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Description	

Establish a Creative Environment for Roadmapping in Academy
-- from the perspective of *i*-system methodology

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Abstract. Roadmapping, originated from industry as a strategic planning tool, is attracting increasing applications in academy. Based on the recognition that roadmapping is a knowledge creation process, this paper analyzes what kind of support is needed or helpful for establishing a creative environment for roadmapping in academy and reviews various types of such support from the perspective of *i*-system methodology. As case studies of such support, this paper further introduces roadmapping pratices in Janpan Advanced Institute of Science and Technology.

Keywords: *i*-system methodology, roadmapping

1 Introduction

Today the term *roadmap* is used liberally by planners in many different types of communities. It appears to have a multiplicity of meanings, and is used in a wide variety of contexts: by commercial organizations, industry associations, governments, and academia, see, e.g., (Kostoff and Schaller, 2001). Perhaps the most widely accepted definition of a roadmap was given by Robert Galvin, a former CEO of Motorola (Galvin, 1998):

> *A roadmap is an extended look at the future of a chosen field of inquiry composed from the collective knowledge and imagination of the brightest drivers of change in that field.*

Thus, a roadmap is not only a plan, but also a vision of future research or actions. Roadmapping is regarded today as a tool for knowledge management in both industry and academia, and it has been recognized that the roadmapping process is, in its essence, a knowledge creation process, see (Li and Kameoka, 2003; Ma et al., 2006b). Most of existing roadmapping solutions and tools were develpped in business area with strong commerical background, and they do not pay much attention to “emerging technologies” and “creative invention”, which are the main targets of ademic labs. This paper argues that *i*-system methodology (Nakamori, 2003; Nakamori and Takagi, 2004) – composed of five subsystems – can help us to figure out how to develop a creative environment for roadmapping in academy.

The rest of this paper is organized as follows. Section 2 reviews the origins of the concept of roadmaps, roadmapping, formats, general roadmapping techniques, and introduces its applications in academy as a knowledge creation process. From the perspective of *i*-system methodology, section 3 analyzes what kind of support is needed or helpful for create a creative environment for roadmapping in academy and reviews various types of such support. Then as case studies of such support, section 4 presents roadmapping practices in JAIST (Japan Advanced Institute of Science and Technology). Section 5 summarizes this paper.

2. Roadmaps, Roadmapping and its Application in Academy

2.1 Roadmaps and Roadmapping

The roots of applying the concept of a roadmap as a strategic planning tool can be tracked back to the late 1970s and early 1980s, when Motorola and Corning developed systematic roadmapping approaches (Probert and Radnor, 2003). The Motorola approach has been more widely recognized (Phaal et al., 2004), leading the spread of roadmapping practice in Philips (Groenveld, 1997), Lucent Technologies (Albright and Kappel, 2003), etc. Therefore, it is widely believed that Motorola was the original creator and user of roadmaps (Probert and Radnor, 2003; Willyard and McClees, 1987). Because the use of the roadmap concept has spread today far beyond its original field of strategic planning for technology and development, we often use *technology roadmapping* in the field of management of technology (MOT); those roadmaps are commonly called *technology roadmaps*.

(Galvin, 1998) pointed out that "*roadmaps are working now in industry and they are beginning to gain a stronghold in science"*. Indeed, in recent years roadmapping has been increasingly used by governments and diverse consortia to support sector-level research collaboration and decision making as well as to plan technological and scientific development, in both national and international contexts. The U.S. Department of Energy initiated a *National Hydrogen Vision and Roadmap* process, and published a *National Hydrogen Energy Roadmap* in 2002 which explored the wide range of activities, including scientific development, required to realize the potential of hydrogen technologies in solving issues of energy security, diversity, and environmental needs in the USA (United States Department of Energy, 2002). NASA also utilized roadmapping to develop a technological and scientific development plan (NASA, 1998). An example of the efforts in an international context is the *International Technology Roadmap for Semiconductors*, developed and updated jointly by the European Semiconductor Industry Association, Japan Advanced Electrics and Information Technology Industries Association, Korea Semiconductor Industry Association, Taiwan Semiconductor Industry Association, and the Semiconductor Industry Association (ITRS, 2004). The European Union routinely uses roadmapping as one of its tools for preparing subsequent *Framework Programmes* for international research and development.

Roadmaps can mean different things to different people. They are developed for different purposes. (Phaal et al., 2004) identified eight types of technology roadmaps in terms of the intended purpose; (Kostoff and Schaller, 2001) summarized dozens of different applications of roadmaps presented in a technology roadmapping workshop in 1998 and found that those applications covered a wide spectrum of uses including:

- science/research roadmaps;
- cross-industry roadmaps;
- industry roadmaps;
- technology roadmaps;
- product roadmaps;
- product–technology roadmaps;
- project or issue roadmaps.

