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7 Creativity Support for Roadmapping

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7.1 Introductory Remarks and Contents

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, 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 action. But this, in a sense, is self-evident: every plan is a vision, only some might have not enough vision. Thus, we might as well understand roadmapping as *vision-enhanced planning.*[5]

Roadmapping is regarded today as a tool for knowledge management in both industry and academia, and it has been recognized that the roadmap-

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[5] This was not stressed before, probably because of the ideological connotations of the word *planning;* but the ideological tensions related to this word seem to have abated already, thus we shall also use it here.

ping process is, in its essence, a knowledge creation process, see (Li and Kameoka 2003, Ma et al. 2005). In this chapter we concentrate on the issue of what kind of support is needed or helpful for the roadmapping process, i.e., how to use the concept of *Creative Space* (Wierzbicki and Nakamori 2006a) and develop a *Creative Environment* for roadmapping.

The rest of this chapter is organized as follows. Section 7.2 reviews the origins of the concept of roadmapping, its applications, formats, general roadmapping techniques and software for roadmapping support. Section 7.3 argues that the roadmapping process is a knowledge creation process which can be seen from diverse perspectives. Section 7.4 analyzes what kind of support is needed or helpful for a roadmapping process from the perspective of the approach expressed by the *I-System* (see Nakamori 2003b, Nakamori 2004b, Nakamori and Takagi 2004) and reviews various types of such support. Section 7.5 presents case studies of the application of roadmapping in JAIST (Japan Advanced Institute of Science and Technology). Section 7.6 summarizes this chapter.

7.2 Science and Technology Roadmaps

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 (see ITRS 2004). The European Union routinely uses roadmapping as one of its tools for preparing subsequent *Framework Programmes* for international research and development.

Roadmapping has been also adopted in academia. 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. 2005) have argued that developing personal academic research roadmaps can be very helpful for individual researchers. Usually, there are many linkages between the development of industrial technologies and scientific research, see, e.g., (Narin et al. 1997). Moreover, the causation between science and technology runs both ways; the causation from technology to science is much more powerful than is generally perceived, see (Rosenberg 2004, Wierzbicki 2005) and Chapter 16 of this book. For those reasons, we will use the term *science and technology roadmaps* or *S&T roadmaps* in short, introduced by (Kostoff and Schaller 2001). Today the concept of a roadmap is widely applied in other human social activities — we hear about “the Middle East roadmap for peace”, “career roadmaps”, and so on, — but this is usually just an uncritical use of a fashionable term. In the rest of this chapter we will use the term *roadmapping* to refer to the process of developing S&T roadmaps.

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.

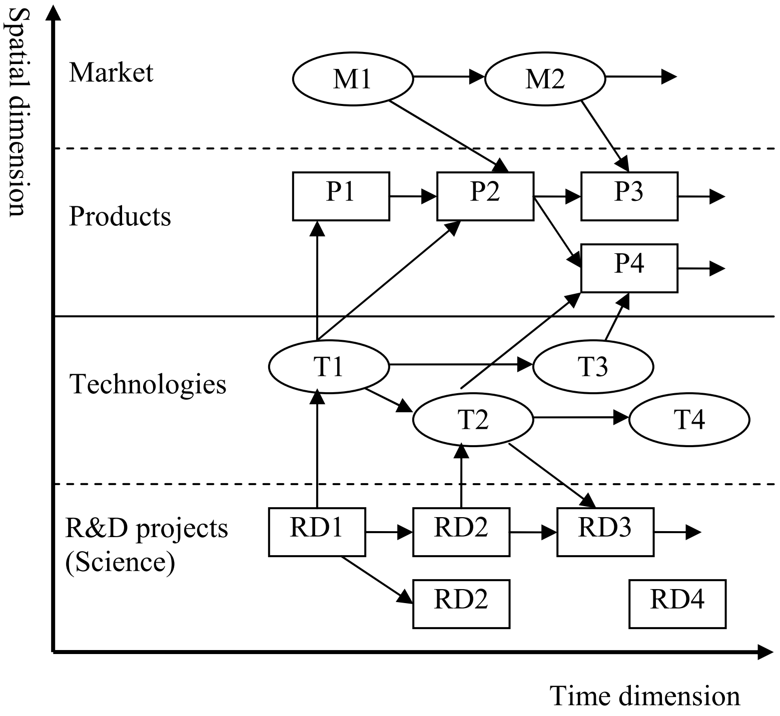

Fig. 7.1 Generic S&T roadmap nodes and links (Kostoff and Schaller 2001)

Roadmaps can have also different formats. Fig. 7.1 presents a generic 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 2005) 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 1998).

(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 neces-*

sary 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, see (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, see (Saritas and Oner 2003).

7.3 Roadmapping as a Knowledge Creation Process

Roadmapping – planning enhanced by creating a vision – can be also considered as a knowledge creation process. We can thus use diverse recent micro-theories of knowledge creation for the purpose of organizing roadmapping activities. From the perspective of the *SECI Spiral* model (Nonaka and Takeuchi 1995, cf. also Fig. 3.5 in Chapter 3), an important way of starting knowledge creation consists of sharing experience and expertise (generally, tacit knowledge) between the participants in a project team during an activity called *Socialisation*; this is also a first step in roadmapping. This is followed by *Externalization,* which means articulating and documenting participants' experience and expertise on the issues related to the project (the roadmap under development), thus making the shared tacit knowledge explicitly available to all the participants. A further step, *Combination,* in the case of roadmapping means using explicitly articulated participants' experience and expertise, and combining them with explicit knowledge and information that is widely available, e.g., from literature or the web; thus, a roadmap can be seen as the product of *Combination.* The *SECI Spiral,* however, is completed by implementation, or learning by doing, in the step called *Internalization;* thus, in the case of roadmapping, using the perspective of the *SECI Spiral* stresses the necessity for a repetitive adjustment and improvement of roadmaps during their implementation. In the process of implementing roadmaps, new tacit knowledge will be created in each participant's mind; these new understandings and new emergent developments in the real world motivate the adjustment of the roadmap. Thus, the *SECI Spiral* perspective can be used to organize a never-ending roadmapping process.

