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Technology Roadmapping: The Integration of Strategic and Technology Planning for Competitiveness

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Extended Abstract

Technology roadmapping is a form of technology planning that can help organizations deal with their increasingly competitive environment. As a DOE national security laboratory with R&D as a major product, Sandia must also do effective technology planning to identify and develop the technologies required to meet its R&D mission. Once an organization identifies required technology enhancements or new technologies, they may be developed internally or collaboratively with external partners. For either approach, technology roadmapping, as described in this paper, is an effective tool for technology planning and coordination, which fits within a broader set of planning activities. The potential benefits of technology roadmapping include identifying critical technologies and gaps, coordination of research activities within companies or industries, and improved technology marketing information. Technology roadmapping is particularly useful when technology investment decisions are not straight forward and for coordinating the development of multiple technologies, especially across multiple projects.

Some technology roadmaps have been produced, but the focus has always been on the roadmap as an end result, not on the process. Therefore, there is very little literature on the process and the main learning and development of the process occurred because sometimes some of the same people were involved in several technology roadmaps. The real contribution of this paper is that it formalizes and documents this technology roadmapping process. It describes the technology roadmapping process and shows how it fits within a corporation's overall strategic and technology planning process.

The technology roadmapping process consists of three phases — preliminary activity, development of the technology roadmap, and follow-up activity. Preliminary activity includes: (1) Satisfy essential conditions. (2) Provide leadership/sponsor-ship. (3) Define the scope and boundaries for the technology roadmap. Development of the technology roadmap includes: (1) Identify the "product" that will be the focus of the roadmap. (2) Identify the critical system requirements and their targets. (3) Specify the major technology areas. (4) Specify the technology drivers and their targets. (5) Identify technology alternatives and their time lines. (6) Recommend the technology alternatives that should be pursued. (7) Create the technology roadmap report. Follow-up activity includes: (1) Critique and validate the roadmap. (2) Develop an implementation plan. (3) Review and update.

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Technology Roadmapping: The Integration of Strategic and Technology Planning for Competitiveness¹

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Abstract. Technology planning is becoming critical with the rapid development and obsolescence of technologies. Technology roadmapping provides a tool for selecting which technologies to pursue in what timeframes. This paper provides a framework for technology roadmaps, describes the roadmapping process, and reviews its application.

I. INTRODUCTION

Globally, most companies are facing an increasing competitive challenge. In some cases, the competition is caused by other companies operating more effectively either alone or in alliances. In other cases, companies' competitiveness is being hurt because they are cutting back their research and development investments. However, at a time when products are becoming more complicated and customized, product time to market is shrinking, and the product life is shortening, these investments are becoming more, not less, critical. Better technology planning can help address this increasingly competitive environment. Technology roadmapping is an important tool for technology planning and coordination both collaboratively for entire industries as well as for internal corporate planning.

Technology roadmapping is a specific technique for technology planning, which fits within a more general set of planning activities. It identifies critical product needs that will drive technology selection and development decisions, determines the technology alternatives that can satisfy those needs, helps select the appropriate technology alternatives, and helps generate and implement a plan to develop and deploy those technologies. In many major projects, these functions of roadmapping have often been done, but in an ad hoc way, rather than using a more formal technology roadmapping methodology.

Technology roadmapping is driven by a need, not a solution. For example, if the need exists for an energy efficient vehicle that gets better miles per gallon, then lightweight composite materials is a possible solution. There may be other more appropriate solutions. Therefore, you must start with the need, not a pre-defined solution. It is a

fundamentally different approach to start with a solution and look for needs. Technology roadmapping provides a way to identify, evaluate, and select technology alternatives that can be used to satisfy the need.

II. BENEFITS OF TECHNOLOGY ROADMAPPING

The main benefit of technology roadmapping is that it provides information to help make better technology investment decisions. It does this first by identifying critical technologies or technology gaps that must be filled to meet product performance targets. Second, it identifies ways to leverage R&D investments through coordinating research activities either within a single company or among alliance members. An additional benefit is that as a marketing tool, a technology roadmap can show that a company really understands customer needs and has access to or is developing (either internally or through alliances) the technologies needed to meet their needs. Industry technology roadmaps may identify technology requirements that a company can support.

Some companies do technology roadmapping internally as one aspect of their technology planning. However, at the industry level, technology roadmapping involves multiple companies, either as a consortium or an entire industry. By focusing on common needs, companies can more effectively address critical research and collaboratively develop the common technologies. For example, the SIA (Semiconductor Industry Association) Semiconductor Technology Roadmap addressed the requirements for semiconductor manufacturing and the NEMI (National Electronics Manufacturing Initiative) Technology Roadmap addressed the common needs for information products to connect to information networks such as NII (National Information Infrastructure). This level of technology roadmap allows industry to collaboratively develop the key underlying technologies, rather than redundantly funding the same research and underfunding or missing other important technologies. This can result in significant benefits because a certain technology may be too expensive for a single company to support or take too long to develop given the resources that can be justified. However, combining the resources across companies may make developing the technology possible and consequently the industry more competitive.