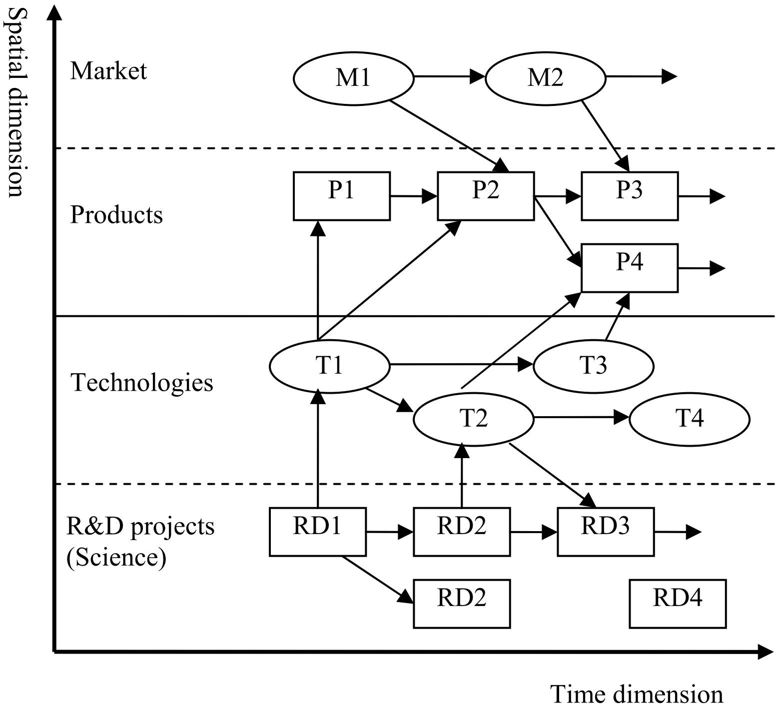

Figure. 1 Generic S&T roadmap nodes and links (Kostoff and Schaller, 2001)

Roadmaps can have also different formats. Fig. 1 presents a generic science and technology (S&T) roadmap that consists of spatial and temporal dimensions (Kostoff and Schaller, 2001; Groenveld, 1997; EIRMA, 1997). Another example of a specific roadmap format is that applied by Honeywell while utilizing Geneva Vision Strategist software (see http://www.alignent.com/) to digitally capture technology projects, components, subassemblies, and the timing of these developments to support product completion (Petrick and Echols, 2004; Rasmussen, 2003).

(Phaal et al., 2004) identified the following eight types of roadmap according to their graphical formats.

(a) *Multiple layers.* This is the most common technology roadmap format, comprised of a number of layers (and sub-layers), such as technology, product, and market. A Philips-type roadmap could be an example of this format, see (Groenveld, 1997).

(b) *Bars.* Many roadmaps are expressed in the form of a set of bars, for each layer or sub-layer. A Motorola-type roadmap is the classic example of this format, see (Willyard and McClees, 1987).

(c) *Tables.* In some cases, entire roadmaps, or layers within the roadmap, are expressed as tables (time vs. performance or requirements). For example, the personal academic research roadmaps introduced in (Ma and Nakamori, 2005b) are in this format.

(d) *Graphs and plots.* A roadmap can be expressed as a simple graph or a plot, typically one for each sub-layer. Often, the plots employed are called *experience curves*, related to *technology S-curves,* see (Grübler, 1996).

(e) *Pictorial representations.* Some roadmaps use more creative pictorial representations to communicate technology integration and plans. Sometimes metaphors are used to support the objective (e.g., a picture of a tree can symbolically represent an environmental commitment). A Sharp-type roadmap could be an example of this format, see (ITRI, 1995).

(f) *Flow charts.* A particular type of pictorial representation is the flow chart, which is typically used to relate objectives, actions, and outcomes. A NASA-type roadmap could be an example of this format, see (NASA, 1998).

(g) *Single layer.* This form is a subset of Type (a), focusing on a single layer of the multiple layer roadmap. The Motorola roadmap (Willyard and McClees, 1987) is an example of a single layer roadmap, focusing on the technological evolution associated with a product and its features.

(h) *Text.* Some roadmaps are entirely or mostly text based, describing the same issues that are included in more conventional graphical roadmaps (which often have text-based reports associated with them). The *National Hydrogen Energy Roadmap* (United States Department of Energy, 2002) and the *International Technology Roadmap for Semiconductors* (ITRS, 2004) are examples of this format.

With these various formats, the most important things are the stories behind different graphs and tables. And what all these different roadmaps have in common, is their goal of strategy development and their orientation towards helping their owners clarify the following three problems:

- Where are we now?
- Where do we want to go?
- How can we get there?

Roadmapping - the process of making roadmaps - is also characterized as a "*disciplined process for identifying the activities and schedules necessary to manage technical (and other) risks and uncertainties associated with solving complex problems*" (Bennett, 2005). According to (Australian Department of Industry, Science and Resources, 2001), there are generally three approaches for making technology roadmaps in industry:

- *Expert-based approach.* A team of experts comes together to identify the structural relationships within the field and specify the quantitative and qualitative attributes of the roadmap.
- *Workshop-based approach.* This technique is used to engage a wider group of industry, research, academic, government and other stakeholders, to draw on their knowledge and experiences.
- *Computer-based approach.* Large databases are scanned to identify relevant research, technology, engineering, and product areas. High-speed computers, intelligent algorithms, and other modeling tools can assist in estimating and quantifying the relative importance of these areas and in exploring their relationships to other fields. This approach is still in its infancy, as large textual databases and efficient information-extracting computational approaches have only begun to emerge.

