Industrial Technology Roadmap as a Decision Making Tool to Support Public R&D Planning

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***Abstract*--There are a variety of methodologies to forecast future technology, economy, and society. Technology roadmap (TRM) is one of the easily implementable methods of technology forecasting. It is a strategic management tool to support R&D planning and new product development at various levels such as a firm and government. This study aims to address a strategic decision making tool in public R&D programs to affect firms' strategic behavior under this umbrella. The main purpose of this paper is to address evolutionary aspects of industrial technology roadmap and provide a more advanced framework of public R&D planning.**

In South Korea, technology roadmapping has been initiated by government since 2000 and nowadays popularized in small and medium-sized companies as well. Despite of its popularity, there are only a few literatures to provide practical guidelines and systematic process to develop TRM applicable to R&D planning in any organizations. The framework of industrial technology roadmap developed by the Korea Institute for the Advancement of Technology which is established bringing together old 6 major government agencies such as Korea Industrial Technology Foundation, Korea Technology Transfer Center, Korea Institute of Industrial Technology Evaluation and Planning, Institute for Information Technology Advancement, Korea Material and Components Industrial Agency, Korea National Cleaner Production Center, Korea Institute of Design Promotion, can be applied to the R&D planning process of diverse government R&D programs in other countries.

The proposed framework can be applied and modified to the R&D planning process in any organizations. The study deals with a variety of industries, having different characteristics, and proposed similar technology roadmap. Consequently, this paper attempts to articulate establishing firms' R&D and business strategy, accompanying with government R&D programs and setting priorities among R&D projects.

I. INTRODUCTION

In most cases, technology forecasting is wrong. Technology forecasting, however, is valuable to give guidance for the direction of promising technology development. The value of technology forecasting lies in its usefulness for making better decisions, not in its coming true [1]. Technology forecasting, in other words, typically partially correct and cannot include all exact future forms. Technology forecasting strives not only to identify research and knowledge gaps to find the right path to reach goals, but to search ranges of environment that will be encountered in the future.

Technology forecasting attempts to reveal a specific characteristic or an attribute of technology over designated time. Joseph Martino defines technology forecasting as “a prediction of the future characteristics of useful machines, procedures or techniques” [1]. In the 1950s and 1960s, Technology Forecasting (TF) was driven by military competition with the Soviet Union. TF was initiated primarily as a tool to help anticipate military technology needs and to help plan and prioritize R&D and systems development [2]. Hal Linstone wrote that technology forecasting (TF) seems to have peaked around 1970 with a decline in methodological advance thereafter [3]. In historical perspective, the use of TF methods is summarized below figure 1.

The corporate has made its efforts on environmental scanning such as bibliometric/patent trend analysis and market analysis to indentify increasingly diversified needs of customers, in order to establish a steady grasp of technology initiatives as well as to improve its future position. In addition, a company should set up R&D strategy in alignment with business strategy such as manufacturing, sales and marketing, personnel, finance, and accounting. Most organizations have investigated major breakthrough technologies, core technology improvements, and state-of-the-art defining technologies. Technology forecasting tool for decision making is more necessarily needed to predict future technology trend than ever before.

A variety of technology forecasting methods have been developed and applied to various industries, organization by diverse purposes. But in the last four decades, especially after the widespread availability of Information Technology, some of the different approaches using much information like patents, journals, and research awards, have been continuously developed by different researchers combing with many other tools.

Technology roadmapping which the study focus is an effective tool for technology planning and communication which fits within a broader set of business planning [36][37]. Technology roadmaps in the corporate setting are used to define the plan for the evolution of a product, linking business strategy to the evolution of the product features and costs to the technologies needed to achieve the strategic objective [38]. There must be a linkage between the technology investment decisions and the business requirements [39]. Roadmapping is implemented to grasp a