II. WHAT IS TECHNOLOGY ROADMAPPING?

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The output of the technology roadmapping process is a technology roadmap. Technology roadmapping is a needs-driven technology planning process to help identify, select, and develop the technology alternatives to satisfy a set of product needs. It brings together a team of experts to develop a framework for organizing and presenting the critical technology-planning information to make the appropriate technology investment decisions and to leverage those investments. (For an example of this teaming process at the industry level see [1].) Technology roadmapping can also help coordinate the development of one or more technologies. This coordination allows the invested resources to be leveraged.

IV. PLANNING CONTEXT FOR TECHNOLOGY ROADMAPPING

Technology roadmapping is an iterative process that fits within the broader corporate strategic planning and technology planning context. However, since there are many successful variations of strategic planning and technology planning processes, this paper does not address how these are done, only their results. Planning activities must link three critical elements — customer/market needs, products/services, and technologies. The corporate vision drives the strategic planning effort, which generates high-level business goals and directions. Given a corporate vision, strategic planning involves decisions that identify and link at a high level the customer/market needs a company wants to address and the products and services to satisfy those needs. Given this strategic plan, technology planning involves identifying, selecting, and investing in the technologies to support these product and service requirements. Business development involves planning for and implementing certain as-

pects of the strategic plan, specifically those involving the development of new products and services and/or new lines of business.

This paper addresses technology roadmapping, which is a type of technology planning. However, technology roadmapping is more appropriate in some cases than in others and a decision needs to be made when to use it. Technology roadmapping is critical when the technology investment decision is not straight forward. This occurs when it is not clear which alternative to pursue (e.g., enhance an existing technology or replace it with a new technology), how quickly the technology is needed, or when there is a need to coordinate the development of multiple technologies.

V. TECHNOLOGY ROADMAPPING PROCESS

This section provides an overview of the three phases in the technology roadmapping process (Fig. 1).

A. Phase I: Preliminary Activity

The first phase involves preliminary activity without which the roadmapping probably should not be done.

1.) *Satisfy essential conditions.* For a technology roadmapping effort to succeed, a number of conditions must be satisfied. This step involves checking to ensure that those conditions are already met or that they will be met. These conditions include: (1) a perceived need for a

Fig. 1 The three phases in the technology roadmapping process.

technology roadmap and collaborative development; (2) input and participation from different groups (for a corporate roadmap participation from marketing, manufacturing, R&D, planning, etc; and for an industry roadmap participation from members of the industry, its customers and suppliers, as well as government and universities); and (3) the technology roadmapping process should be needs-driven, not solution-driven.

2.) *Provide leadership/sponsorship.* Because of the time and effort involved in roadmapping, there must be committed leadership/sponsorship from the group that is going to do the actual implementation and benefit from it.

3.) *Define the scope and boundaries for the technology roadmap.* This step ensures that the context for the roadmap has been specified. It develops or ensures that a vision exists, that a roadmap can support that vision, and identifies why the technology roadmap is needed and how it will be used. The time horizon for technology roadmaps varies, but it must be specific (typically 10 to 15 years for industry roadmaps and shorter for corporate roadmaps).

B. Phase II: Development of the Technology Roadmap

The second phase is the development of the technology roadmap.

1.) *Identify the "product" that will be the focus of the roadmap.* The critical step in roadmapping is to get the participants to identify and agree on common product needs (e.g., for an energy-efficient vehicle) that must be satisfied. Since the product may be complex and there may be many components and levels on which the roadmap may focus, selecting the appropriate focus is critical.

2.) *Identify the critical system requirements and their targets.* The critical system requirements provide the overall framework for the roadmap and are the high-level dimensions to which the technologies relate. Examples of critical system requirements for an energy-efficient vehicle include mpg, reliability, safety, and cost. Examples of targets include 60 miles per gallon (mpg) by 2000 and 80 mpg by 2005.

3.) *Specify the major technology areas.* These are the major technology areas that can help achieve the critical system requirements for the product. Examples of technology areas to meet the performance target of 80 mpg by 2005 for an energy efficient car include materials, engine controls, sensors, and modeling and simulation.

4.) *Specify the technology drivers and their targets.* At this point, the critical system requirements are transformed into technology drivers for the specific technology areas. These technology drivers are the critical variables that will determine which technology alternatives are selected. For the materials technology area, examples of technology drivers could include vehicle weight and acceptable engine tempera-

ture, while for the engine controls technology area a technology driver could be the cycle time for the computer controlling the engine.

