are often integrated with Enterprise Resource Planning (ERP) systems. The creativity of decision support systems can be regarded as a feature that is superior to those usually termed "intelligent". A formal definition of creativity in the context of decision making has been given in [3].

Specialized strategic decision support systems (SDSS) dedicated to solving problems concerning technology transfer and commercialization and endowed with creativity features would strive to:

- acquire from heterogeneous sources, mainly web-based, collect, process, and verify knowledge about the environment (economic, ecological, social, scientific, technical, etc.) in which organizations that implement new technologies operate
- develop quantitative and qualitative models of these environmental factors, examine their interdependencies and identify their dynamics, with the application of optimization and game theory models
- classify the causative factors of processes taking place in the environment in order to identify the environmental impact and consequences of future decisions to be made [4]
- create a general vision of the future (forecasts, trends, scenarios) of the organization and its environment, as well as information concerning the development of specific technologies and products.

The latter goal reflects the obvious fact that the exploration of the future socio-economic and technological development is essential for brand building, acquisitions, and strategic market positioning. The public availability of forecast and foresight results can make it considerably easier to deal with uncertainties related to different visions of the future, but it requires highly penetrative data analysis and verification approaches. The ultimate goal of an SDSS is to develop adaptive rules for decision making that optimize relevant strategic planning criteria. Depending on how the decision problem is formulated, these rules may take the form of a strategic plan, a list of priorities or a business plan related to the particular technology or product.

The mobilization of human resources and know-how to fulfill the above-presented goals can take form of technological roadmapping (TR) [5], which is regarded as an efficient but costly and complex business intelligence process [6]. TR and other strategic planning processes have contributed to the market success of some well-known corporations such as Motorola [5], Philips, or Lucent. The role of roadmapping to stimulate the creativity in the company's strategic management has been noted by some authors involved in developing roadmapping support tools [7],[8]. Spontaneous expressions of future visions, goals, visionary new products and services, ways to cope with threats and disruptive events by roadmapping participants can be a decisive factor for the quality and competitiveness of strategic planning.

However, a large number of participants and a lack of standardized technology transfer models suitable for implementation in ERP systems can easily make this process converge too slow to a constructive solution. Another important but often overlooked issue is developing algorithms to modify a strategic plan for enterprises that is dependent on specific future event scenarios.

This paper addresses the issue of designing and implementing strategic decision support methods that would allow organizations to reach high quality technological strategic planning at low cost due to:

- the availability of free or affordable [6] information on the web, including technological foresight results

- a strict formulation of the technological strategic planning problem within the new product development and market placement framework
- increased creativity in filtering information and building knowledge.

We argue that the general scheme of TR may be used as a basis for designing standardized modules supporting technology transfer that can be embedded in ERP systems.

Creativity remains an essential feature of roadmapping. We will show that TR is a methodology that allows for stimulating creativity during the integration of knowledge from different sources, including exploration of online resources by autonomous agents, as well as expert Delphi. Roadmapping-based intelligent decision support systems applied to solving dynamic multicriteria optimization problems can thus be regarded as creativity support systems (CSS) capable of strengthening the organizations in building their future.

The scenarios fed by foresight exercises serve as a basis for defining sequences of company-related events during creative workshops organized within the TR. A thorough study is performed for those factors which most directly influence the decision to be made. Only the information that can be represented in a computer-aided CDSS either quantitatively or as verifiable expert judgments is processed by the system. The above decision support methodology has been applied for a new product development and market placement problem (NPD-MP) using information on development trends and scenarios of selected information technologies [7].

This paper presents only a small selection of TR application possibilities, focusing on decision problems associated with Information Technology (IT) implementation and commercialization. There are further areas of application for this method in economic, political and social fields (cf. e.g. [5], [10]). These will be discussed briefly in Section V. Further on, we will present the system architecture which makes it possible to implement the above functions in organizations dealing with technology development, such as innovative companies, R&D institutions, technology transfer centers. In other organizations, such as financial institutions, government agencies and in the education sector, roadmapping can also be used for similar tasks, which include forming R&D financing and innovation support strategies.

II. The Foundations of Technological Roadmapping

The essence of the above outlined technological roadmapping approach [6],[10],[11],[12],[13] is:

- breaking down the organization's environment into *layers* corresponding to interrelated groups of homogeneous factors, objects and operations
- decomposing the relationships within and between layers, where an attempt is made to rank the layers so that the factors of layer *n* are only associated with the factors of the *(n-1)*st and *(n+1)*st layer
- taking into account the time relationships between factors (causal and probabilistic relationships, trends, scenarios, descriptions of dynamics, etc.)
- creating diagrams of dependency factors taking into account the different relationships and their gradation (called roadmaps due to the apparent similarity to the use of road network maps for selecting the shortest route; they are also similar to PERT diagrams within each layer)
- identifying key decision points in the diagrams, solving optimization and decision support problems associated with them.