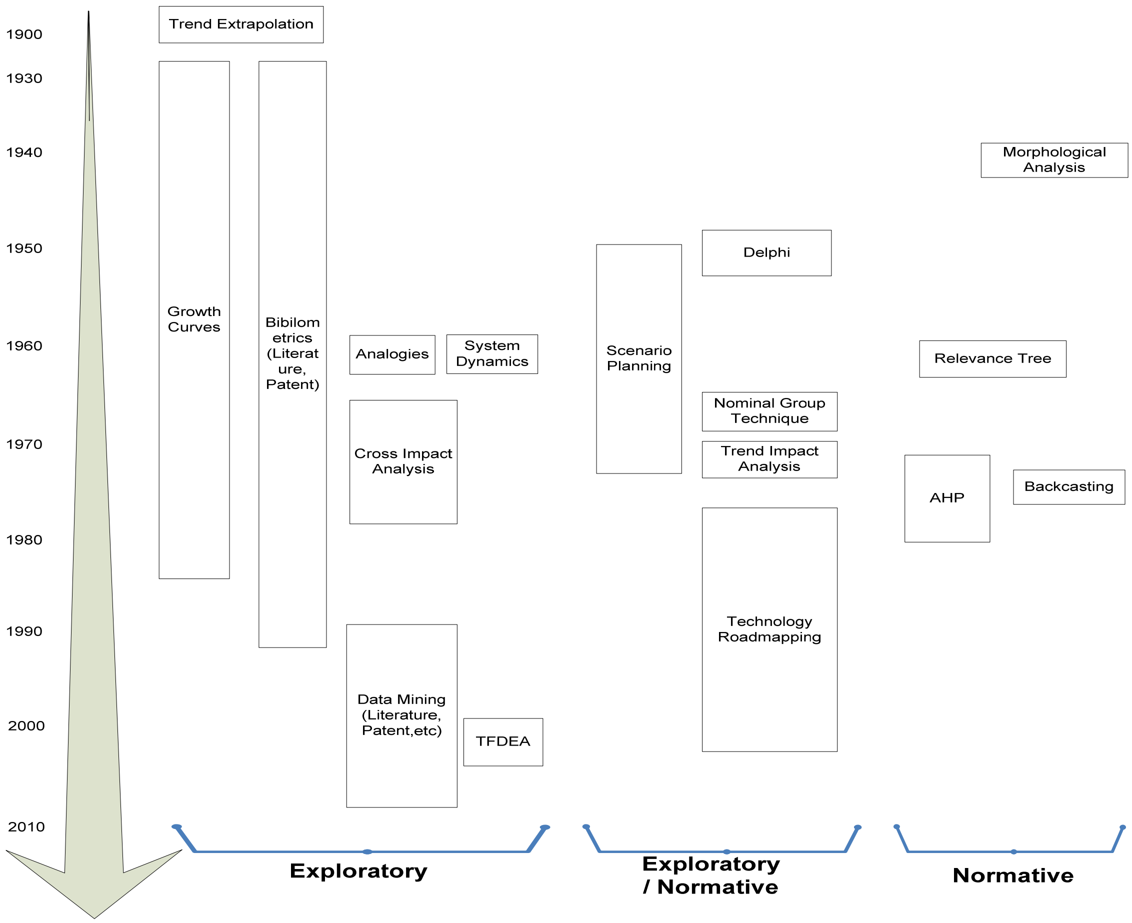

Fig. 1. The Chronological Tree of Technology Forecasting techniques [4].

TABLE 1. TECHNOLOGY FORECASTING TOOLS

Approach	Techniques	References
Environmental Scanning	- bibliometric analysis - patent landscape analysis, patent alert system, fuzzy-based clustering - data mining, text mining, database tomography, tech mining	[5][6][7][8] [9][10][11] [12][13][14] [15][16][17]
Stochastic forecasting	- probabilistic trends and time lags	[18]
Trend Extrapolation	- multiple regression, multivariate regression, etc	[1][19]
Measure of Technology	- scoring model, technology frontier	[1][20][21]
Time Series Analysis	- AR, MA, ARIMA	[8][19][22]
Growth Curves (S-curves)	- pearl, logistics, gompertz fisher-pry, bass diffusion model, and life cycle analysis	[1][23]
Modeling and Simulation	- system dynamics, agent-based models	[8][24]
Expert Judgmental Forecasting	- Delphi, survey, FGI, role playing, AHP, analogy model, scenario planning, technology roadmapping, etc	[1][18] [19] [25][26][27] [28][29][30] [31]
Normative Method	- relevance tree, morphological analysis, backcasting, mission flow diagram	[1][32][33] [34][35]

stronger awareness of how to serve potential and current market with the right product features at the right time to improve the cross-functional cooperation required integrating technology, product and market drivers for the new product and service creation in terms of customer requirements [40]. Company must generate an effective technology planning aligning with business plan to identify and develop the technologies required to meet its customer's future needs.