Of course, these three approaches are not mutually exclusive and not independent. For example, when the expert-based approach is applied to making roadmaps, it is usual to organize some workshops (through local or remote meetings), while computers, intelligent algorithms, etc. can be used to provide supplemental information and knowledge to experts. Thus, during the roadmapping process, it is most likely that all three of these approaches are used, though one approach might be dominant. For example, (Kostoff et al., 2004) developed a roadmapping process which starts from identifying major contributory technical and managerial disciplines by text mining (literature-based discovery), followed by workshops in which experts participate. In practice, the roadmapping process should be customized according to its objectives, the organizational culture, and other contextual aspects.

Roadmapping involves a consensus building process. In this sense, roadmapping is similar to the foresight process, (Salo and Cuhls, 2003). The difference between them is that foresight is essentially aimed at building broad social support for a vision of what the future will be like, while roadmapping tries to find the best way to realize the expected future. Thus, roadmapping could be used as a tool or as an approach to the foresight process.

2.2 Roadmapping in Academy as a Knowledge Creation Process

In recent years, roadmapping has seen its increasing applications in academy. Some academic institutions developed roadmaps as strategic research plans; for example, the Berkeley Laboratory at the University of California prepared and published a research roadmap for its High-Performance Data Centers (Tschudi et al., 2002). Ma et al. (2006b) have argued that developing personal academic research roadmaps can be very helpful for individual researchers, and have put forward a roadmapping solution for individual researchers based on Interactive Planning methodology (Ackoff, 2001). The reason why roadmapping – a methodology originated from industry – sees increasing applications in academia is that a roadmapping process is, in its essence, a knowledge creation process.

From the view point of Nonaka and Takeuchi's SECI model (Fig. 2), when people start roadmapping, they begin to share their experience and expertise (mainly in the form of tacit knowledge) -- *Socialisation*; by articulating and documenting participators' experience and expertise on the issues related to the topic of the roadmap under developing, those shared tacit knowledge become available to all the participators -- *Externalisation*; roadmaps are the results of converting articulated participators' experience and expertise -- *Combination*; during the process of implementing roadmaps, new tacit knowledge will come into being in individual member's mind -- *Internalisation*. Roadmaps need to be continuously adjusted and improved according to members' new understandings and the emergency in the real world. A never-ending process of roadmapping thus is a SECI spiral of knowledge creation.

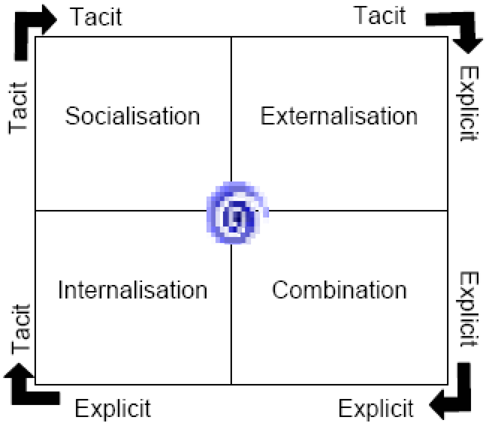

Figure 2. The SECI spiral of knowledge creation (Nonaka and Takeuchi, 1995)

From the perspective of the *Double EDISEEIS Spiral* (Wierzbicki and Nakamori, 2006a) which describes the knowledge creation process in academy, roadmapping, as a consensus building process, might start from the individual ideas of each participant, generated by individual intuition through a transition called *Enlightenment,* transferring the idea to individual rationality. A joint discussion and *Debate* between the participants results in a first-cut roadmap, which can be viewed as group rationality. After distributing the roadmap among all participants and other stakeholders, they have some time to reflect on it, for *Immersion* in their intuition; in this way, it becomes a group intuition. Inspired by the group intuition, new individual intuitions will come into being through the *Selection* of new ideas; this completes the *EDIS Spiral,* see Fig. 3. The first-cut roadmap can be considerably improved when repeating the *Debate,* using the power of the group intuition inspired by the former *Debate;* this corresponds to the *Principle of Double Debate* (Wierzbicki and Nakamori, 2006a).

Most of existing roadmapping solutions and tools were develpped in business area with strong commerical background, and they do not pay much attention to "emerging technologies" and "creative invention", which are the main targets of ademic labs. So when roadmapping is implemented in academy, it makes sense to apply some methodologies, such as the *i*-system methodology introduced in the next section, to figure out what kind of support is needed or helpful for establishing a creative environment for roadmapping in academy.