Another special feature of roadmapping is the simultaneous use of formal and quantitative knowledge, as well as informal expertise and managerial heuristics. The data mining approaches can be merged with foresight methodologies, such as Delphi surveys, structured workshops, expert panels, morphological analysis, KJ method [7], trend analysis, etc. Through these methods, a wider and bolder look into the future is possible, as opposed to methods based solely on formal knowledge.

The concept of roadmapping is currently used in a variety of contexts. In this paper, roadmapping is an interactive, group instrument used for:

- finding the relationships between the individual elements of complex objects related to the technology transfer as well as analyzing cause-effect relations
- adapting strategic planning in technology issues
- creative decision support, through well-structured knowledge of the analyzed problem context.

Due to the diversity of scale and area of applications, no uniform methodological approach to roadmapping exists. There are many variants of this methodology, which differ by the number and type of layers, number of analyzed factors, type of temporal and causal relationships under consideration, time horizon of decisions, etc. They depend on the problem area, the purpose of the analysis and target group. This is why the roadmapping process described below should be treated as a blueprint that allows us to create relational structures helpful in modeling and analyzing the problem being solved. Roadmapping will therefore be understood as a scheme for implementing creative decision support methods for planning and predicting technological development.

Applying technological roadmapping in enterprises can take the following form:

a) modeling the evolution of technologies used by organizations
b) forecasting demand for products and technologies
c) planning and optimizing strategies that ensure the technological development of organizations.

In Problem (c), roadmapping is used to solve a multicriteria optimization problem. The choice of technological strategy is a result of the simultaneous optimization of several criteria such as net profit regarded as a function of time (yielding the problem of discrete trajectory optimization [1]), the risk associated with the implementation of specific strategies, as well as the company's strategic position (including its market position). Organizations with different goals can apply additional individually defined criteria.

A. Technological strategic planning problem formulation

A basic strategic problem that can be solved with computer-aided roadmapping techniques is New Product Development and Market Placement (NPD-MP or NPD for short). It can be formulated as follows:

A company faces the challenge of developing a product that will be competitive in the market. Assuming the technological investment has been made, the following pre-criteria will determine the market success of the product:

- time t_0 to product launch (measured from the start of implementation activities or as a relative criterion, a delay/advance with respect to a known or estimated launch time of similar products by competitors)
- average unit cost of the product $c(k)$ in the k-th forecasting period, $[t_k, t_k+\Delta t)$, not including the cost of depreciation of the technology
- predicted market life, $T-t_0$, where T is the expected date of production completion
- estimated demand $s(k)$ for the product by customers in the k-th period, $s(k):= \Sigma_i s_i(\rho_i(k),\ \sigma_i(k))$,

where $\rho_i(k)$ is the price of the product on the i-th market, and $\sigma_i(k)$ is the estimated product market position index in the i-th market in the period $[t_k,\ t_k+\Delta t)$, which is dependent on factors such as the degree to which the product meets customer needs and the presence of competing products. A sum is made of all the markets where the product will be offered.

Estimating the values of these criteria requires the implementation of product market research, competition analysis and a study on the technologies currently available and expected in the planning period. The latter can be usually accomplished by acquiring results from a foresight exercise [2].

The concept of product used above is a simplification, as a 'product' can also be technology, and in certain cases it can be identified with the technology employed in its production. The product can also be understood here as a portfolio of complementary products manufactured using the same technology, or as a result of the same investment process.

The final decision to make the technological investment is dependent on the assessment of the financial parameters of the product throughout its life cycle. Discounted cash flow (Net Present Value) related to the implementation and operation of the new technology is usually taken into consideration as the final criterion:

$$NPV(I,t,d) := C(0) + \sum_{k=1}^{t} \frac{C(k)}{\prod_{1 \le j \le k} (1+d_j)}, \qquad (1)$$

where:

I – the technological investment characterized by cash flow $(C(0),\ldots,C(t))$ in subsequent accounting periods, $C(0)$ is the initial investment,

t – the number of time units since the beginning of the technological investment until the planned completion of production T,

$d=(d_1,\ldots,d_t)$ - the average expected discount rates in subsequent accounting periods.