In 1987, Motorola published its own technology roadmap as a planning tool to position themselves and their product better in the market, with the communication between design & development engineers and marketing personnel which technologies will be required in future products. The Motorola's roadmap is an example of a single layer roadmap, focusing on the technological evolution associated with a product and it's features [41]. Since TRM's inception more than 25 years ago [42], Technology Roadmapping can provide quite a bit implementable tool to align technology strategy with business strategy, providing a structured framework to address three key questions: Where do a company want to go?, Where is a company now?, and How can a company get its target? [43] Technology roadmapping has gained significant and subsequent acceptance within corporations[38][40][41][44], across industries[45][46][47][48], and national foresights [49]. The development of roadmapping has been largely driven by practice within companies, government agencies and consulting firms [50]. In addition, there have been various studies to broaden application of TRM with other strategic viewpoint [51]. (See Table 2.)

In case of South Korea, most of government R&D programs are designed to take part in firms, academia and government-funded national laboratories. Especially, small and medium sized firms are proactively engaged in government R&D projects to acquire R&D funding to develop their technology and products. In such a context technology roadmapping provides a decision making tool to allocate public R&D funding. This paper proposes evolutionary roadmapping processes to effectively implement public R&D planning. These processes mainly developed by KIAT (Korea Institute for the Advancement of Technology) are expected to provide strategic decision making tool to effectively help improve the overall R&D performance and quality in public R&D investment at the end.

II. THE EVOLUTION OF INDUSTRIAL TECHNOLOGY ROADMAPPING

Since Sept. 2000, MOTIE (Ministry of Trade, Industry, and Energy) has initiated a project to develop the industrial TRM almost annually in South Korea. Since 2001, for about 4 years, KOTEF (Korea Industrial Technology Foundation) had been trying to set up the process of industrial technology roadmap. Each incremental change of processes has added up, subsequently, the management system of industrial technology roadmapping has been established. Technology planning is a deliberate and delicate task requiring a scientific and methodological design. The industrial TRM has played a compass role in technology planning in complex and turbulent environments. It has been utilized as an effective tool for the government to allocate R&D resources efficiently and for participants to share the information and promote cooperative research among them. Industrial TRM aims to support industry and a wider community of technology management by providing focused domains for practical R&D and a forum to promote productive discussions among industry-academic-national laboratory entities.

The evolutionary phases of industrial TRM can fall into two parts with retrospective. The earlier phase of TRM is summarized below Fig. 2. At this phase, the framework of industrial TRM has been tested, established and expanded to the integration of other methodologies, cooperation with other organizations and dealt with other crucial subject matter such as international cooperation, R&D infrastructure, IPR(Intellectual Property Right), Standards, and Regional Innovation Policy. Specially, at the 5th stage, industrial TRM was used as a strategic planning tool to forecast future needs and develop pictures of future vision, specifically home, industry, and city areas, induced from new emerging technology development of 19 different sectors in 2015.

TABLE 2. THE APPLICATIONS OF TECHNOLOGY ROADMAP TECHNIQUE

TRM applications	Characteristics	Reference
TRM incorporate disruptive technology	● identify potential disruptive technologies and products explaining that disruptive technology roadmapping process is different from that of sustaining technology	[52][53][54][55] [56] (2004)
TRM incorporate supply chain management	● reduce investment uncertainty through shared information within an integrated supply chain	[57][58][59] (2002)
TRM incorporate service strategy	● integrate more sophisticated service functions to the conventional products and systems, bridging Gaps in service operations	[60] [61] (2006)
TRM incorporate new product development	● propose heuristic approach combining technology roadmapping, information technology (IT) and supply chain management to make more sustainable new product development decisions	[57] (2004)
TRM integrate with scenario planning	● combine scenario planning with technology roadmapping to mitigate limitations both have, generate multi-scenario roadmapping	[62][63] (2004)
TRM incorporate business model	● combine business modelling to create new business value and strategic roadmapping method	[64] (2009)
TRM incorporate knowledge management	● deal with knowledge management actions upward to business objectives and strategies and downwards to specific knowledge assets	[65][66][67] (1998)