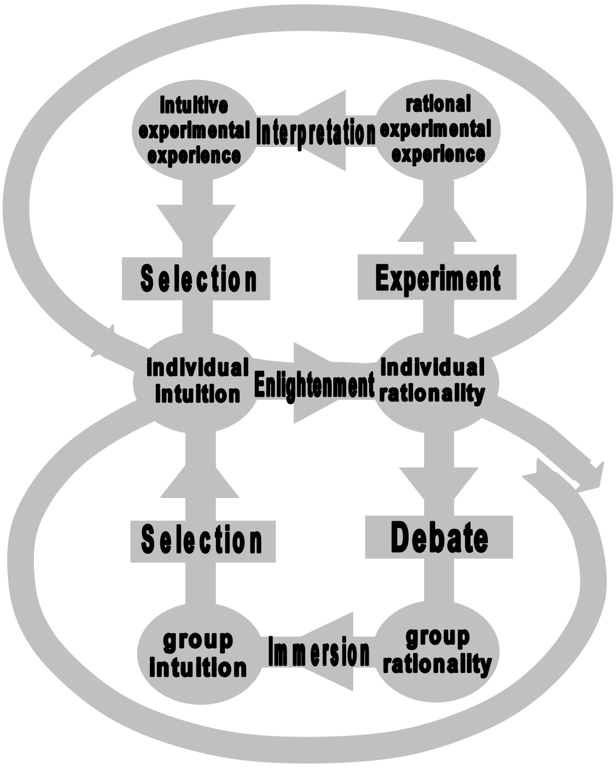

Figure. 3. The *Double EDISEEIS Spiral* of intersubjective and objective knowledge creation and verification (Wierzbicki and Nakamori, 2006a)

3. *I-System* Methodology and Knowledge Creation Support for Roadmapping in Academy

The *i-system* methodology uses aspects of social and natural sciences complementarily (Nakamori, 2003; Nakamori and Takagi, 2004). *I-system* combines five subsystems, namely, *Intervention, Intelligence, Imagination, Involvement* and *Integration,* as shown in Fig. 4.

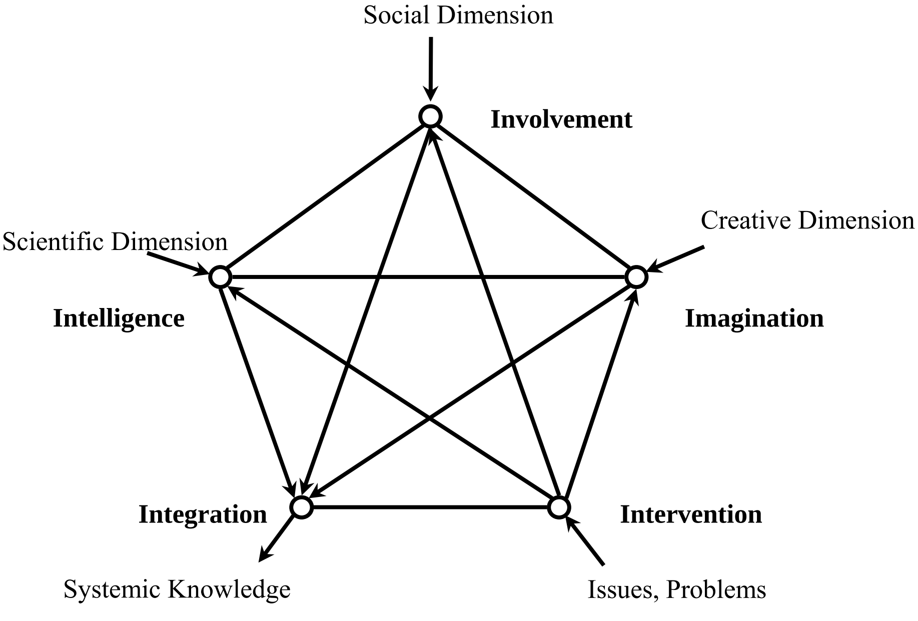

Figure 4 The *i-system* (Nakamori 2003)

Because the *i-system* methodology is intended as a synthesis of systemic approaches, *Integration* is in a sense its final dimension, and all arrows in Fig. 4 converge to *Integration* interpreted as a node; links without arrows denote the possibility of impact in both directions. The beginning node is *Intervention,* where problems or issues perceived by the individual or the group motivate further analysis and all creative process. The node *Intelligence* corresponds to diverse types of knowledge, the node *Involvement* represents social aspects. The creative aspects are represented mostly in the node *Imagination.*

Originally, the *i-System* methodology did not specify a sequential process or interrelated phases as guidelines for applications. Nevertheless, it identified five important dimensions and a description of the relationship among these dimensions of knowledge creation helped create a better understanding of knowledge creation processes. Later, in (Wierzbicki and Nakamori, 2006b), a sequential interpretation of the *i-System* as a spiral was given; this interpretation indicates a suggested order for the subsystems: *Intervention, Intelligence, Involvement, Imagination* and *Integration*. We will use this order to discuss what knowledge creation support is needed or helpful for roadmapping in academy, in each of these five dimensions.