Cash flows $C(k)$ over period k consist of revenues from sales generated by the investment $C_1(k):=N_1(k)*p(k)$, remaining investment revenue, including revenue from the reinvestment of surplus cash $C_2(k)$, costs of investment $C_3(k)$, fixed production maintenance costs $C_4(k)$, as well as variable costs of production $C_5(k):=N_2(k)*c(k)$ which depend on its size i.e.

$$C(k)=N_1(k)*p(k)+C_2(k)–C_3(k)–C_4(k)–N_2(k)*c(k),\ k=1..t \qquad (2)$$

All these functions should be treated as random variables with distributions estimated from a sample as well as on the basis of market research and various heuristics. In practice, eqs. (1) and (2) apply to expected values, and stochastic analysis reduces to variance analysis or other risk measures.

Note that in the criterion (1) we have already taken into account the values of pre-criteria k_0, $T-k_0$, $c(t)$ and $s(t)$. The latter is included in the sales forecast $N_1(t)$.

B. Integrating real options and risk models in roadmapping

Criterion (1) can be further extended to include terms related to real options values [14], [15] that can often be identified in IT management problems. This allows for a more realistic modeling of the strategic situation of the organization implementing the new product or technology.

The detection and identification of real options is a creative group activity that can be a part of an inter-layer analysis of the roadmapping diagram building. Through analysis of the market, technology and legislative environment layers, the roadmapping participants can detect and evaluate various option rights, such as:

- rights to choose or change the technological investment variants (switching options)
- rights to abandon the investment in whole or in part (abandonment options)
- rights to sell the license or a patent resulting from an R&D project included in the technological development portfolio
- right to sell the overall enterprise, or its part
- rights to engage in another investment related to the present one, including its continuation.

The liabilities that accompany technological investment plans can be described as real options in a similar manner [2], remembering that the rights are transferred to third parties, not vice-versa. The following, among others, can be modeled and evaluated as real options:

- the liability to sell the license or a patent resulting from an R&D project included in the technological development portfolio
- infrastructural or social investment liabilities that do not belong to the core investment and cannot be fully justified by the economic objectives related to the investment efficiency
- constraints, restrictions, and limits arising from the legal regulations, such as limits on profit transfers abroad, dividend payments, obligations to reinvest profit in further research etc.
- obligations to supply products and/or services to specific customers at non-market prices
- the obligation to sell the overall undertaking under specific circumstances.

If we compare the above to equity options, the first group corresponds to the long option position, while for the second one, the investor is an option writer so that this group can be identified with a short position that decreases the investment value. Assuming that the option values are independent from demand and sales (2), the criterion (1) can be replaced by the e*xtended NPV (ENPV)* defined as

$$ENPV(I,t,d) := NPV(I,t,d) + \sum_{i=1}^{n} OVl_i(I,t,d) - \sum_{j=1}^{m} OVs_j(I,t,d) \quad (3)$$

When using real options, the forecasted demand function *s(t)* for *t=0,…T* can be considered a time series that plays the role of a financial quotation in the real options valuation.

As mentioned above, the measures of investment risk are further performance criteria of the strategic planning process. The following can be used, alternatively or simultaneously:

- a variance or semivariance of *NPV(I,t,d)* (cf. (1)-(2))
- the risk of a liquidity loss in the organization during the investment that results from an analysis of *C(k)*
- the probabilities of achieving each of the technological investment goals, which affect the probability distribution of *NPV* and *ENPV*.

In addition, in supporting decisions related to technological planning, commercialization of technology and production development, objectives and strategic criteria are taken into account. These include conformity of the investment with the strategic objectives of the company, conquering new markets, weakening competitors' positions, and achieving a competitive advantage. Other criteria can include the degree of achievement of another strategic objective, which may be to gain strategic customers, etc. These indicators can be in the form of reference sets [1].

The need to take into account multiple criteria simultaneously transforms problem (1)-(3) into a multi-objective optimization problem. Moreover, if in the above problem the criteria (1) or (3) are treated as functions of final time *T*, problem (1)-(3) can be formulated as a discrete dynamic multi-objective optimization problem:

$$[J \ni \mathrm{I} \rightarrow (ENPV\ (I, t_1, \cdot), ..., ENPV\ (I, t_2, \cdot)] \rightarrow \max \quad (4)$$

where J is the set of allowable technology strategies (under consideration), t_1 and t_2 correspond to the minimum and maximum permissible deadlines for the settlement of the investment to be made. In problem (4), the discount rate is not a decision-making variable, but an external random variable whose values are estimated in the forecasting process. Note also that (4) is equivalent to the problem:

$$[J \ni \mathrm{I} \rightarrow (ENPV(I, t_1, \cdot), \frac{C(t_1+1)}{\prod_{1 \le j \le t_1+1}(1+d_j)}, ..., \frac{C(t_2)}{\prod_{1 \le j \le t_2}(1+d_j)})] \rightarrow \max \quad (5)$$

where the pre-criteria are related to criteria in a more intuitive way. Finally, applying the above observation to criteria related to risk as well as strategic position, a multi-objective optimization problem associated with the choice of technological strategy can be formulated as

$$\begin{aligned} &[J \ni \mathrm{I} \rightarrow (ENPV\ (I, t_1, \cdot), ..., ENPV\ (I, t_2, \cdot)] \rightarrow \max \\ &[J \ni \mathrm{I} \rightarrow (R(I, t_1, \cdot), ..., R(I, t_2, \cdot)] \rightarrow \min \\ &[J \ni \mathrm{I} \rightarrow (S(I, t_1, \cdot), ..., S(I, t_2, \cdot)] \rightarrow \max, \end{aligned} \quad (6)$$

where R is the measure of risk and S is a valuation of the strategic position of the company concerned. The investment I should be interpreted as an investment portfolio rather than a single technological project. Determining the pre-criteria values, the relationships between pre-criteria, as well as cash flow values and consequently R and S as formal criteria in problem (6) is generally not an easy task. It requires an examination of the relationship between technologies, products, sales markets, as well as market, technological, economic and political environment forecasts. All the elements and factors are interrelated, while in real-life problems the number of relationships can be very high, and their nature is usually heterogeneous: deterministic, stochastic, interval, or fuzzy. To solve problem (6), additional preference information must be obtained from the decision makers as well as from external experts, and used within a multicriteria decision making (MCDM) procedure.

While a discussion on the selection and use of MCDM methods is not the main subject of this paper, let us note that the reference sets method [16],[3] proved particularly useful as a creative goal-setting technique. Reference sets coupled with the attribute evolution method [1], [2] are also suitable for solving the multi-stage strategic planning problem (6).

Problem (6) is the main formal basis for roadmapping applications in NPD problems. Section III will present an application scheme of roadmapping in technological planning. An example of a similar roadmapping process applied to real-life NPD-MP problems was described in [2] and [6].

III. Applying Roadmapping in Technological Development Planning

In this section we will provide an algorithmic description of formulating and solving problem (6) within the roadmapping framework. Both formal and non-formal methods of acquiring knowledge about the environment to define all coefficients and functions occurring in (6) can be applied. This takes into account estimates of *C(k), R, S*, and the rules of a compromise strategy choice in (6). Roadmapping requires the quantitative and qualitative analysis of a large number of events in various fields, which need not be directly related to the development of the product itself, but may cover an entire sphere of business activity. At the preference modeling stage, the formal criteria (6) can be mapped monotonically into more intuitive ultimate objectives that describe future benefits (financial, knowledge, human resources) under resource constraints. A general roadmapping scheme for the NPD-MP problem (1)-(6) is shown in Figure 1.

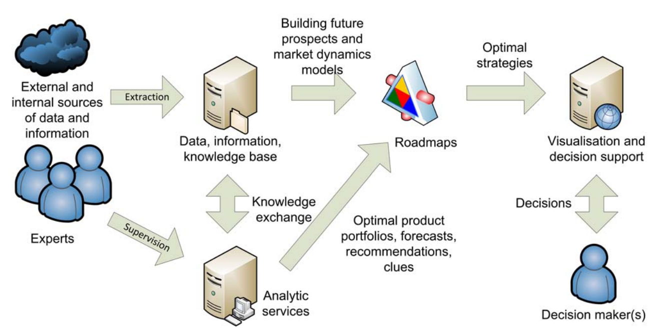

Figure 1. A simple scheme of computer-assisted roadmapping

The resulting roadmapping diagram is a projection of alternative visions of present and future linkages in the areas most important for the activity of an organization. The primary area – and also three key layers in virtually all roadmapping diagrams – contain the relationships between markets, products, and technologies.

During a creative analysis supported by a CDSS, the causal relations between these areas and between their objects are detected, discussed, defined, verified, and quantified. Analyzing the object dynamics is an essential component of roadmapping so that any action taken during this planning process involves forecasts that depend on different assumptions and anticipated future decisions. The resulting roadmap is a basis for setting priorities and creating a medium- and long-term organizational strategy. It primarily helps decision makers in an organization to identify nondominated technology investment alternatives, then to select the best one.