However, we also can use diverse other micro-theories of knowledge creation for the purpose of organizing roadmapping. From the perspective of the *Double EDISEEIS Spiral* (Wierzbicki and Nakamori 2005) 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. 7.2. 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).

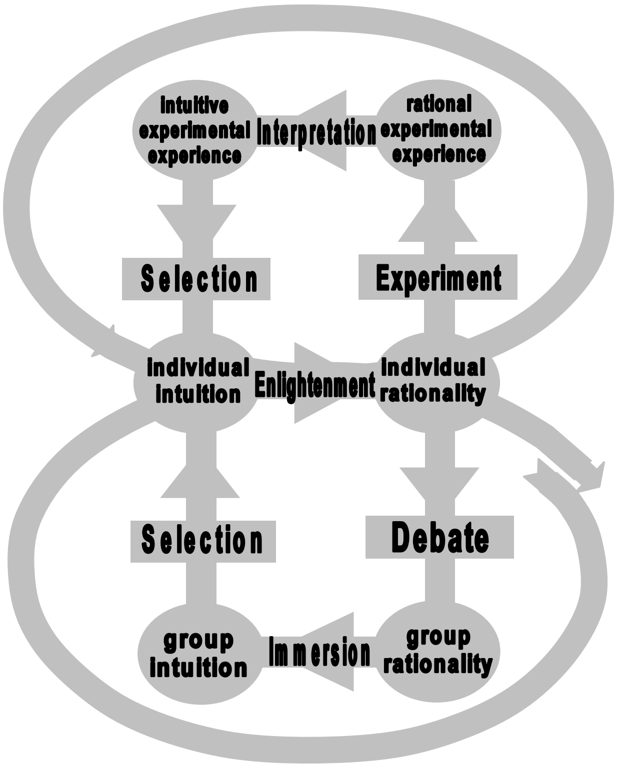

Fig. 7.2. The *Double EDISEEIS Spiral* of intersubjective and objective knowledge creation and verification

Other micro-theories or tools of knowledge creation, such as *brainstorming,* see, e.g., (Kunifuji 2004), can be also used in organizing the roadmapping process. And conversely, roadmapping can also be seen as a tool, a part of a larger knowledge process, as in the *Nanatsudaki Model* of knowledge creation processes, see Chapter 3 of this book.

Since roadmapping is a kind of knowledge creation process, it is important to reflect upon what kind of creation support is needed or helpful in roadmapping. We address these questions in the next section.

On the other hand, the implementation of the roadmap carried out in the real world, learning by doing, is shortly characterized in the *SECI Spiral* by the step called *Internalization,* but can be analyzed in more detail from the perspective of the *Experimental EEIS Spiral.* The lessons from a real life *Experiment* amount to a rational experience; then they are subjected to an *Interpretation,* thus becoming intuitive experience, which helps in the *Selection* of new ideas for how to adjust the roadmap. When a roadmap is refined according to people's new understanding, along with new experiences from activities in the real world, it becomes a synthesis of intersubjective and objective knowledge creation.[6]

7.4 *I-System* and Knowledge Creation Support in Roadmapping

The *I-System* approach uses aspects of social and natural sciences complementarily (Nakamori 2003b, Nakamori 2004b, Nakamori and Takagi 2004). *I-System* combines five subsystems, namely, *Intervention, Intelligence, Imagination, Involvement* and *Integration,* as shown in Fig. 7.3.

There are several interpretations of the *I-System* approach; we will first outline an interpretation related to the theory of *Creative Space* (Wierzbicki and Nakamori 2006a). According to this interpretation, the five constitutive subsystems correspond to the five diverse dimensions of *Creative Space,* stressing the need to move freely between them.

Because the *I-System* approach is intended as a synthesis of systemic approaches, *Integration* is in a sense its final dimension, and all arrows in Fig. 7.3 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.* See (Wierzbicki and Nakamori 2006a) for a more detailed discussion of the relation between the *I-System* and the *Creative Space*.

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[6] From the similarity of the two descriptions, one might conclude that the *Double EDISEEIS Spiral* is nothing but an enhancement of the *SECI Spiral.* But there are also essential differences between these two approaches. The *SECI Spiral* stresses a collective (in a sense, Oriental) way of generating of ideas that occurs during *Socialization;* moreover, the *SECI Spiral* describes knowledge creation in a market-oriented organization. The *EDISEEIS Spiral* stresses the individual (in a sense Occidental) way that ideas are generated that occurs during *Enlightenment;* moreover, the *EDISEEIS Spiral* describes knowledge creation in a normal academic form.

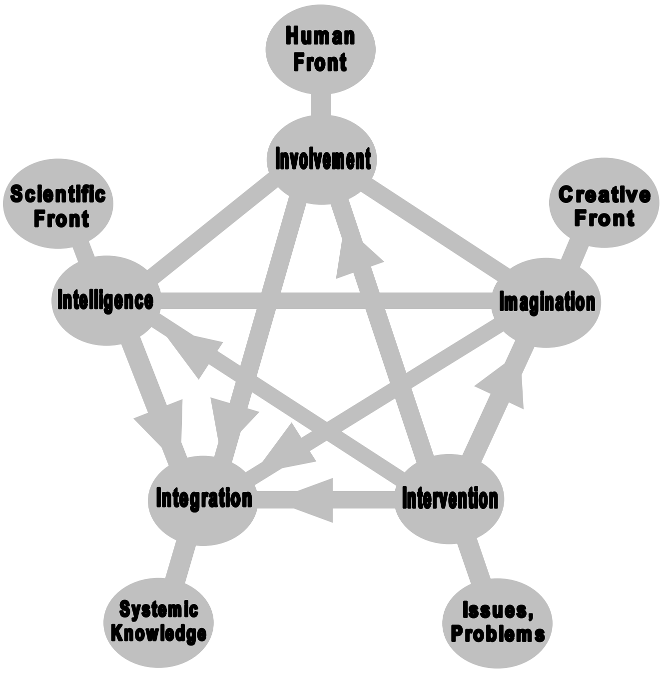

Fig. 7.3 The *I-System* or *Pentagram System* (Nakamori 2000)

Originally, the *I-System* approach 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,* (see Fig. 3.7 in Chapter 3). We will use this order to discuss what knowledge creation support is needed or helpful in roadmapping, 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 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 on 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 complete the *hermeneutic EAIR Spiral* (see, e.g., Chapter 3) – that is, 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. 2005), etc. However, the 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 2005). 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. Another example of stimulating imagination concerns simulations involving role playing and gaming (see Chapter 11).