1) *Intervention*

Intervention can be understood as a motivational dimension, the drive, determination, or even dedication to solving a problem. Starting a roadmapping process can be thus thought of as an intervention for issues motivating strategic plans. In this dimension, initiators of the roadmapping process should first have a deep understanding of the motivation for making that particular roadmap. Secondly, they should also know what roadmaps and roadmapping are, what advantages roadmapping has, and how to do roadmapping. Finally, initiators or coordinators must also consider who should participate in the roadmapping team and motivate them to join, customize a roadmapping process and schedule, and let all participants know the purpose and schedule and their roles in the roadmapping process.

When the team starts roadmapping, the major contributory technical and managerial disciplines should be identified. For example, if the team is making a roadmap for low carbon-emission cars, the team should identify:

- Current carbon-emission level of cars,
- Current technologies for reducing emissions,
- Future requests for abatement of carbon-emissions in car industry,
- Potential technologies for fulfilling the requests,
- General context, e.g., impacts on issues of climate change, etc.

2) *Intelligence*

Intelligence has two aspects: rational/explicit and intuitive/tacit. It is a duty of the coordinator and of all participants of a roadmapping process to search for relevant explicit information. In this task, the following kinds of support could be helpful:

- **Scientific databases**. The access either to disciplinary or to general scientific databases such as *Scopus* (http://www.scopus.com), ScienceDirect (http://www.sciencedirect.com), etc., can be very helpful for researchers to understand what has been done, what is being done, and what should be done.
- **Text mining tools**. The amount of scientific literature increases very rapidly, thus help in finding relevant explicit information is necessary. For examples, readers can refer to (Kostoff et al., 2004; Greengrass, 1997; Huang, 2005).
- **Workshops** in which many experts are involved. Here some selected groupware, such as Pathmaker (see http://www.skymark.com), could be applied to help structure and manage discussions among experts.

In fact, the third method already involves some elements of intuitive or tacit expert knowledge. But an important aspect of good intelligence is individual reflection on and interpretation of the explicit information previously obtained, thus every participant of the roadmapping process should individually perform *Analysis, Hermeneutic Immersion, Reflection,* and in this way prepare *Enlightenment,* the generation of new ideas related to the discipline and topic of roadmapping.

3) *Involvement*

Involvement is a social dimension, related to two aspects: societal motivation and consensus building in the group of participants.

Some aspects of societal motivation should already have been addressed in the beginning stage of *Intervention.* However, after gathering relevant information and reflecting on it, the participants should again review the issue of societal motivation, in a specially organized group discussion.

Roadmapping in a group is a consensus building process. This process might include many researchers, experts, and other stakeholders. There are the following important aspects in this dimension.

Participation of administrative authorities and coordinators. Roadmapping can be an unwieldy and time consuming process; this can discourage participation. The involvement of administrative authorities in the coordination of the roadmapping process helps it to proceed smoothly.

Customized solutions. Preparing a template of a solution for the roadmapping process also helps it to proceed smoothly. There are many existing solutions that might serve as templates, such as T-plan (Phaal et al, 2001), disruptive technology roadmaps (Kostoff, 2004), interactive planning solutions for personal research roadmaps (Ma et al., 2006b), etc. However, a roadmapping process – even with those well developed templates – should be customized according to the objectives, the organizational culture, etc., and often further adjusted according to real progress in implementation.

Internet-based groupware. The use of internet-based groupware can contribute to *Involvement* in the following two ways:

- It helps avoid the possibility of overt or tacit domination of the debate by senior participants during group meetings. This is especially helpful in brainstorming: by using Internet-based groupware, people can participate without seeing each other and not be afraid that their ideas sound silly.
- Experts involved in a roadmapping process sometimes come from diverse locations, and it is not feasible for them to gather very frequently. Internet-based groupware enables the participants to work together to keep the process moving without having to physically meet each other.

4) *Imagination*

Imagination is needed during the entire roadmapping process; it should help to create vision. Participants are encouraged to imagine the purposeful future *where should we go* and the means for *how to get there.* All the three levels of imagination listed in (Wierzbicki and Nakamiri, 2006a): *routine, diversity,* and *fantasy* might be needed. We can use information technology and many other methods to stimulate imagination.

Graphic presentation tools. Graphic presentation tools can help people to express and refine their imagination. As in computer aided design (CAD), graphic presentation tools are also very helpful in roadmapping. These tools can range from very general-purpose software (such as, e.g., MS PowerPoint) to very specific systems (such as, e.g., Geneva Vision Strategist, developed specifically for roadmapping, http://www.alignent.com).

Simulations. Simulations can enhance and stimulate imagination, especially when it comes to complex dynamic processes, (Arthur, 1999; Ma and Nakamori, 2005a). A variety of simulation platforms have been developed for diverse purposes, such as *SWARM* for agent-based simulations (http://www.swarm.org), Matlab Simulink for system dynamics and model-based design (http://www.mathworks.com/products/simulink), etc. For examples of how simulations could be helpful for roadmapping, see (Grisevskyi and Nakicenovic, 2000; Grübler and Grisevskyi, 2002). When making roadmaps for future energy use, participants have to consider uncertain factors such as technology transfer and learning, technology spillover effects, effects of carbon taxes, future legal regulations, etc. Without simulations, it is difficult to imagine the best pathway for achieving a future low-emission energy system; computer simulations can help us generate pathways that are optimized with respect to diverse criteria.

