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TECHNOLOGY ROADMAPPING AS A SUPPORTING TOOL FOR MANAGEMENT OF NEW PRODUCT DEVELOPMENT PROCESSES IN SMALL AND MEDIUM ENTERPRISES

Key words

Technology roadmapping, systems engineering, requirement management, interface management.

Abstract

Technology roadmapping enables the effective planning of enterprise technical development at the strategic level. The use of this tool allows an enterprise to more effectively allocate the resources required for developing their technical potential and developing and introducing new products.

Technology roadmapping is frequently used by large technology-intensive production and, less commonly, service enterprises.

The paper presents experience with using technology roadmapping tools by a consortium of small and medium-sized organisations including enterprises and research institutes. The presentation focuses specifically on the impact of the use of technology roadmapping in combination with selected systems engineering tools on the management of the development of a new technologically advanced product.

Introduction

The first company to use technology roadmapping – a technology development strategic planning tool – for new product development planning was Motorola [1][1]. In addition to new product development, technology roadmapping can be used to analyse technology development in specific industries [2].

One of the determinants of effective market competition is the ability to efficiently introduce new products.[2] The important factor in this process is not only whether the final products meets customers' expectations and requirements but also the manner and time of its introduction. More and more frequently, keeping up with the competition and the ability to introduce technologically advanced products require the cooperation of many organisations, including enterprises possessing knowledge of the market and research organisations possessing knowledge on techniques and the available technologies. For this reason, such undertakings are commonly carried out by consortia. This allows both for quick decision-making within individual organisations and the use of resources distributed in several consortium members. However, the development and introduction of such products requires the objectives of the undertaking to be coordinated with the business objectives of the individual participating organisations, and thus a greater effort related to coordination of the entire project.

Technology roadmapping is by definition intended to coordinate technology development at the strategic level. Because of this, the practical use of this method is frequently accompanied by the application of other tools/techniques. The paper presents a case of the use of technology roadmapping supplemented by selected systems engineering tools.

1. Technology Roadmapping

The theoretical assumptions were developed at Cambridge University. They are accepted as a sort of framework that can be modelled according to the need, i.e. the purpose for which a technology map is being developed. As previously mentioned, technology roadmapping was first used by Motorola. Many companies followed its example, deciding to implement roadmapping procedures, mainly in planning enterprise technical development and new products. An attempt to systematise this tool was undertaken by the members of EIRMA (European Industrial Research Management Association) establishing, in 1996, the relevant EIRMA Working Group. The result of the group's work was a report presenting a comprehensive Technology Roadmapping implementation model [3]. The group's work demonstrated that, while different

[1] This represented the first publication of a technology roadmap.
[2] In the present paper, "product" covers both physical objects and services.

enterprises had a different approach to the issue (depending largely on the industry in which they operated), they were willing to use it in both technology development and new product planning. It should be noted that the experience of enterprises indicates that Technology Roadmapping is an important tool for the strategic management of technology in the enterprise.

Technology roadmapping is used for strategic technology development planning at the level of an industry [4], as well as with respect to products or product families [5, 6, 7]. Technology maps are most frequently developed in large industrial enterprises for "product families" that use advanced technology. An important element of a technology map is the planning horizon, which usually corresponds to the length of the analysed product's lifecycle[3]. In the case of developing a technology map for an industry, the planning horizon may be much longer.

A technology roadmap covers all stages of technology development from basic research through applied research, development work to the market introduction of a product that uses that technology. In addition, it may contain various functional levels, e.g., projects, systems, services and products, on which the mapped technologies are used. Figure 1 shows the structure of a technology roadmap.