5.) *Identify technology alternatives and their time lines.* Once the technology drivers and their targets are specified, the technology alternatives that can satisfy those targets must be identified. A difficult target may require breakthroughs in several technologies or a technology may impact multiple targets. For each of the identified technology alternatives, the roadmap must also estimate a time line for how it will mature with respect to the technology driver targets.

6.) *Recommend the technology alternatives that should be pursued.* This step selects the subset of technology alternatives to be pursued. These technology alternatives vary in terms of cost, schedule, and/or performance. In some cases, there may be analytical and modeling tools to help determine which technology alternative to pursue and when to shift to a different technology (i.e. when to jump to a new technology curve). In other cases, the trade-offs and decisions must be determined by the best judgement of the experts. In either case, the technology roadmapping process has consolidated the best information and developed a consensus from many experts. Furthermore, the roadmapping process has begun a collaborative effort that, when carried into the implementation, will result in more effective and efficient use of limited technology investment resources.

7.) *Create the technology roadmap report.* In addition to the actual technology roadmap, this report should also identify and describe each technology area and its current status; specify any critical factors (show-stoppers) which if not met will cause the roadmap to fail; clearly identify areas not addressed in the roadmap; and provide any technical and implementation recommendations.

C. Phase III: Follow-up Activity

The third phase is the follow-up and use of the technology roadmap.

1.) *Critique and validate the technology roadmap.* This work must be exposed to a much larger group for validation and buy-in for two reasons. First, the draft needs to be reviewed, critiqued, and validated. Second, there must be buy-in from the broader corporate or industry group that will be involved in implementing the plan.

2.) *Develop an implementation plan.* At this point, there is enough information to make better technology selection and investment decisions. Based on the recommended technology alternatives, a plan is then developed.

3.) *Review and update.* Technology roadmaps and plans should be routinely reviewed and updated. The review cycle should be based on the rate at which the technology and/or the need is changing.

VI. TECHNOLOGY ROADMAP EXAMPLE

This section provides an example of a needs-driven technology roadmap and Phase II of the process to develop it. The SIA roadmap, which has become one of the most frequently referenced examples of an industry technology roadmap, is used. The purpose of this example is to show the process flow from product need to actual roadmap, not to completely describe the SIA process and roadmap.

First, the product focus of the roadmap was semiconductors which could be used in various types of products (such as memories, consumer products, portable, and high performance computers) each of which had different requirements. However, semiconductor manufacturing technology was the common area on which the industry could cooperate. They competed on semiconductor designs and the products that used them, not the underlying manufacturing technology.

Second, the critical system requirements included smaller size (i.e. feature size), lower cost, and power dissipation for portable equipment. As an example of targets, they projected feature size between 1992 and 2007 as declining in three year increments from 0.5 to 0.1 microns.

Third, the roadmap identified 11 technical areas (e.g. chip design and test, lithography, and manufacturing systems). Using the critical system requirements as an overall framework, teams were set up for each technical area and technology roadmaps were developed for each area. Fourth, each team developed a set of technology drivers specific to their area, but which were derived from and related to one or more of the critical system requirements. For example, technology drivers in the lithography area that related to feature size included overlay, resolution, and device size. The lithography area was further decomposed into exposure technology; mask writing, inspection, repair, processing, and metrology; and resist, track, and metrology.

Fifth, for each technology area (e.g. lithography) and/or subarea (e.g. exposure technology), the roadmap identified technology alternatives -- such as x-ray, e-beam, and ion projection. Technology driver performance was projected for each technology alternative for various time points. Sixth, based on these projections and their impact on the critical system requirement targets, certain alternatives were recommended. Seven, the completed technology roadmap report was created in preparation for the follow-up activity. A major workshop was held to critique and validate the roadmap.

The roadmap is being used by Sematech to evaluate and prioritize potential projects. Does the project fit within the roadmap and if so where? It has also been used by Sandia National Laboratories to determine where its expertise can best be used and to develop projects that address specific parts of the roadmap. Other Sematech participants can also use the roadmap to focus their research and development activities. The roadmap has already undergone two review and revision cycles. The current version [7] is now noticeably different from the initial version.

CONCLUSIONS

Technology roadmapping is a useful technology planning tool in an increasingly competitive environment. It is needed when the technology investment decisions are not straight forward. For a successful technology roadmapping process, it is critical to identify why you are doing the roadmapping and how it will be used. Technology roadmapping is particularly useful when the technology investment decisions are not straight forward and for coordinating the development of multiple technologies. This coordination is critical when dealing with technologies that are related to a corporation's core competencies. The information about and analysis of needs and technology alternatives is far more important than following a precise process and format. In summary, technology roadmapping is a valuable process if done for the right reasons, but it should not be undertaken lightly or without good justification.

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