The main prerequisite of the quantitative strategy building is treating the roadmapping diagram as a hypergraph encompassing causality, binary, ternary, and higher-order relations as edges and objects as vertices. Such a hypergraph can usually be hierarchically decomposed into components that can be analyzed autonomously. The quantitative analysis is equivalent to finding multicriteria shortest paths in a hypergraph. However, the labeling of edges and hyperedges requires the prior establishing of appropriate models of all relations. The labels arise as results of transformations corresponding to the models. For instance, if a causality relation between objects has been modeled as controlled difference equations, the label can be determined as the optimal value of a performance index.

Problem (6) can be embedded into the analysis by calculating the plausible values of criteria for each vertex of alternative future paths. Desired scopes of compromise values result from a group decision-making process involving the company management and external experts (other types of roadmapping may involve stakeholders, politicians etc.) in the NPD-MP problems. The culmination of the roadmapping process is an analytical report, which is based on a diagram analysis and contains recommendations for decision makers as regards the priorities of technological investment strategy, with the anticipated values of strategic objectives for each plausible scenario.

The solution to the technological planning problems and its place in the TR is shown in Figure 2. The strategic business planning outlined above runs in four phases:

Phase 1. Preliminary activities

These activities involve preparing the data necessary to initiate roadmapping. The scope of the project together with its constraints, objectives and time horizon, are to be defined.

Phase 2. Roadmap diagram development

As part of this phase, a diagram will be constructed by:

a) isolating *n* classes (layers) of modelled objects: technology, products, markets, marketing activities, etc. within a 'moderated brainstorming' process

b) studying structural links between the layer objects, which leads to the analysis of $n(n-1)/2$ bipartite graphs

c) studying timelines and trends and how they develop

d) studying higher-order relations between layers

e) detection of real options, opportunities, threats and challenges.

Phase 3. Solving problem (6) to find plausible strategies

Problem (6) is regarded as a dynamic multicriteria optimization problem with parameters defined as labels of a roadmapping diagram. The admissible actions at each decision node in the roadmapping diagram are prioritized according to criteria (6) so that the final choice of an investment strategy is determined from their ranking.

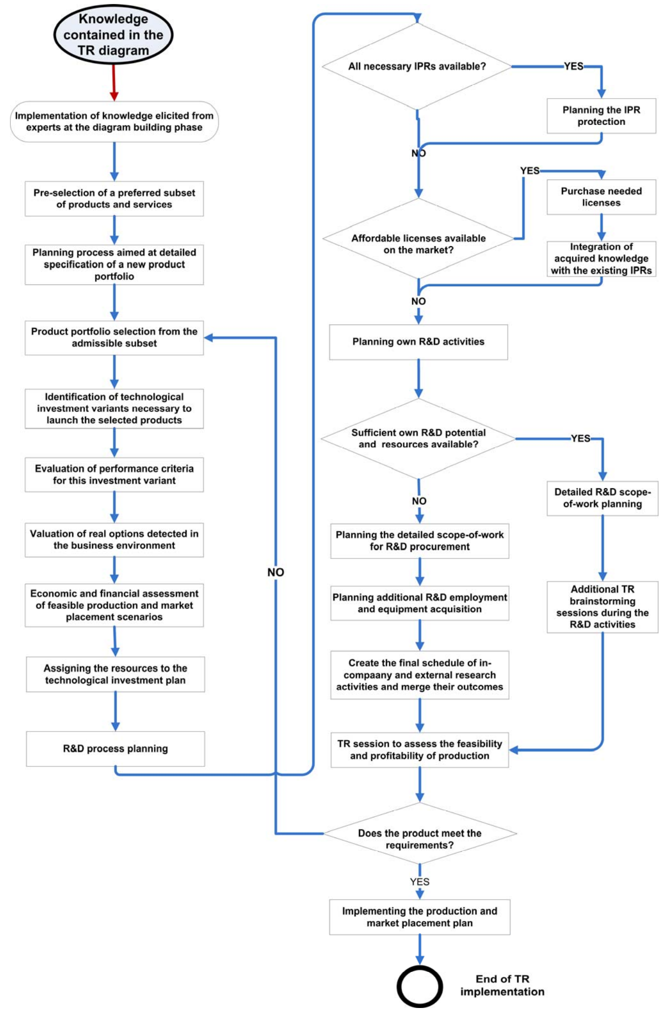

Figure 2. A scheme illustrating the decision-making and implementation processes in TR

Phase 4. Result discussion, implementation, monitoring and complementary activities.