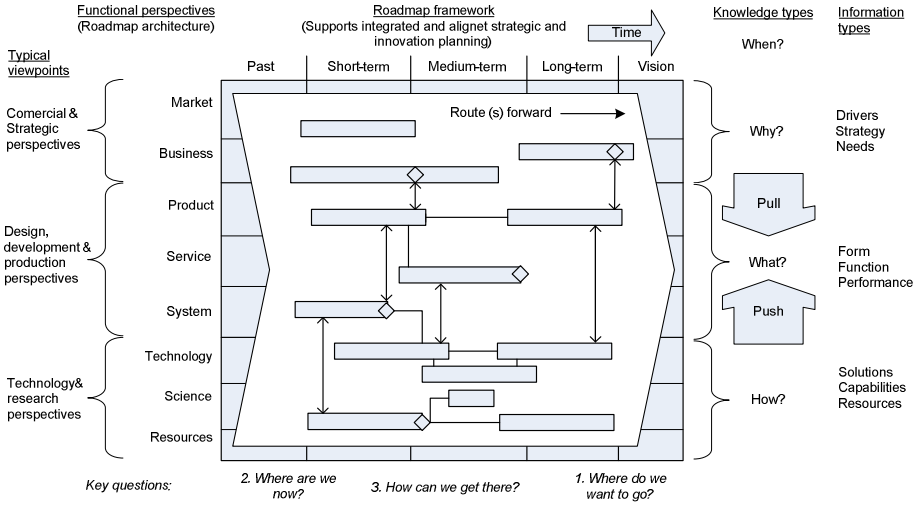

Fig. 1. Technology roadmap structure [8]

A technology roadmap provides answers to the following questions (along a time axis):

- Where do we want to be in the future? What market position do we want to achieve? What needs do we want to satisfy? What products do we have to

[3] It is assumed that in the case of, e.g., passenger airplanes the product lifecycle is ca. 30 years.

offer to satisfy those needs? What resources and technologies will be required to develop and introduce those products?
- Where are we now? What is our market position? What needs do we satisfy? What products do we offer to satisfy identified needs? What resources are required to manufacture the target products?
- How do we want to migrate from the current to the future condition, taking into account all the intermediate steps (e.g., prototypes, initial versions etc.)?

Technology roadmaps should also consider the development directions of markets, the products offered by the enterprise, and define the types of technologies and resources required to achieve the foreseen market objectives.

The mapping process results in a technology roadmap that should take into account the roadmapping objective and contexts, e.g., the specific characteristics of the enterprise and industry. However, as when using other strategic analysis (e.g., SWOT analysis), it is the process of developing the map – usually performed during so-called strategy workshops – which is much more significant. Such workshops should be conducted periodically as the undertaking being mapped (in this case, the technology development process) progresses. In order to ensure that a workshop results in a roadmap that represents real value, it should be correctly prepared, this includes, specifically, ensuring that all the data that constitutes the input into the roadmap is collected and undergoes preliminary analysis before the workshop.

It is also recommended that a special team be appointed for the roadmapping process who is responsible for collection of data, its initial analysis, and for the logistical preparation of the strategy workshops.

The preparation of the first technology roadmap begins with an analysis of the current and future market. The initial objective is the definition of future market needs and expectations. The characteristics of the future product or product range are then defined in response to the identified needs. It is also possible to consider "intermediate products," which may include prototypes. The next step is the identification of the technologies/components necessary to design/manufacture the products being developed and implemented. At this stage, it is also necessary to decide how specific technologies/components will be acquired, i.e. whether they are to be developed internally by the consortium or outsourced. The most important step of building a roadmap is combining all its elements into a logical whole, including the definitions of the interdependencies between its individual elements. While constructing the map, it is also necessary to consider alternative solutions that will allow for the analysis of different scenarios. Another important element is considering the time axis, both in relation to individual project tasks and the entire undertaking, and to checkpoints (milestones) which will enable effective time management.

The technology roadmap development process is presented below (Fig. 2).

A technology roadmap allows for a "bird's eye view" of the undertaking, but this is insufficient for the effective management of new product development

and implementation at the operational level. For that reason at that level, it is necessary to use additional tools supporting the new product development process.

2. Description of the undertaking studied and problem definition

The undertaking analysed was a multi-year project aimed at the development of a new device – a system for monitoring the status and degree of charge equalization in lithium-ion cells connected in series in dedicated batteries for electric vehicles. The device was designed based on embedded systems.

Initial work on the device, including market analysis, was performed by the enterprise that initiated and later coordinated the project. The enterprise financed the initial work and market analysis entirely on its own. The initial analysis of the scope of the undertaking showed that the enterprise would be unable to develop the products and introduce them on the market on its own and thus, after the project objective and the scope of the product development and implementation were specified, a project consortium was formed.

The establishment of the consortium brought with it the problem of coordinating the individual project tasks that were carried out by different organisations. In addition, some of the most critical tasks involved several enterprises each.