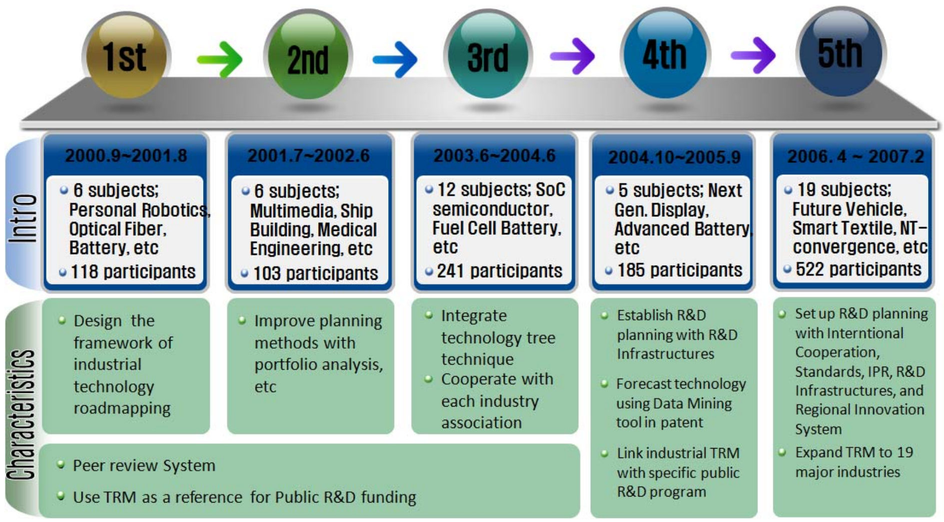

Fig. 2. The 1st phase of Industrial TRM 2000-2007

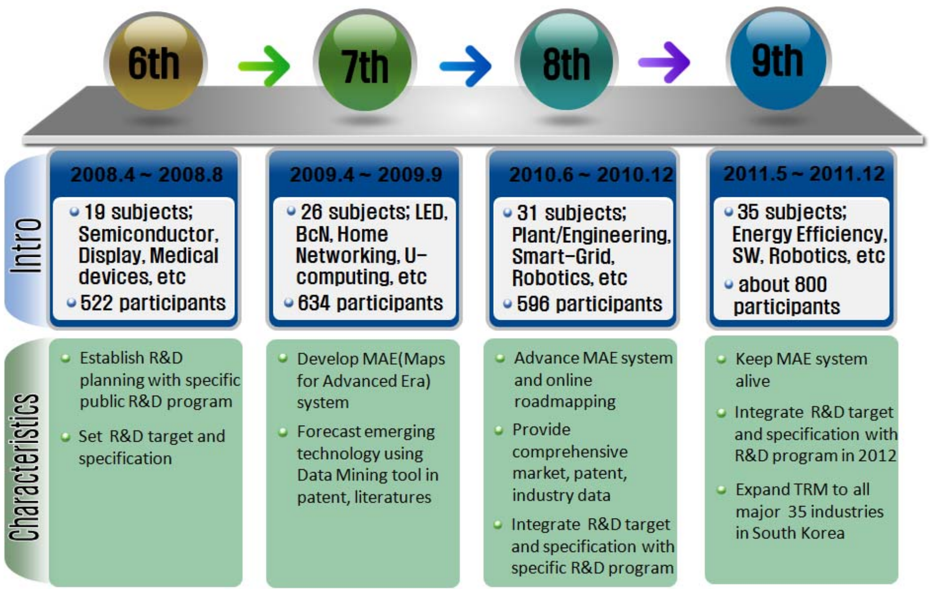

Fig. 3. The 2nd phase of Industrial TRM 2008-2011

The 2nd phase of industrial TRM is illustrated in Fig. 3. At this phase, industrial TRM has been much more associated with specific R&D programs or projects by providing a framework for R&D planning and coordinating R&D efforts with operational requirements. It also presents a development plan to meet future needs and fill the technological gaps and opportunities identified in the process.