Critical debate. This is probably the most fundamental way of promoting imagination: debate, if sufficiently critical, stimulates the participants to imagine new ideas and arguments, to externalize their tacit or intuitive knowledge, even if they would not do so in other circumstances.

Brainstorming. Brainstorming is, in a sense, a counterpart of critical debate; it encourages people to generate and express diverse, even fantastic ideas, and is directly related to imagination. Internet-based groupware for brainstorming, such as the brainstorming tool in Pathmaker (http://www.skymark.com), can help participants freely express even the wildest ideas without feeling responsibility for them.

Idealized design. Idealized design is a unique and essential feature of the *Interactive Planning* approach (Ackoff, 1974; Ackoff, 1978; Ackoff, 1981) which is regarded as a basic method for solving creative problems,[1] (Flood and Jackson, 1991). Idealized design is meant to generate maximum creativity among all the stakeholders involved. To ensure this, only two types of constraints upon the design are admissible:

- First, the design must be technologically feasible, not a work of science fiction; in other words, it must be possible with known technology or likely technological developments - it should not for example, assume telepathy.
- Second, the design must be operationally viable; that is, it should be capable of working and surviving if it is implemented.
- Financial, political, or similar constraints are not allowed to restrict the creativity of the design. Applying idealized design is a way to stimulate diversity and fantasy in imagination.
- When the above principles are followed, an idealized design results from going through three steps combining standard strategic thinking with systemic design:
- Selecting the mission — a general-purpose statement incorporating the responsibilities of an organization to its environment and stakeholders, and proposing a vision of what the organization could be like, which generates commitment;
- Specifying the desired properties of the design — a comprehensive list of the desired properties stakeholders agree should be built into the designed system;
- Designing the system — setting out how all the specified properties of the idealized design can be obtained.

5) *Integration*

Integration must be applied several times during roadmapping, at least when making the first-cut, refined, and final versions of the roadmap. Integration includes all knowledge of the other four dimensions, thus is interdisciplinary and systemic. Diverse rational systemic approaches, such as the *Analytical Hierarchy Process* (AHP) and *meta-synthesis approach* (Gu and Tang, 2005), might be helpful. However, in order to be creative and visionary, integration cannot rely only on rational, explicit knowledge; it also must rely on preverbal, intuitive and emotional knowledge.

Therefore, software with a heuristic interface and graphic representation tools is essential for help in this dimension. For example, the number of nodes and links in a roadmap might be large, and difficult to master by the unaided human brain. A properly chosen perspective of graphic representation of the roadmap might, therefore, be essential. In order to choose such a perspective, a heuristic interface can be applied to infer the preferred features of graphical roadmaps.

4. Case Studies – Roadmapping Practices in JAIST

The School of Knowledge Science at the Japan Advanced Institute of Science and Technology (JAIST) started a 21st Century COE program on *Strategic Development of Science and Technology* in October 2003. The goal of this program is to promote an interdisciplinary research field - *Studies in Scientific Knowledge Creation*. A main project in this program is to find solutions for developing academic research roadmaps, and further to help researchers to develop their research roadmaps. This project was successfully done with the support identified in the previous section. Here we introduce the practices in this project from the five dimensions of the *i*-system methodology.

1) *Intervention*

Treating roadmapping as a team activity, the *intervention* in our roadmapping practices starts from forming groups**.** Groups were formed across labs, even across schools, according to researchers' background and research interests. A group commonly contained two kinds of members in addition to the regular members. The

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[1] At least, by social scientists, though not necessarily by technologists or engineers, for whom idealized design is not a method, but an obvious and basic premise that they have followed since James Watt. An engineer starts by creating a technologically feasible design and, like an artist, dislikes being influenced by financial, political etc. constraints – even though she/he might be forced by management to finally take them into account. Credit is due to R.L. Ackhoff for making managers aware of the principles of idealized design. Thus, engineering design always stimulates diversity and fantasy in imagination (actually, its creativity relies on the fact that it is mostly intuitive, not relying on words and logic).

first was experienced researchers, for example, professors, associate professors, and so on. Because of availability, it was not often to have many experienced researchers in a team, but at least one was present. The second was knowledge coordinators. Knowledge coordinators are those people who can manage creative research activities based on the theory of knowledge creation (Nakamori, 2003). In our practices, knowledge coordinators were master or doctoral students, sponsored by the COE program. Commonly each group had one or two knowledge coordinators.

After a roadmapping group was formed, the knowledge coordinator was required to explain the following things to all group members.

- The role of every member
- The purpose and advantage of making research roadmaps
- The usage of research roadmaps
- The contents and format of a research roadmap
- The process of making personal research roadmap
- The schedule of the group's roadmapping activity

In sum, the explanation made every member aware of the aim of the group, what he/she should do, and when, where and how to do it. During the explanation, all members were encouraged to ask questions on points which were not clear.