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 (see Chapter 6).

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 (see Chapter 5). 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 1974b, 1978, 1981) which is regarded as a basic method for solving creative problems,[7] (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.

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[7] 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 (see Chapter 16 of this book), 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).

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,* see (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.

General Features of Information Technology Support for Roadmapping

In the preceding section we discussed what types of information technology and other support is needed or helpful in each dimension of roadmapping. Some tools can be helpful in more than one dimension. For example, *graphical representation tools* are helpful both for imagination and integration. Here we summarize some selected aspects of such support.

- *Scientific databases and text mining tools.* Scientific databases are storing an enormous amount of explicit scientific knowledge, and text mining tools can help to find knowledge in that vast body of literature. Both are essential for the *Intelligence* dimension.
- *Templates and customized solutions, coordinators, and participation of administrative authorities.* Roadmapping, as a consensus building and knowledge creation process, requires the participation of many stakeholders, and may be very time consuming. Without template solutions, their customization, competent coordinators, and the involvement of administrative authorities, roadmapping becomes unwieldy and unnecessarily prolonged.
- *Internet-based groupware with at least the following three kinds of components.*

- *Central database.* A central database is helpful for the storage and later integration of all data, information and explicit knowledge related to the roadmapping process, and thus is helpful for refining roadmaps.
- *Graphic representation tools.* A figure is worth a thousand words.[8] Graphic representation tools are especially important for representing nodes and links in roadmaps, to make them comprehensive.
- *Brainstorming tools.* Internet-based brainstorming is helpful for enabling the free expression of even the wildest ideas without participants feeling responsibility for them, and for avoiding domination of a debate by senior participants during group meetings.

In addition, Internet-based groupware enables participants of a project to work together without having to physically meet each other; it also helps to keep the process moving.

These are only selected aspects of support for roadmapping. Many others, such as simulations or idealized design to stimulate *Imagination,* also might be useful.

7.5 Case Studies - Making Academic Research Roadmaps 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*. This new research field includes modeling processes of knowledge creation, knowledge management, and information technology support for them, see (Nakamori 2003b).

Many doctoral students and researchers in the School of Knowledge Science participate in the COE program. While the general purpose of the program is known, they need ideas about their specific research tasks: where they should start, what results should they postulate, and how they can reach their goals. Making personal roadmaps is an important and helpful part of their research work in the following sense:

- Roadmapping can help a researcher better understand the state of her/his research (where she/he is now), the kind of results that might be

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[8] Actually, a picture is worth at least ten thousand words. See the rational justification of the power of preverbal and intuitive knowledge in (Wierzbicki 1997, Wierzbicki and Nakamori 2006).

postulated (where she/he wants to go), and the activities that should be planned (how she/he can get there).

- Roadmapping can promote communication among researchers, especially within a research group or within the same laboratory.
- When academic researchers work together on a bigger project, roadmaps can clarify the roles of every researcher in the project.
- Roadmapping helps supervisors to understand the progress of each researcher's work. On a personal roadmap there are milestones for the researcher’s activities, hence it helps supervisors know what the researcher has achieved, what he/she is doing now, what he/she will do, when, and how. This enables supervisors to better manage and coordinate the work.

The contents and format of the personal academic research roadmaps proposed below follow the academic technology roadmap model (ATRM), see (Okuzu 2002). There are five blocks in the ATRM model shown in Fig. 7.4.

- *Block I: Prototype or past research.* This describes the objective the researcher wants to focus on and the current status of the research objective.
- *Block II: Experience.* This describes what skills and knowledge the researcher already has.[9]
- *Block III: Research schedule.* This describes the research projects the researcher will do and the schedule and milestones for doing those projects.
- *Block IV: Study schedule.* This describes the kinds of skills and knowledge the researcher must acquire in order to fulfill the research plan.
- *Block V: Future possibilities.* This describes what kind of future work can be done after finishing the research schedule in Block III, and what kind of future results might be obtained.

Past	**Present**	**Future**
Block I Prototype Past research	Block III Research schedule	Block V Possibilities
Block II Experience	Block IV Study schedule	

Fig. 7.4 ATRM Model (Okuzu 2002)

In the following discussion, we will first present an approach to making personal research roadmaps based on *Interactive Planning* (Ackoff 1974b,

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[9] Unfortunately, an approach in explicit terms only, though the tacit aspects of a researcher’s experience are much more important.

1978, 1981). This approach emphasizes the requirements of coordinators and the participation of administrative authorities. Then we will introduce a web-based roadmapping support system with a very simple text-mining function. Finally we give a simple example of applying such roadmaps.

An *Interactive Planning* (*IP*)Based Roadmapping Approach

Interactive Planning is an approach[10] to solving creative problems, with three important principles, namely the *participative principle, continuity principle* and *holistic principle*.

- *Participative principle.* Ackoff stresses that members of the organization will come to understand the organization and the role they can play in it by being involved in the planning process; thus all those who are affected by planning should be involved in it.
- *Continuity principle.* This principle stresses that planning is a never-ending process, since the values of the organization's stakeholders will change over time and unexpected events will occur.
- *Holistic principle.* This principle insists that people should make plans both simultaneously and interdependently, because decisions taken at one level will usually have effects at other levels as well.[11]

Since roadmaps are strategic plans, a good customized roadmapping process should follow these three principles. An *Interactive Planning* approach assumes that the objects of planning are organizations or systems, and that the planning process is composed of five interrelated phases: *formulating the issue, ends planning, means planning, resource planning,* and *design of the implementation and controls*. Sometimes the final phase is divided into two, design of the implementation and design of the controls (Ackoff 2001). These phases should be *regarded as constituting a systemic process* (Flood and Jackson 1991), in the sense that they do not constitute a linear description, only a general outline of repetitive planning:

1. *Formulating the Issue*. In this phase problems, prospects, threats, and opportunities facing the organization are highlighted.