Finally, the recommendations are presented to decision makers – the diagram is converted into specific actions that are taken in order to achieve the roadmapping objectives.

Further information and a comparison of roadmapping uses and processes is given in[4],[5],[6],[11],[12],[13].

IV. An Implementation of a Computer-Assisted Roadmapping Support Systems and Its Applications

The main advantages of implementing the TR process as a web-based SDSS are apparent in the systematic building of even large roadmapping diagrams (Phase 2 above), which can cope with complex relation models, process hypergraphs, as well as interactively solve problem (6) in Phase 3. Moreover, focus groups using a collaborative internet environment can more easily distinguish objects within layers, show the relationships between them and objects in other layers. This is an interactive process, and the intermediate results are assessed, discussed and improved upon. A draft roadmapping report can be generated automatically and compiled together with recommendations for decision makers.

To sum up, the SDSS represents the TR outputs as:

- roadmap diagrams with key decision points, scenario bifurcations, and quantitative characteristics of each scenario in terms of criteria (6)
- a roadmapping report with final assessments of planning scenarios and a presentation of their ranking in accordance with the user preferences expressed during Phase 3.

Specific technological investment recommendations can also be derived and presented as a detailed appendix to the roadmapping report.

During the roadmapping process, two types of linkages are identified: within layers and between layers. For example, relationships between objects in the layer "*Products*" depend chronologically on the launch of individual products on the market, taking into account depreciation of the technology and marketing expenditure. They are mostly cause-and-effect relationships labeled by time parameters, such as product lifetime, duration of the inception marketing phase, obligatory servicing time after ceasing production etc.

The implementation of the TR-specific functionalities presented in Secs. II and III required a novel DSS architecture capable of separating analytic solving of multicriteria problem (6) from collaborative discovery and decision making activities. This has been achieved with the aid of available Microsoft technology: SQL Server, Sharepoint Services as collaboration software for the organization, Silverlight, WPF as programming framework. The BPMN diagram for data, and knowledge transfer in the SDSS is presented in Fig.3.

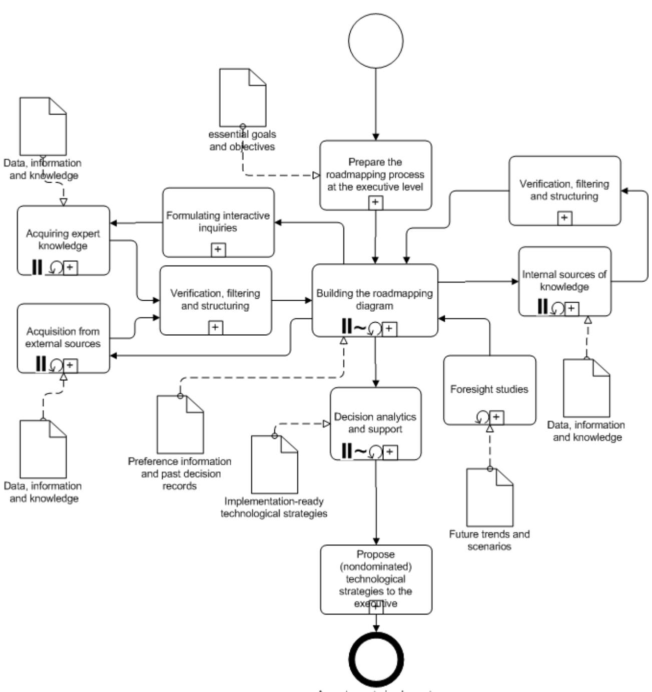

Figure 3. A BPMN diagram of the roadmapping-based SDSS

The ontologies and semantic open source web technologies form the basis of the information processing in the system. An example of a basic package used to create knowledge bases in our system is Jena API (www.openjena.org), developed first by HP Labs. Use of this package provides access to technologies such as OWL, SPARQL and Pellet.

The set of relationships between layers defines the various contexts for the objects of one layer. For example, the product can be analyzed in terms of development opportunities as well as real time profit. In a similar way the Scientific Research layer can be viewed from the standpoint of the organization's technological portfolio. In turn, the technologies at the disposal of the organization can be used to design and manufacture future products. To illustrate the NPD-MP-related roadmapping principles and activities stimulating the creativity, we present the following simple example referring to the analysis of basic ICT technologies in project [9].