After the explanation from coordinators, each member who was supposed to make their research roadmaps was required to describe their experience (the skills and knowledge) he/she already had and write out his/her research proposal for group discussions.

2) *Intelligence*

In this dimension, the following two kinds of support were provided.

Knowledge from experienced researchers and other members. The knowledge coordinators commonly organize several seminars or workshops for the group to discuss

- basic knowledge in the research field,
- the leading groups/labs over the world in the research field,
- list of journals related to this field,
- the common equipments and skills needed in this field,
- and any other information and knowledge which is helpful for members making their research roadmaps.

Knowledge obtained by mining scientific literatures and other databases related to developing research roadmaps. We developed a computer-based approach which aims to help academic researchers to explore the triple helix of academia-industry-government based on three kinds of databases, namely, scientific databases, patent databases, and project databases. These databases can be used as knowledge source for exploring the triple helix of academia-industry-government. But they are built and maintained by different agencies and for different purpose; in other words, they are distributed and not linked with each other. Thus it is not convenient and easy for researchers to get knowledge about the triple helix from them. In our approach, we constructed ontology based on these three kinds of databases to link them for a specific domain. For example, when helping researchers in School of Material Sciences to develop their research roadmaps of fuel cell technology, we built ontology of the fuel cell research field for three separated databases. The first one is from the National Institute of Advanced Industrial Science and Technology, Japan (http://www.aist.go.jp/RRPDB/system/Koukai.Top), which includes scientific publications in this research field; the second one is from the patent circulation database, Japan (http://www.ryutu.ncipi.go.jp/PDDB/Service/PDDBService) which includes the patent information in this research field; and the third one is from NII (National Institute of Informatics) Scholarly and Academic Information Portal, Japan (http://ge.nii.ac.jp/genii/jsp/index.jsp), which includes the information of scientific projects sponsored by government in this research field. A web-based support system was developed for helping researchers to explore the triple helix of academia-industry-government in this domain. The system was developed with JSP (Java Server Page) technology[2]. It can be accessed with a browser and an Internet connection. This system's main functions including

- **Searching.** Researchers can search the three data sets with any element in the ontology.

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[2] Details of JSP can be referred to: http://java.sun.com/products/jsp/

- **Network visualization.** Here nodes in the network visualization include elements of the ontology, researchers, publications, patents, and projects.
- **Calculating distance/similarity.** The system provides distance/similarity between two nodes with various calculating methods.
- **Connections between nodes.** The system provides a function to help researchers to identify connections between two specific nodes in networks

With the above functions, the system is helpful for researchers to find potential collaborators and select new research topics. For more detail of the approach and the support system, please refer to (Yan, 2007).

3) *Involvement*

In addition to forming roadmapping groups and establishing the role of knowledge coordinators and experienced researchers, internet-based groupware was widely used in our roadmapping practices to promote the *involvement*. In addition to existing groupware such as Pathemaker, a web-based roadmapping support system was developed to

- help researchers to managing their personal roadmaps,
- help supervisors to manage his/her group/lab's research,
- promote the knowledge sharing among researchers, especially promote the dispute among researchers,
- and build roadmap archives that can be used as the source of data mining (knowledge discovery).

After logging in the system, a member can input and edit his own research roadmap, he/she can view and make comments on other members' research roadmaps, and of course he can also see other people's comments on his/her roadmap. The system allows users to make comments anonymously. As mentioned by Wierzbicki: Far Eastern societies are better than Western at Socialization and achieving consensus but (perhaps therefore) worse in Dispute (Wierzbicki, 2004). Allowing making comments anonymously will promote the dispute among researchers, which is very important for knowledge creation. With some data mining technologies, the system can help users to find potential cooperators. For more details of the system, please refer to (Ma and Nakamori, 2005b).

4) *Imagination*

In addition to the graphic presentation tools in the support systems introduced above, simulations and brain storming were widely used in our roadmapping practices for enhancing and promoting researchers' imagination.

As an example of using simulation to aid researchers' imagination, when helping researchers in School of Material Sciences to develop their research roadmaps of fuel cell technology, an agent-based model was developed to simulate the evolution of the structure and complexity of an energy technological system. The objective of the simulation model was to study under what conditions increasing degrees of technological interdependence and complexity emerge endogenously. We used the example of a hypothetical, simplified, but to a certain degree realistic energy system, the elements (technologies) of which were represented by customary engineering and economic variables that were treated as dynamic in the simulations. In the model, new energy chains are formed by combining or linking previously existing chains or individual technologies that convert primary energies into energy services demanded by consumers. In turn new chains offer themselves as possible components for the construction of further new energy chains leading to increasing complexification of the energy system. For more details of the model and simulations, please refer to (Ma et al., 2006a). The simulation model can aid researchers' imagination about how the future energy system would like, and how advanced technology such as fuel cell could be introduced into an existing energy system and get wide adoption.