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[10] Called also *basic methodology* by social scientists (Flood and Jackson 1991); however, the word *methodology* has different meanings in different fields and disciplines, thus we avoid using it in this context.

[11] This is actually only the consensus part of the principle of holism, which actually has the broader meaning of an intuitive integration of all information and relations between systemic parts.

2. *Ends Planning.* Ends planning concerns specifying the ends to be pursued in terms of ideals, objectives, and goals. Idealized design, discussed in an earlier section, is applied in this phase.

3. *Means Planning*. During this phase policies and action proposals are generated and examined in order to decide whether they can help fill the gap between the desired future and the way the future appears at the moment.

4. *Resource Planning*. During this planning stage, four classical aspects of resources should be taken into account:

- Inputs - materials, supplies, energy and services
- Facilities and equipment - capital investments
- Personnel
- Money

5. Design of Implementation and Control. This important phase of any problem solving or planning activity addresses the questions *who is to do what, when, where, and how?* It should be remembered, however, that even the best implementation *planning* is not equivalent to actual *doing,* see (Pfeffer and Sutton 2000), hence an adequate control of implementation must be achieved and continually monitored. This feedback is the basis of learning and improvement according to the *continuity principle.*

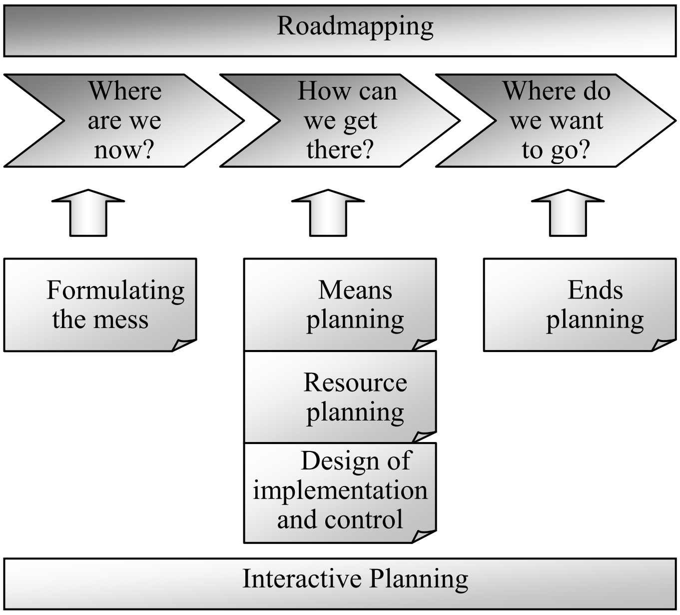

Fig. 7.5 *IP* and Roadmapping.

The *IP-based roadmapping approach* developed and applied in JAIST treats a personal academic research roadmap in the ATRM format (Fig. 7.5) as a system with five main components. As shown in the figure, the five phases of *IP* can be clearly mapped to the three fundamental questions that roadmapping aims to answer. The first phase of *IP*, *formulating the issue*, tries to answer the question *where are we now;* the second phase, *ends planning*, corresponds to the question *where do we want to go;* and the remaining three phases, *means planning, resource planning* and *design of implementation and control* are responsible for answering the question *how can we get there*.

The *IP based roadmapping approach* is composed of six phases with some cycles among those phases (see Fig. 7.6):

Phase 1: Forming groups. Although it concentrates on personal roadmaps, the approach treats roadmapping as a team activity, according to the participative principle of *IP*. Groups can be formed inside a single laboratory, but also a group can be composed of researchers from several laboratories, even from different fields. A group should contain two kinds of members in addition to regular participants. The first type is experienced researchers, for example, professors; at least one should be present. The second type is knowledge coordinators, researchers with some experience in the management of creative research activities based on the theory of knowledge creation (Nakamori 2003a). Each group needs one or two knowledge coordinators. The number of participants in a group should be 6-12: small enough for effective communication among group members, but large enough to facilitate knowledge sharing and creation.

Phase 2: Explanation from Knowledge Coordinators. To ensure that the process runs smoothly, the knowledge coordinator should first explain the following to all group members.

- The role of every member
- The purposes and advantages of making personal research roadmaps
- The usage of personal research roadmaps
- The contents and format of a personal research roadmap
- The process of making a personal research roadmap
- The schedule of the group roadmapping activity

In conclusion, the explanation should make every member aware of the aim of the group, what she/he is expected to do, and when, where, and how to do it. All members are encouraged to ask questions on points which are not clear.