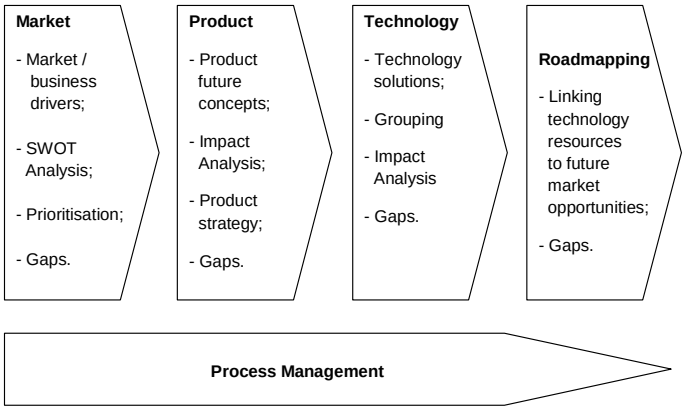

Fig. 2. Process of technology map preparation [9]

The consortium consisted of the following:

- An enterprise which was to manufacture the device and which was the initiator of the undertaking;
- Enterprises acting as subcontractors for specific project work;
- Research organisations, including a certification unit, also responsible for a portion of the research work;

- An HEI, responsible for a number of R&D tasks; and,
- The indirectly involved suppliers of the components for the designed device, e.g., cells.

In spite of the fact that it had been present on the market for a long time, the project leader had no experience in carrying out work involving so many participants or the development of such a technologically advanced product. The enterprise confronted the need to select the manner of coordinating work on the device and specifically the way of designing it and initiating its production within the assumed timeframe and the allocated budget[4]. A significant risk was the incorrect definition of the technical requirements for the device. For that reason, one of the coordinator's critical tasks was to identify all the technical requirements for the final product and determine these requirements' impact on the performance of the undertaking. In addition, the results of the preceding tasks had a large impact on the type and scope of succeeding tasks. For this reason, the consortium decided to use project management tools specially dedicated to scientific research projects, i.e. technology roadmapping, followed by systems engineering.

1. Case study description

Some of the team members became acquainted with the technology roadmapping methodology only at the project planning and scope definition stage of the project. Representatives of the enterprises within the consortium initially had a sceptical attitude toward the idea of using this tool, fearing it would increase the bureaucratic burden. In addition, they did not see the added value that the use of technology roadmapping would bring. Finally, however, the coordinator decided to use technology roadmapping to a narrow extent to support the technical aspects of project management, mainly in strategic planning and scenario analysis.

The roadmapping team consisted of two sub-teams, one permanent, and one temporary. The permanent sub-team consisted of the project coordinator, the head of the technology department and an external consultant responsible for the methodology. The temporary sub-team consisted of representatives of the organisations responsible for specific tasks. Developed first was the preliminary roadmap presented in Fig. 3. This roadmap was modified as the project progressed. The map presents the interdependencies between the individual tasks, as well as information on the task performers.

However, at the beginning of the work, problems appeared with the interfaces between the individual tasks, executed by different performers, mainly teams (usually also consisting of representatives of the consortium members) including the following:

[4] The work was partly financed with public funds.

- The mechanics responsible for the product's mechanical components,
- The electronic engineers responsible for the design of electronic circuits, and
- The programmers responsible for writing the control software for the device.

During the attempts to integrate the work results, there appeared errors the removal of which caused (in exceptional situations) delays in the performance of project tasks and posed the danger that the project budget would be exceeded. Individual tasks were modified several times, which necessitated introducing frequent modifications to the roadmap.