A. An example of portable PC development planning

We will analyze the situation, where the product is 'personal computing devices' and the roadmapping sponsor is its manufacturer or a distributor seeking to expand production and market share. Roadmapping activities are undertaken to determine priority research areas, most promising technologies, to select product portfolios and their time-to-market (TTM), define marketing strategies, acquire licenses and know-how, etc. In order to achieve the above strategic objectives, six roadmap layers have been considered, while four of them have been selected for a detailed study (cf. Fig.4):

- Market, with the sub-layers: competition, market and business environment factors, market portfolio, and market opportunities (including real options)
- Products
- Technology
- scientific Research related to IT and electronics.

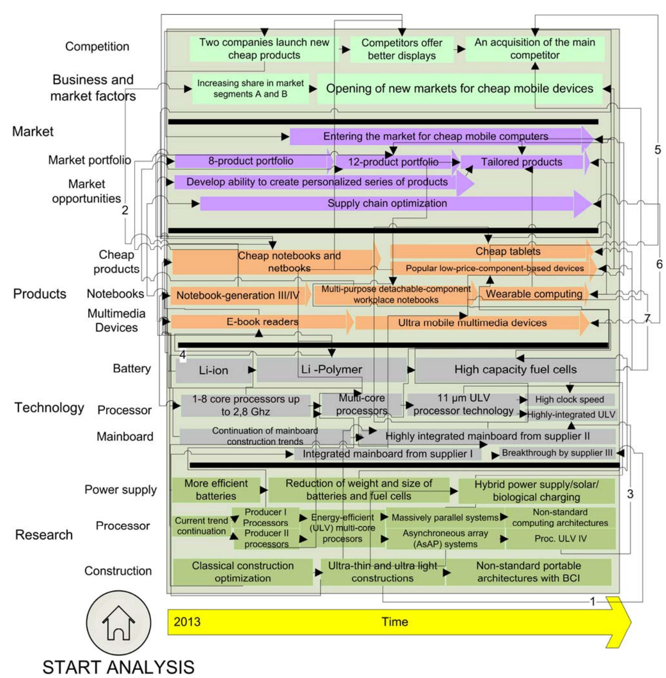

Figure 4. An example of the roadmapping diagram for PC devices

Initial layers, objects, and relations have been input into the model by experts that organize the overall process. They constitute an initial skeleton of the roadmapping diagram that indicates the directions to make further steps by the community of the sponsor's managers, employees, and external experts. Then a series of workshops has been organized, alternating with the on-line desk work, to construct a diagram that contains, possibly, all relevant components necessary to derive a viable technological strategy.

The higher level of creativity is manifested by the TR participants, the more adequately models a diagram the business and technological environment of the NPD-MP problem. A common roadmapping approach to stimulate the creativity is the 'structured brainstorming', where the participants define objects and relations by sticking their ideas to the draft diagram displayed on the board and discuss them periodically with experts. The participants have been assisted by the availability of ICT foresight results: technological trends, forecasts and scenarios until 2025 [9] that helped to pre-define the layers "Technology", and "Research". No consensus achievement has been therefore necessary, as more scenario-related options enhanced the diagram. They have then been filtered during the analytic diagram construction phase when the probabilities have been assigned to each product development trajectory based on the IT foresight scenarios plausibility. In this example two workshops, organized in form of expert panels were sufficient to build a diagram that was accurate enough for its purposes.

Fig. 4 shows a number of relationships to illustrate this process. For example, the relation marked {1} corresponds to the knowledge that the research program on ultra-light and ultra-thin constructions carried out by the research center of the company X will enable the creation of a class of resistant casing that may cause a breakthrough made by its subsidiary Y when used in their new product series a few years later. The label {4} indicates the causal relationship between the research carried out at the AGH university and development of more efficient Li-Polymer batteries after a time lapse of 3 to 5 years. Objects in the same layer are connected by a time-sequence relationships, similar as in MPM diagrams. All relations are described by a set of quantitative as well as qualitative parameters. Higher order relations have been defined in a similar way: The set of relationships between layers defines the various contexts for the objects of one layer. For example, the layer "Technology" includes objects from the technological organization portfolio that can be turned into real marketable products under favorite circumstances and vice versa. If the research on biologically charged devices is successful, then it will more likely result in the domination of this technology in wearable devices, challenging high-capacity fuel cells (cf. the relationship {7}). In a similar way the Scientific Research layer can be viewed from the standpoint of the organization's technological portfolio.

Once the diagram is defined, it supplies the coefficients of the problem (1)-(6). Now it came the second moment to exhibit intensive decision-making creativity: the interactive solution to (6) taking into account additional preference information, specifically the company's financial risk profile. The products have been analyzed in terms of development opportunities as well as real time profit.