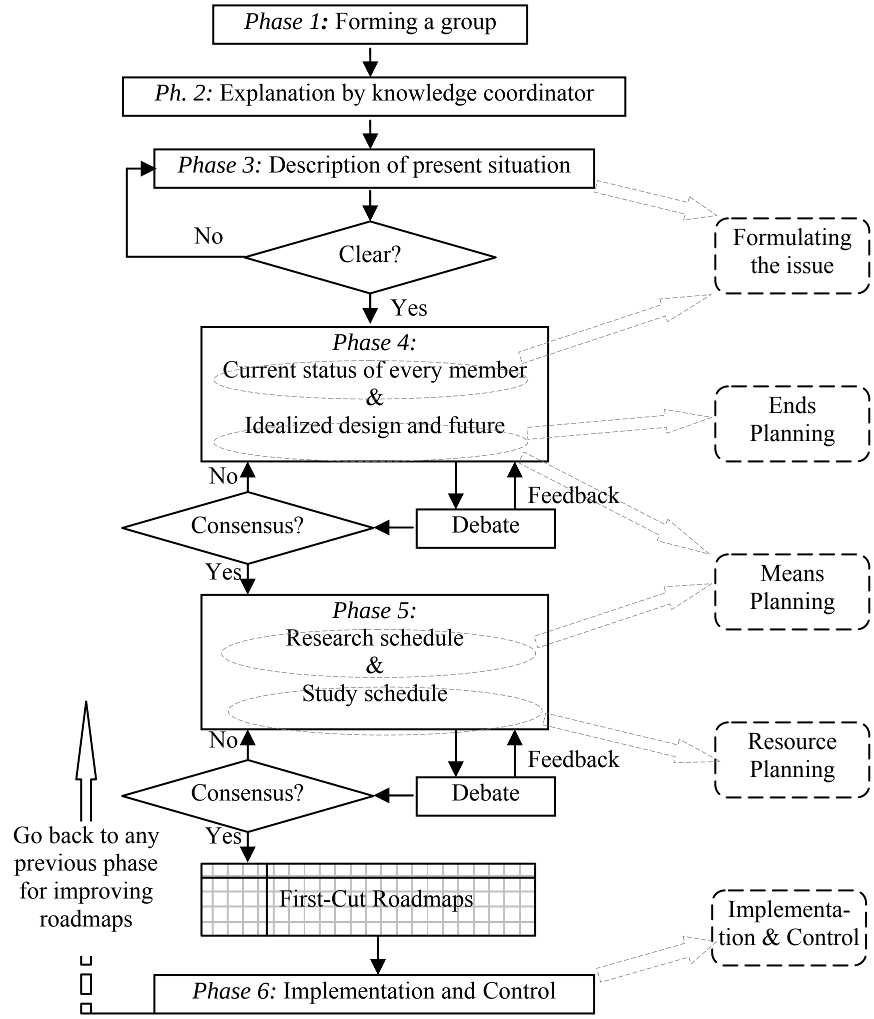

Fig. 7.6 The *IP* based approach to making personal academic research roadmaps

Phase 3: Description of present situation. In this phase, the experienced researchers give a description of the present situation which includes:

- Basic knowledge in this research field
- The leading groups or laboratories in the world in the research field
- List of journals related to this field
- The basic equipment and skills needed in this field

- Any other information and knowledge which will be helpful for members making their research roadmaps

In fact, it is rather difficult to present all this information at one time, hence this phase might include several workshops or seminars.

Phase 4: Current status of every member and idealized design. In this phase, every member should first describe the experience (the skills and knowledge) she/he already possesses. The list should be shared with the entire group, so that other members will be able to effectively contribute good opinions and ideas in later discussions. Every member's skills and knowledge list should be documented; this corresponds to block II in Fig. 7.4. A participant can perform this part alone. Next, each member defines her/his research topic more specifically and summarizes current research in the related area; if possible, she/he identifies the most closely related previous work, called the *prototype* of her/his research. This part should be documented in block I in Fig. 7.4. From the perspective of *IP,* this part and phase 3 relate to *formulating the issue.*[12] During this process, participants should share their knowledge and experience in discussions with each other. While using the principles of *idealized design* in order to achieve maximal creativity, every participant describes his/her research goals and how to reach them. The outcomes might be called *individual idealized designs* and are discussed by the whole group; in this way each participant can refine and modify his/her idealized design with the benefit of whole group's explicit and tacit knowledge. In this phase, the knowledge coordinator needs to arrange several workshops or seminars, until individual idealized designs of all participants have been discussed and accepted by the group. Future possibilities (corresponding to block V in Fig. 7.4) can also be identified in this phase, through discussion.[13]

Phase 5: Research schedule and study schedule. Phase 4 helped to answer the basic roadmapping questions: all participants should know where they are, where they want to go and how to get there. Those answers should be integrated now into final roadmaps. In this phase, each participant prepares a research schedule (block III in Fig. 7.4) and study schedule

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[12] There is no one-to-one correspondence between *IP* and research roadmapping, since *IP* was devised for solving managerial tasks, while knowledge creation has its own specific aspects; thus, *formulating the issue* can be done at the beginning of a managerial *IP,* while it extends to more phases of research roadmapping. Another example: the principles of *idealized design* are helpful, but in no way sufficient for achieving creativity in research. Other, diverse ways of stimulating intuition are needed.

[13] By discussing what research tasks should be included in the current roadmap and which should be postponed for future research. In practice, future possibilities are usually identified later, during implementation and roadmap review.

(block IV in Fig. 7.4) consistent with her/his research goals; more than one option of a schedule can be also prepared. These schedules are presented to all group members. After obtaining opinions and ideas from other participants, research and study schedules can be refined and modified. As in phase 4, this phase might also require several meetings or workshops until the research and study schedules of all participants have been accepted by the group. This phase corresponds to *means planning* (research schedule) and *resource planning* (study schedule) in *IP*.

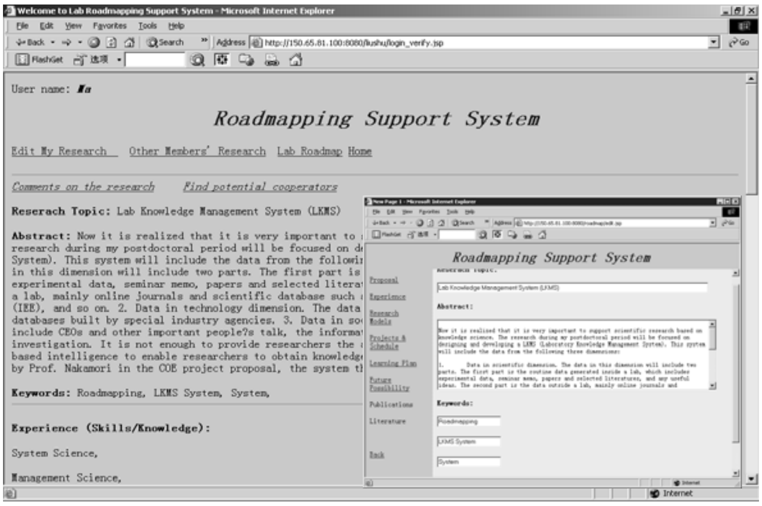
Phase 6: Implementation and Control. After phase 5, the personal research roadmap of each participant is ready. The knowledge coordinator should arrange regular seminars and workshops to monitor and control the implementation of the roadmaps. Even though much effort has gone into making a reasonable research roadmap, it is still a first cut. The roadmap should be continuously refined in practice, which accords with the *continuity principle* of *IP*. In simpler words, participants need to review and go back to previous phases, but not necessarily to the very beginning, again and again. The group can start again from any previous phase according to the demands of a real situation. However, one warning should be added: we should not confuse refining plans with actual implementation, we must limit the former and leave enough time for the latter, in order to close the gap between *knowing* and *doing,* see (Pfeffer and Stutton 2000).