At each stage, research results were given an objective assurance through inspections by a review committee, a series of workshops and public hearing (on and off) with various experts and interest groups to ensure the balance of expertise and viewpoints. Roadmapping committees are staffed by a mixture of different backgrounds from industry, government, and academia. For example, from April 2006 to Feb. 2007, about 522 experts from industries, academia and research institutes participated and developed industrial Technology Roadmaps in 19 industrial sectors. Industrial TRM in 19 domains was open to the public on Mar. 2007. 9 areas of them were regarded as key fields in the economic growth of South Korea. Among them, 7 areas were related to the main basic industries of South Korea, such as semiconductor, automotive, and etc; the others to the future strategic industries like nano technology, bio technology and cognitive robot. In 2007, Industrial TRM and Future Vision 2015 proposed images of future of 19 different sectors in 2015, eliciting practical application tools and technologies by the megatrends of our society such as globalization, multi-polar economy, climate change, socio-demographic change, changing customer needs and new emerging technologies in global surroundings. Not only did it support technology strategy and planning at the national level, but it linked market opportunities to product and technology development at the firm level.

Industrial TRM has been employed as a decision making tool to support public R&D planning and technology forecasting. It helps to forecast technology trend and industry trend based on expert decisions as well as quantitative data such as market trend data, patents, and literatures. Technology roadmap is used as a market needs-driven R&D planning process to help identify, select, and develop technology alternatives that satisfy a set of product needs. Korean governments, firms, academia and industrial consortia utilize industrial technology roadmaps to explore the dynamic linkages among the changing environment, organizational strategies, and technological resources.

III. THE FRAMEWORK OF INDUSTRIAL TECHNOLOGY ROADMAPPING

The framework of industrial TRM has been standardized and established for a decade, designed to support overall and specific R&D programs. Industrial TRM needs a lot of efforts to determine industry and technology areas to focus on. Especially, identifying emerging technologies and setting R&D development targets in each technology area requires much more sophisticated tools such as gap analysis, portfolio analysis, literatures and patent data mining and expert decisions. To fulfill R&D planning, STEEP (social, technological, economic, environmental and political) trends and needs should be investigated along with evaluating current technology capabilities compared to its competitor's in each field. The process of industrial TRM consists of three stages: preparation stage, roadmapping and follow-up stage.

A. Preparation stage

At this stage, decision-makers discuss and reach a consensus regarding areas that TRMs are necessarily developed in order to resolve current issues that society faces. Consensus is very crucial and required for TRM to be consecutively maintained and alive.

Preliminary Planning

Determining relevant areas and methodologies requires great efforts and elaborate works to be done in view of TRM project management. A TRM team is formed, the framework of TRM is designed, and a roadmapping schedule is organized. After a number of discussions on the methods used in technology roadmapping, a series of peer reviews and the Delphi method is typically selected. This process is performed through a survey of thousands of experts, consensus-building among the external advisory group, and consulting with related government officials. Internal team meetings to set up the framework of industrial TRM usually are held over 10 times.

To develop industrial TRMs, KIAT organize committees with various experts from academia, firms, national research labs and government. Committees are one of the most significant elements for the success of industrial