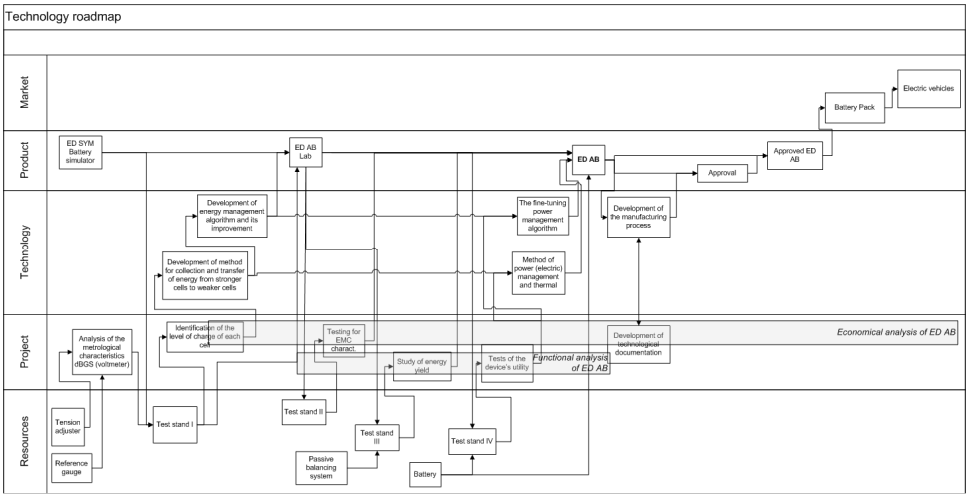

Fig. 3. Initial technology map for a system for monitoring the status and degree of charge equalization in lithium-ion cells [10]

When designing new products based on embedded systems, systems engineering tools are often used. More on utilization of systems engineering for new product development may be found in [11]. For this reason, it was decided that one of the elements of systems engineering – interface management – would be used in the studied project. The decision was made to perform an additional analysis that would indicate new improvement areas in the management of interfaces between the elements of the system for monitoring the degree of charge equalization in lithium-ion cells. The analysis showed that the main cause of the errors were shortcomings in defining the requirements regarding individual project tasks and sub-tasks / system elements. Another problem was the fact that the requirements identified earlier underwent frequent changes and neither the coordinating team nor the teams responsible for specific tasks were able to determine all the project areas in which these changes would impact or the extent of this impact, i.e. they were unable to ensure the traceability of the requirements. The frequent changes of requirements were partly due to the

project team's lack of experience in developing this type of product, and specifically in the following areas:

- The automotive industry, and
- The designing of technologically advanced systems, including those based on embedded systems.

The increased effectiveness of requirement management enabled the shortening of several tasks, including through focusing the design work exclusively on those requirements that were key from the final customers' point of view. This had a very positive impact on streamlining the new product development process, which in turn reduced the risk of project delays and budget overruns.

In addition, the increased tolerances for the critical requirements, and subsequently for selected system elements, allowed for more efficient construction product development scenarios, i.e. a single designed system element could be used in several types of target products, for example, electric forklifts, motors, or low power tractors, or in batteries consisting of variable cells.

The method which was intended to be used to define customer requirements and translate them into product parameters was QFD – Quality Function Deployment House if Quality [12]; however, due to the high number of requirements, their varied level of detail and complexity and their variability over time, the method was abandoned.

Ultimately the requirements for the system for monitoring the status and degree of charge equalization in lithium-ion cells were defined using the procedure shown in Fig. 4. Identification of the product scope required, first of all, the identification of all the stakeholders with an impact on the new product and their requirements. The project team then defined which of the product elements would fulfil which of the customers' specific needs and to what extent. One of the most important issues connected with the design of a new technologically advanced product was the definition of the principles of cooperation between the different components, i.e. defining the requirements for the interfaces between them.

After requirements are assigned to individual system elements, it is possible to introduce modifications to the new product design more rapidly and effectively in response to changes in stakeholder requirements or additional requirements.

Generally speaking, requirement management makes use of especially dedicated software packages, but these are tailored to the needs of large enterprises that frequently use them to coordinate the operations of workers scattered worldwide. A significant drawback of these tools is their high price, which puts them beyond the reach of small businesses. For that reason, a spreadsheet was specially prepared for requirement management. The product requirements were defined with a view toward achieving the characteristics presented in Table 1.