Note that the *holistic principle* of *IP* is actually dominant in the approach described here, since individual research roadmaps require group consensus. This principle is especially important when all participants are working on a joint research project. In this case, it is necessary to make a hierarchy of roadmaps; the group needs to make roadmaps for various parts of the project. In such a case the lower-level roadmaps should be integrated into next-level roadmaps.

A web-based roadmapping support system

A roadmapping support system is under development as a research project supported by the JAIST COE Program. The objective is to create a system that will provide the following benefits to its users:

- Help researchers manage their personal roadmaps
- Help supervisors manage research in a group or laboratory
- Promote knowledge sharing and debate, especially among researchers
- Build roadmap archives that can be used as a source of knowledge discovery and data mining



User name: **Ma**

Roadmapping Support System

Edit My Research Other Members' Research Lab Roadmap Home

Comments on the research *Find potential cooperators*

Reserach Topic: Lab Knowledge Management System (LKMS)

Abstract: Now it is realized that it is very important to
research during my postdoctoral period will be focused on de
System). This system will include the data from the followi
in this dimension will include two parts. The first part is
experimental data, seminar memo, papers and selected litera
a lab, mainly online journals and scientific database such
(IEE), and so on. 2. Data in technology dimension. The data
databases built by special industry agencies. 3. Data in so
include CEOs and other important people?s talk, the informa
investigation. It is not enough to provide researchers the
based intelligence to enable researchers to obtain knowledg
by Prof. Nakamori in the COE project proposal, the system t

Keywords: Roadmapping, LKMS System, System,

Experience (Skills/Knowledge):

System Science,

Management Science,

Roadmapping Support System

Lab Knowledge Management System (LKMS)

Abstract:

Now it is realised that it is very important to support scientific research based on knowledge science. The research during my postdoctoral period will be focused on designing and developing a LKMS (Laboratory Knowledge Management System). This system will include the data from the following three dimensions:

1. Data in scientific dimension. The data in this dimension will include two parts. The first part is the routine data generated inside a lab, which includes experimental data, seminar memo, papers and selected literatures, and any useful ideas. The second part is the data outside a lab, mainly online journals and

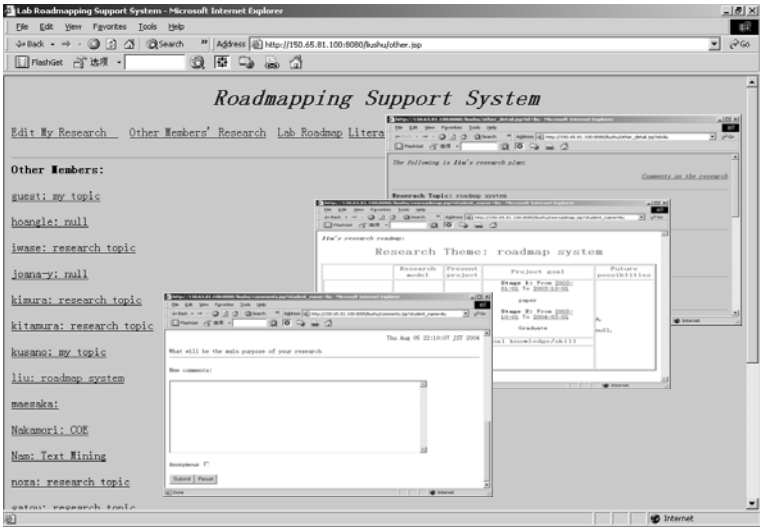
Keywords:

Roadmapping

LKMS System

System

Fig. 7.7 Interface after log in



Roadmapping Support System

Edit My Research Other Members' Research Lab Roadmap Litera

Other Members:

guest: my topic

hoangle: null

iwase: research topic

joana-y: null

kimura: research topic

kitamura: research topic

kusano: my topic

liu: roadmap system

maesaka:

Nakamori: COE

Nam: Text Mining

noza: research topic

The following is liu's research plan:

Comments on the research

Research Topic: roadmap system

liu's research roadmap:

Research Theme: roadmap system

Thu Aug 05 22:10:07 JST 2004

What will be the main purpose of your research

New comments:

Anonymous ☐

Submit Reset

Fig. 7.8 Viewing and commenting upon other research roadmaps

The system is web-based. Basically, users need only a web browser, such as Internet Explorer or Netscape, and an Internet connection to access the system. Both English and Japanese versions are provided. Fig. 7.7 shows the user interface at the log-in stage. The user can prepare a research roadmap in a given template format, store it in the system, and view it whenever needed. The user can modify the roadmap, as shown in the small window in the lower right corner of Fig. 7.7. Beside the functions of viewing and editing her/his personal research roadmap, there are several other functions for users.

In Fig. 7.8, the largest window lists all of the other participants and their research topics. Users can view other participants' research roadmaps by clicking their names or research topics. The system provides two formats for a research roadmap, a text description (the first small window on the right in Fig. 7.8), or a tabular format (*ATRM* model, the second small window from the right in Fig. 7.8).