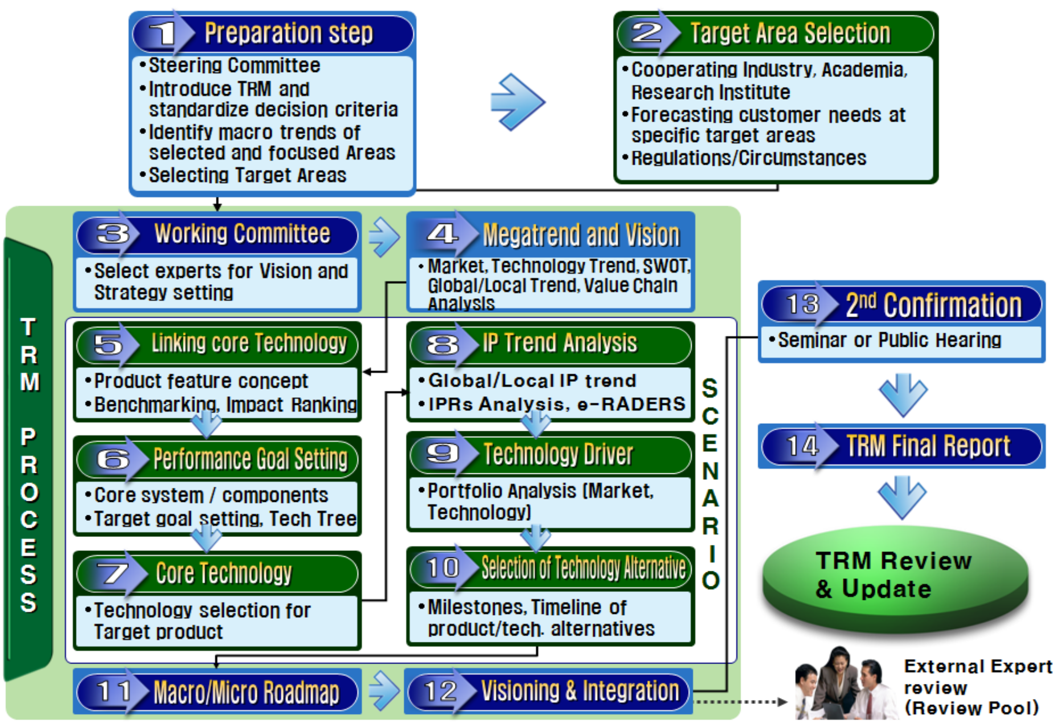

Fig. 4. The overall process of industrial TRM

TRM, since the future demands and needs, target products and emerging technologies can only be identified through discussion among them due to extremely high uncertainty. Consequently, steering committee, operational committee and supporting group should be carefully selected in each technology field for the benefit of TRM. Above all, industry must play a proactive role in the industrial TRM process, in order to be an industry-led TRM along with taking into account of consumers and suppliers. Finally, such issues inherent in peer review system like the 'old boys' network to protect established fields and leniency effect should be eliminated.

B. Roadmapping stage

It includes all activities associated with industrial TRMs. Roadmapping process is described in figure 1.

a. Select subjects of TRM
b. Identify major experts in each area
c. Determine decision criteria and clarify roadmap procedure
d. Select committee
e. Plan workshop for roadmapping in each field
f. Confirm necessary information with respect to TRM
g. Open workshop for roadmapping in each field
   - 50% participants consists of experts from industry
   - All interested group (Academia, Research Institute, Consumer, and Company) should be involved
   - All participants must have expertise about the selected area so that they may contribute to the workshop
h. Sum up workshop reports.
i. Consist of subcommittee to prepare the first draft of TRM
j. Develop the first draft Roadmap
k. Take feedbacks after circulating the first draft Roadmap
l. Consolidate TRM with additional evaluations and comments from industry
m. Establish and execute attainable plans.

There are major 7 steps(4~10) of workshops not simply to provide blueprints of technology development, but to allocate public R&D investment with the assistance of experts and knowledge clustering. Furthermore, there were 2~3 small group meetings between 7 steps of workshops.

Visioning and Integration Workshop

TRM project management team must develop the images of future through workshops, even though it is recommended that visioning & integration workshop should be comprised of CEO, technology forecasting expert and developer of a long term vision. Images of future vision should be developed with the help of working committee, via internet and relevant forecasting sources like picture of future from Siemens, due to the lack of experience as well as no expertise of selected technologies.

Portfolio analysis

Technology areas are determined by the following criteria along with the help of experts;

- Can we make commercialized products which meet the future needs?
- Can it gain access to a niche market?
- Can it achieve world-class competitiveness in a short time?

While TRM presents a series of milestones to attain the object of technology development, the portfolio analysis clearly proposes the priorities of investment related to various technologies identified by TRM. Decision criteria includes global market size, strategic importance, market and technology trends, technology importance, relatively technology position, potential competitive advantage, and synergy effects on both economy and industries.

In portfolio analysis, the X-axis indicates the technological maturity which depends on the possibility of taking out a patent and the degree of concentration of core technologies. It is affected by the investment plan and outcome relevant to a specific technology. Meanwhile, the Y-axis indicates the technological importance that means the relative potential in creating value and the value-added level of a specific technology. It is mainly affected by the current status of relevant technologies in a technological life cycle. The concept of each domain of technical portfolio is described in following figure 4.

Final report of TRM

Following the submission of the final reports from each working committee, TRM project team critically analyze them and sum up a synthesis report, which included the review of the process, a summary of each working committee report in a coherent format, along with the analysis of findings and recommendations of the external experts.

C. Follow-up stage

TRM should be reviewed and updated periodically in order to keep it alive. Follow-up step justifies TRM, reevaluates, updates and develops feasible plans with respect to all post activities. This procedure is necessary but, generally a little bit hard to follow this step.