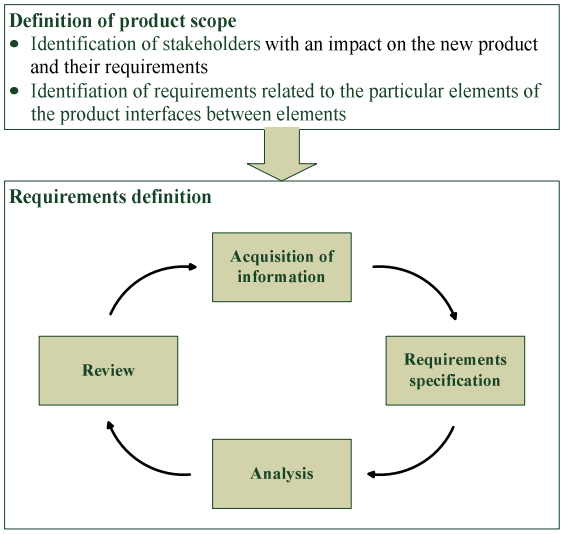

Fig. 4. Process of the definition of product requirement. Based on [13]

Table 1. Product requirements characteristics [14]

Nr	Attribute	Description of attribute
1	Realistic	The requirement can be met within the cost and schedule constraints of the program.
2	Correct	The requirement represents something necessary for the system to be built and satisfaction of some need.
3	Understandable	The stakeholders can easily comprehend the meaning of the requirement with minima explanation.
4	Complete	The requirement captures everything that is intended with not to-be-determined or to-be-resolved.
5	Verifiable	The requirement is written in such a way that enables cost effective verification that the system fulfils it.
6	Validated	The requirement is necessary to build the right system that meets user/customer needs.
7	Traced / traceable	The requirement is allocated and linked to all other supporting requirements at higher and lower levels.
8	Unambiguous	The requirement has only one possible interpretation.
9	Consistent	The requirement is not in conflict with any other requirement.
10	Precise	The requirement numeric quantities are accurate and specified to an appropriate level.
11	Concise	The requirement communicates the information using as few words as possible.
12	Design independent	The requirement enables flexibility in the design process by defining what is necessary, not how it should be designed or implemented.
13	Annotated	The requirement necessity and relative importance are documented.
14	Not redundant	The requirement information is not stated more than once without a good reason to do so.

In the final outcome, supplementation of the technology roadmapping approach with selected systems engineering tools – requirement management and interface management – had a positive impact on project performance.

4. Summary and evaluation results

Technology roadmapping was used in managing a project involving the design and implementation of a new technologically advanced product. In the project consortium members' opinion, the application of this tool brought a number of real benefits.

Technology planning could be proactive, i.e. it was possible to create its own solutions based on expected market developments. Previously the enterprise had mainly reacted to changes occurring on the market, which, in view of the frequent market fluctuations, meant that products were developed and introduced with a delay.

The technology roadmap was a key element of the platform of communication between individual consortium members. Specifically, the map description contained information including:

- The relationship between inputs and outputs of individual tasks;
- The duration of individual tasks; and,
- The performers of individual tasks and the resources required to perform those tasks.

The use of technology roadmapping without additional tools did not enable effective operational management of the project. For this reason, a decision was made to use engineering tools that, among others, enabled correct management of product requirements. The above example shows that the application of technology roadmapping can be supplemented by the use of systems engineering tools.

Experience with the use of the above tools shows that, in spite of being developed for large enterprises, they can also be used by smaller organisations.

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Roadmapping technologiczny jako narzędzie wspomagające zarządzanie procesem opracowywania nowych produktów w małych i średnich przedsiębiorstwach

Słowa kluczowe

Roadmapping technologiczny, inżynieria systemów, zarządzanie wymaganiami, zarządzanie interfejsami.

Streszczenie

Roadmapping technologiczny pozwala w sposób efektywny planować rozwój technologiczny przedsiębiorstwa na poziomie strategicznym. Wykorzystując to narzędzie, przedsiębiorstwo uzyskuje możliwość bardziej efektywnej

alokacji zasobów niezbędnych do rozwijania potencjału technologicznego przedsiębiorstwa oraz opracowywania i wprowadzania nowych produktów na rynek.

Jako narzędzie roadmapping technologiczny jest wykorzystywany zwykle przez duże, intensywnie wykorzystujące nowoczesne technologie przedsiębiorstwa przemysłowe, rzadziej usługowe.

W niniejszym artykule przedstawiono doświadczenia z wykorzystania instrumentarium roadmappingu technologicznego przez konsorcjum małych i średnich organizacji, w tym przedsiębiorstw i jednostek naukowych. W szczególności przedstawiono, jaki wpływ miało wykorzystanie roadmappingu technologicznego na zarządzanie procesem opracowania nowego, zaawansowanego technologicznie produktu.