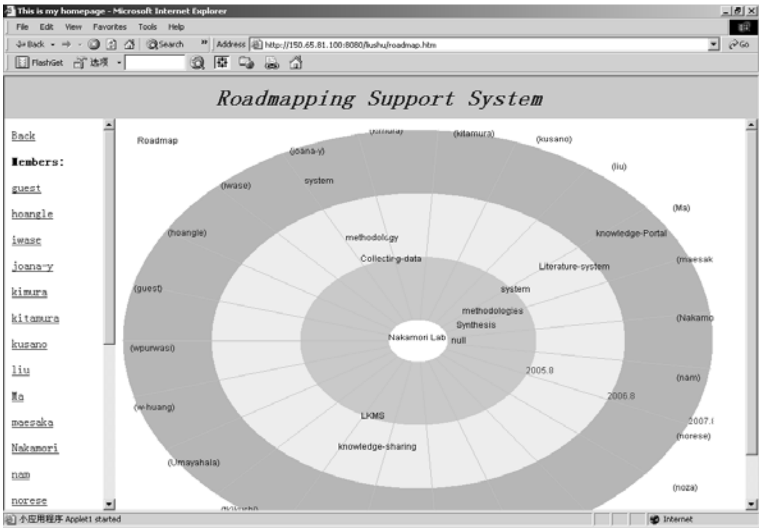
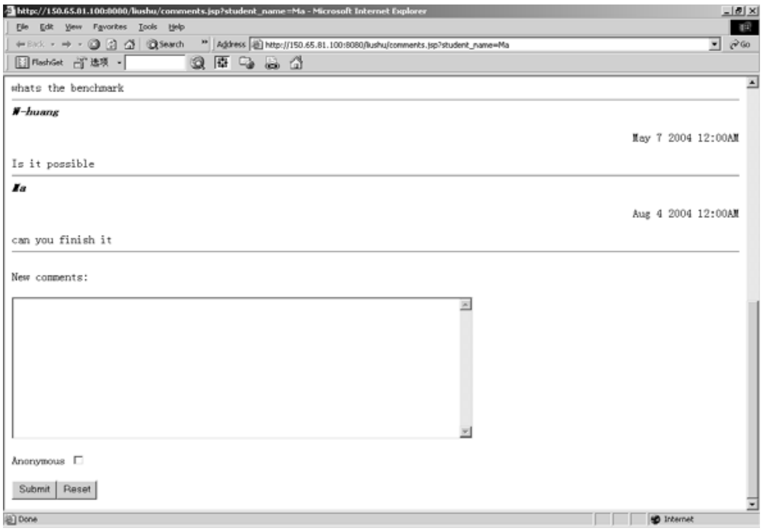


Fig. 7.9 A general view of the group's research

Users can make comments on other participants' research roadmaps. The system allows these comments to be made anonymously. As mentioned in (Wierzbicki and Nakamori 2004): *Far Eastern societies are better than Western at Socialization and achieving consensus but (perhaps therefore) worse in Dispute*. Allowing anonymous comments has the purpose of promoting debate among researchers, which is very important for stimulating intuition and knowledge creation.

Some users, especially the coordinator or supervisor of the group, might like to have a general structure or a view of the research. The system provides a chart visualizing the research in the entire group, as shown in Fig. 7.9. In this chart, each line denotes one participant's research roadmap, and each ellipse denotes a time stamp, which means that points in the same ellipse correspond to the same time. This makes it easy to see what the group is doing now, what it plans to do and when it will be done. It is also important to be able to visualize what the group has already done, which will be included in a future version of the system. Each participant's detailed research plan can be seen by clicking the names listed in the left side in Fig. 7.9.



whats the benchmark

W-huang

May 7 2004 12:00AM

Is it possible

Ma

Aug 4 2004 12:00AM

can you finish it

New comments:

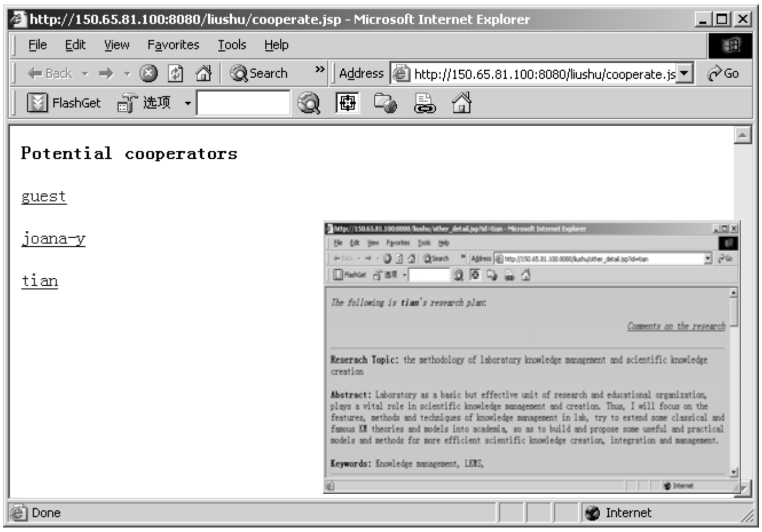
Anonymous ☐

Submit Reset

Fig. 7.10 Viewing comments from other members

Users can also see comments from other members, and they can reply to those comments online, as shown in Fig 7.10. The system can also help the user find potential collaborators by text-mining. In the existing version, the system finds potential collaborators based on keywords only. In future versions, the system should involve more complicated text-mining algorithms and approaches, together with the possibility of more complex conditions defined by users to find potential collaborators. Fig. 7.11 shows an example in which three potential cooperators have been found; their detailed research roadmaps (illustrated by the small window in Fig. 7.11) can be seen by clicking their names.

This system can be used together with any other groupware, such as *Pathmaker*, which includes a good brainstorming tool; in future versions, a brainstorming tool should be also included in this system.



Potential cooperators

guest

joana-y

tian

The following is ***tian****'s research plan:*

Comments on the research

Reserach Topic: the methodology of laboratory knowledge management and scientific knowledge creation

Abstract: Laboratory as a basic but effective unit of research and educational organization, plays a vital role in scientific knowledge management and creation. Thus, I will focus on the features, methods and techniques of knowledge management in lab, try to extend some classical and famous KM theories and models into academia, so as to build and propose some useful and practical models and methods for more efficient scientific knowledge creation, integration and management.

Keywords: Knowledge management, LKMS,

Fig. 7.11 Finding potential cooperators

Experience in Applications of Roadmapping at JAIST

Here we present two applications of roadmapping in JAIST: one related to individual research roadmaps with the *IP*-based approach and the roadmapping support system described above, and the second related to the development of fuel cell technology in a cooperative university-industry project.