IV. THE ORGANIZATIONAL PERSPECTIVE ON INDUSTRIAL TRM

Effectively organizing expert committees is one of the significant elements for high-quality TRM, because TRM highly depends upon the commitment of expert committees. Consequently, it is very important whether TRM team might select appropriate experts in a committee, especially a competent person from each relevant association, research institutes and firms. Furthermore, the quality of TRM belongs to the facilitator’s management skill of committee. In committee, some experts should have knowledge and

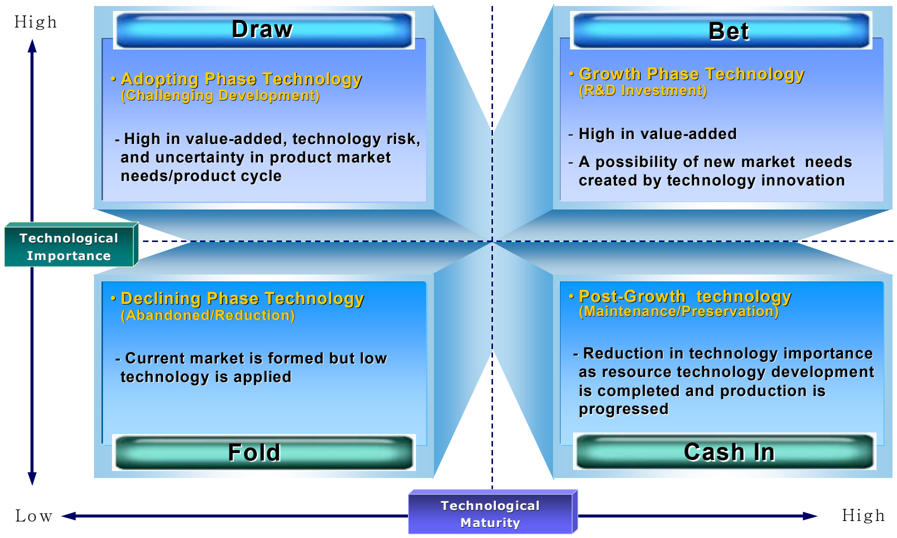

Fig. 5. Quadrants of portfolio analysis

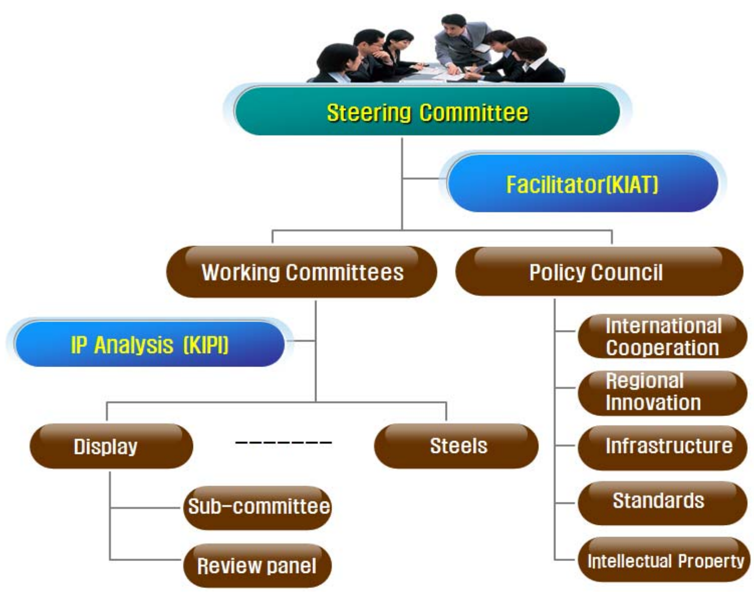

Fig. 6. The structure of expert committees of industrial TRM

experience in terms of technology roadmapping. These skills cover leading people in a committee. They can be other project managers in technology roadmapping.

In constructing industrial TRM, there are various sub-groups to interact such as steering committee, working committee, policy council, IP analysis team, and review panel, as following figure 5 illustrate. It requires the advanced management skill of a number of work packages such as communication, interaction, cooperation, and etc.