As an example of applying brainstorming in roadmapping, when helping a doctor student in School of Knowledge Science to make her research roadmap, three brainstorming workshops were organized. In the first brainstorming workshop, the doctor student was asked to write out her research topic, and then all group members wrote out their opinions and comments on her research topic. The brainstorming was done with the groupware Pathmaker, each member submitted his/her opinions and comments through his/her own PC. At the same time, every member could see comments and opinions from other members but did not know who submitted them. After half an hour, around 60 opinions and comments were gathered, then with Pathmaker's Brainstorming Toolbox, those opinions and comments were classified into 8 clusters. The doctor students then revised her research topic based on those opinions and comments, and then wrote out her research proposal. The second brainstorming workshop was held to gather opinions and comments on her research proposal, still with the support of Pathmaker. The doctor student improved her research proposal based on the result of the second brainstorming workshop, and then she was asked to prepare a detailed research agenda. The third brainstorming workshop gathered opinions and comments on her research agenda. After the three brainstorming workshops, the doctor students felt more clearly what she should do, how and when, i.e., the three brainstorming workshops helped her to make her research roadmap.

5) ***Integration***

For supporting *integration* in roadmapping, we developed heuristic interfaces and graphic representation tools in the web-based system introduced in *involvement*. After a user logged in to create a roadmap, the system asks the user questions such as what skills he/she has, what courses he/she already took, what research target he/she wants to achieve, and so on. After the user answered those questions, the system automatically organizes those information with the format shown in Fig. 5, thus a first-cut roadmap is ready. For helping a group leader or a supervisor to have a genertal structure or a gerenal view of his/her group's research. The system provides a chart to integrate and visualize the whole group's research roadmaps along time dimension. For more details, please refer to (Ma and Nakamori, 2005b).

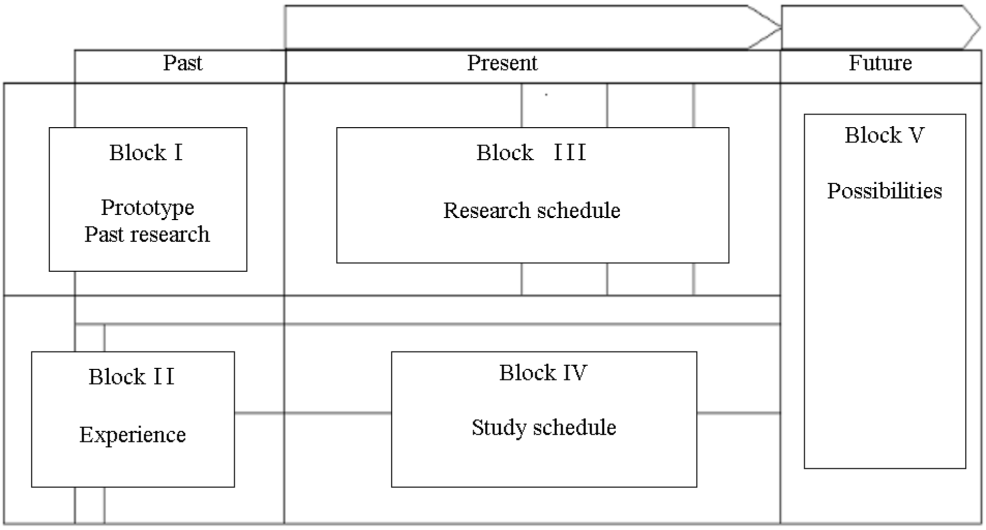

Figure 5: ATRM Model (Okuzu, 2002)

In our practices, we found that roadmapping was more welcomed by junior researchers than senior researchers. It seems the benefits of roadmapping for junior researchers are obvious than those for senior researchers. Senior researchers are more likely to believe that they can arrange their research by themselves, and will be reluctant to spend time on roadmapping, but most of them would like to help making junior researchers' roadmaps. The junior researchers are more likely to find that they can get useful information, knowledge, and good suggestions and ideas through the roadmapping process. We also found that the more individualistic character of academic research might be a reason for the slower adoption of roadmapping in academia than in industry. This indicates the need to develop more specialized support tools both for academic research and for cooperation between industry, the academia, and government.

5. Conclusions

Roadmapping originated from large commercial organizations as a vision enhanced planning tool, originally for exploring and communicating the relationships between the ever-changing preferences of consumers, the market environment, and technology development. When implementing roadmapping in academy, it makes sense to enhance a creative environment since most of existing roadmapping solutions were developed in industry with strong commercial background and pay little attention to "emerging technologies" and "creative invention", which are the main targets of ademic labs.

From the perspective of *i*-system methodology, this paper analyzed useful support for establishing a creative environment for roadmapping in academy. The general types of support for roadmapping in academy can be summarized as the following:

- Scientific databases and text mining tools

- Templates and customized solutions, coordinators, and participation of administrative authorities
- Internet-based groupware with at least the following three kinds of components:
  - A central database
  - Graphical representation tools
  - Brainstorming tools

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