The real options (cf. Sec. IIB) in this example cannot generally be separated as objects, but they are parameters of other relationships. For example, the right to buy mainboards with 2.8 Ghz ULV processors influences the relations between all types of devices where these mainboards can be used.

In this example, the time horizon is 10-12 years. Taking into account the relatively short life cycle for the individual products, periodic updates are necessary within the developed schedule. In this case, measures for upgrading and improving recommendations will be taken each year, which highlights that TR is a knowledge-building process.

V. Final remarks and conclusions

In accordance with roadmapping requirements, we have developed a web-based system that allows active sharing of data, information and knowledge in an online NPD-oriented strategic planning process. The technological and financial objectives are quantified, merged with the qualitative order structure of strategic goals and solved as an MCDM problem. Knowledge management is based on the general idea of creating and exploring approximate dynamic models of all relevant outer systems influencing the company's performance. They are then coupled with internal enterprise subsystems and decision mechanisms. Due to the open availability of technological foresight results financed from public funds, this process can even be undertaken by small technological companies. When used repeatedly in the same enterprise, TR allows the re-use of previously gathered knowledge and procedures. SDSS technologies based on ontologies provide appropriate tools for achieving the TR objectives.

A. Roadmapping vs. other creativity support procedures

Brainstorming and other intensive group interaction activities are essential in order to creatively define the potential actions, products, features, rights and obligations, etc. in all phases of roadmapping. Such activities can be more efficient when they are systematic, consensus-oriented, and well-moderated. For instance, an efficient structuring of brainstorming may be achieved by using the KJ (Jiro Kawakita's [7], [17]) method that belongs to the family of "convergent thinking" approaches. This is a creative problem-solving methodology which may provide clues to the TR stakeholders.

The KJ method introduces a positive brainstorming attitude among the participants, and one of its implementations, the Label Method, also referred to as the Affinity Diagram, can be particularly attractive for the TR participants, especially in Phases 1 and 4. Each label contains one idea related to the problem to be solved, the situation and so on. This is followed by label grouping according to multiple criteria, related either to similarities or to a dissimilarity, etc. Different relations between labels can be explored. This allows users to identify, discuss and mitigate the complexity of real-life problems. A more complete description of the method is contained in [7]. It has been further developed and promoted in [17], with so-called W-shaped problem-solving methodology. The method can be computer supported, either by separate systems supporting convergent and divergent problem solving, or by holistic creativity support systems. In addition, it can be easily combined with other structured workshop approaches such as nomadic virtual expert panels.

Another TR-related approach to modeling complex business environments, is presented in [18], where a group modeling technique is used to establish a large-scale dynamical model by an interacting group of experts. This approach is not enterprise-centered but can be coupled with an additional business model using the system outcomes as inputs. The creativity of participants is stimulated by a flexible approach to defining relations, and by the interactive verification of them within a multi-round Delphi.

B. Conclusions

Roadmapping-based SDSS can be used to indicate several feasible activity scenarios for achieving equivalent strategic results. Different strategic plans can be derived from foresight scenarios used at the roadmap building and decision analytics stages. Roadmapping yields nondominated strategies from the point of view of cost (the cheapest solution), time (the earliest milestone for achieving the desired results) and risk (minimal CVaR or statistical moments). Prospects for improving the strategic position of the organization by additional actions such as nature-friendly activities, fulfilling security and quality standards, obtaining ISO certificates, etc. are also indicated.

The formulation of the above goals as a dynamic multi-objective optimization problem allows for the elimination of dominated solutions within an analytic procedure. When seeking the best technological development strategy, quantitative criteria optimization is supplemented by a qualitative assessment of the impact of strategy implementation. Then, supplementary preference information such as reference sets and trade-off constraints are fed to the SDSS during dedicated creative group decision procedures. It allows the organizers of the process to formulate realistic criteria levels to be achieved, even under high levels of market and financial uncertainties, as well as reach a consensus as regards selecting a compromise technological investment strategy. The possibility of interactively generating scenarios in roadmapping-oriented SDSS means that an adequate model of action under different external conditions affecting an enterprise is achieved more quickly.

In addition to strategic planning, the above-presented TR methodology constitutes an effective organizational framework for creating knowledge bases on economic, social and technological trends and innovative ideas, which drive future enterprise development. It can easily be adapted to a particular application area in virtually all innovative organizations.

The TR has been implemented as a flexible SDSS capable of applying foresight results, with analytic engines available in the cloud while sensitive company data is stored in its intranet. It allows the user to automate the process of data acquisition [19] when creating models, and building the knowledge base.

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