Steering Committee

'Steering Committee(SC)' serves as a final decision maker in TRM process. It consists of about 20 experts such that about 12 members of it come from industry, 6 people have interdisciplinary backgrounds like in economics or management, a government official, and a director from the MOTIE. It prioritizes industry sectors or technology domains to be focused on and gives some advice on overall technology roadmapping. From our long experience, the appropriate size of SC should be around 9~13 for high quality of TRM.

Working Committee

'Working Committee(WC)' plays a major role in technology roadmapping, prioritizing candidate items through portfolio analysis, selecting criteria such as global market size and strategic importance, investigating market and technology trends, potential competitive advantage, and synergy effects on both overall economy and each relevant industry. WC identifies core technologies and products from subcommittees in every target domain and develops TRM. 3~4 subcommittees are required to deal with much more concrete R&D planning in WC. The output of subcommittee is finally reviewed by the chairperson of WC. Half of WC comes from each relevant industry, 4 people from academia, 3 members from research institute, a government official, a facilitator from KIAT and etc. In total, it consists of about 17 experts. A government official in WC usually serves as an observer rather than as a secretary for the group. In addition, relevant associations should take part in WC, since it also have ownership of each industrial TRM. The proactive involvement and cooperation with industry association is very significant for technology roadmapping to be successful. Subsequently, it needs motivation and incentive to establish the complete TRM development process. We recommend that the wisdom of it be communication.

IP Analysis

The protection of intellectual property rights (IPRs) has become an increasingly important issue in multilateral trade negotiations. In the midst of technology roadmapping, the strategy of IPRs should be developed simultaneously, through the participation of KIPO [1] (Korean Intellectual Property Office)'s officials and experts of each sector from KIPI(Korea Institute of Patent Information) for IP information analysis. Patent information is mainly used to monitor competitors for the development of R&D planning. They analyze global and local IP trend of targeted items with the assistance of WC.

Policy Council

'Policy Council' is involved in challenges of infrastructure such as regional innovation, international cooperation, standardization, intellectual property. Specific organizations with requisite expertise should participate to develop a technically credible TRM in each domain. It requires strong cooperation between these organizations.

V. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

In South Korea, the industrial technology roadmap has been popularized in the aspect that it attempts to construct each TRM at industry level, but had limit because this roadmap had some broad concept and development plan in the scope of roadmapping, and it did not have any information in terms of collaborators or sponsors who can play a major role in the development, acquisition and operation of technology identified in TRM. Hereafter, industrial TRM has evolved to R&D planning tool to directly link specific R&D programs or projects to overcome this kind of weakness. In addition, it has evolved to have much more comprehensive description about why, when, and for whom the emerging technology is necessary and what consequential losses may follow if the technology cannot be developed.

In organizational perspective, industrial TRM has been trying to diversify the alternative solutions through adding non-technological elements as well as alternative scenarios by policy council. Industrial TRM necessarily introduce the availability of identified technologies, which means where, by whom, how and how much the technology is used right now. It also addresses the scope of technology application, whether it can be applied to another industry or not.

Recommendations

There are several critical factors that have to be considered for the benefit of industrial TRM. Although developing industrial TRM in itself is significant for political issues, after that R&D investment plans of government are to be given with a concrete form and carried out. It enables TRM much more valuable to stakeholders. Second, cost-benefit analysis has to be supplemented. In TRM's activities, cost is easily calculated including all the expenses to be paid for the development, acquisition and operation of the technology. On the other hand, the benefit might be evaluated as the demand estimated in the market where the technology is supposed to be.

To accomplish roadmapping successfully, government should fill the gaps identified in roadmapping process. Government must play a role of promoter or catalyst by active participation in a committee. To promote the development of TRM, it is better way for government to select target areas of TRM. Moreover, government has to maintain transparency and objectivity in constructing TRM. Lastly, government should support sufficient funds and allocate enough time like over 12 months and within 15 months to effectively develop industrial TRM.

As it is recommended that technology roadmapping be substantially led by industry [68], industrial TRM also has a general guidance on that industry should lead roadmapping process with around 50% participation of experts from industry in a committee. Finally, it would be more efficient and worthwhile for industry associations to develop their own technology roadmapping process. It is clear that much is yet to be learnt about the structure and development of TRM. Nonetheless, the framework of industrial TRM presents rich findings of public R&D planning obtained from Korean cases over a decade.

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