Individual Research Roadmaps

The COE Program *Technology Creation Based on Knowledge Science: Theory and Practice* is well known to researchers in JAIST, since several scientific conferences devoted to this program have been held. One aim of the program is to provide support in technology creation to researchers in the School of Material Science in JAIST. The *IP*-based approach and the roadmapping support system described above were developed as a part of this program, by researchers from the School of Knowledge Science. An interdisciplinary group was formed, including several students and researchers from the Schools of Material Science and Information Science (invited as consultants); the author of the roadmapping support system was nominated to be the knowledge coordinator.

After forming the group, three workshops were held to initiate the roadmapping process. In workshop 1, the knowledge coordinator explained the issues related to *Phase* 2 of the *IP*-based approach. Participants asked questions for clarification and shared their opinions and ideas about roadmapping.

In workshop 2, a detailed description of the COE program was given, for those members from the School of Materials Science and the School of Information Science who might not have attended previous scientific conferences. *Pathmaker* groupware was used for a brainstorming session on the topic *what kind of support is needed for scientific research*. Many ideas were obtained from the brainstorming; these were classified into the following four groups:

- Support for research planning
- Support for doing experiments
- Support for writing papers
- Support for promoting communications

A summary was prepared and workshop 3 was organized to discuss what kind of work can be done based on those ideas; in parallel, the new roadmapping support system was developed. After workshop 3, the actual roadmapping started. This required seven working seminars. First, each participant prepared a description of her/his current skills and knowledge as an input into the new roadmapping support system. Then the participants described their individual research topics, along with an indication of what work had already been done related to the topic.

Two intensive seminars, seminar 1 and seminar 2, were held in order to give other participants the opportunity to present suggestions, opinions and additional knowledge related to the research topics, and to finalize the research topics; finally, the research topic of every participant was accepted by the group. In the next step, participants were asked to determine their research goals, using idealized design, and to consider how they could reach their goals. The idealized design of every participant was discussed in seminars 3 and 4; participants used the results of these discussions to modify and improve their idealized designs.

By seminar 4, those participants who wanted to make personal roadmaps had knowledge of *where they were, where they wanted to go* and partial knowledge of *how they could get there*. In order to finalize these answers in the form of roadmaps, seminars 5, 6, and 7 were held. Every participant was required to write out research and study schedules ahead of time and present them in seminar 5. Other members gave their comments and ideas, and then the owners of the schedules modified them according to those opinions. This was continued in seminars 6 and 7. In seminar 7 a consensus was reached, hence no additional seminars were needed. The first-cut personal academic research roadmaps of all participants were completed and stored in the roadmapping support system.

For the process of implementation and control, the group designed regular seminars and reports to monitor how things were going. Generally, researchers who were making and improving their personal roadmaps felt they had much clearer ideas about where they were, where they wanted to go, and how they could reach their goals.

The original roadmapping process took 3 workshops and 7 seminars, quite a long time. This might be judged too long, but we also found that roadmapping is much more welcomed by junior researchers than senior researchers. It seems that the benefits of roadmapping for junior researchers are more obvious than for senior researchers. With more experience and intuition concerning research problems, the latter are more likely to believe that they can arrange their research by themselves, and are reluctant to spend a lot of time on personal roadmaps; however, most of them are willing to help junior researchers in their roadmapping. Junior researchers are more likely to value the explicit, useful information, knowledge, good suggestions and ideas that they can obtain during the roadmapping process.[14], This means that roadmapping can be an important tool for supporting knowledge creation in graduate education and research institutes, such as JAIST.

Case Study: Roadmaps for Development of Fuel-Cell Technology

Fuel-cell development can trace its roots back to the 1800s. A Welsh-born, Oxford-educated barrister named Sir William Robert Grove realized that if electrolysis, using electricity, could split water into hydrogen and oxygen, then the opposite would also be true. An appropriate method of combining hydrogen and oxygen should produce electricity. To test his reasoning, Grove built a device that would combine hydrogen and oxygen to produce electricity, the world’s first gas battery, later renamed the fuel cell. Because of their characteristics such as long durability, high efficiency and no pollution, fuel cells represent a promising energy technology for human society (see Nakicenovic et al. 2005).

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[14] This is consistent with the observation of (Dreyfus and Dreyfus 1986) that novices, beginners, and apprentices need analytical, explicit support in decision making, while experts and master experts make decisions deliberatively, based on intuition and tacit knowledge.

Based on diverse applications, fuel cells can be classified into five types:

- Portable: A portable artefact generating electric power
- Experimental: Experimental artefact generating electric power
- Stationary: Supply station for electric power in houses, hotels, hospitals, etc.
- Transportation: Battery to supply electric power to busses, cars, or other vehicles
- Micro: Power supply for mini-products.

After collecting 291 data records of information on fuel-cell products from over the world, it was found that transportation-oriented fuel-cell products constitute only 11.6% of research interests in fuel cells in general. It is well known that, if fuel cells were to be substituted for gasoline-powered internal combustion engines, carbon oxide and sulfur oxide emissions would be greatly decreased. Why has the development of vehicles using fuel-cell products been so slow? How can we best support cooperation among academia, industry and government to promote research in this field? How does technology creation proceed in this area? What data and information is needed to accelerate such technology creation?

With these questions in mind, fuel-cell researchers from three universities were interviewed. They said that fuel-cell technologies are already being widely used, but in some fields, particularly for vehicles, fuel-cell technology is still not fully developed. This motivated a roadmapping case study to support researchers in the field of transportation-oriented fuel-cell technology. This case study proceeded in the following steps:

- Step 1: Data and information were collected from the homepages of researchers involved in transportation-oriented fuel-cell technology creation in the academia, or involved in governmental policy making related to fuel-cell technology. The results are contained in two databases: a product database (products names, technology, marketing information scenarios etc.) and a researcher database (researchers' name, research topics etc.).
- Step 2: After analysis of the data we got an overlook roadmap as shown in Fig.7.12, in which the following conventions were adopted:
  - The roadmap provides an overlook of transportation-oriented fuel-cell technology development in the past, present and future, including technological, social and marketing aspects
  - Technologies were re-classified into 10 types: hydrogen storage technology, long-lasting fuel cell technology, technology for using fuel-cells in adverse environments, safety of fuel-cell technology, technology of metallic materials for fuel-cells, cost reduction of fuel-

cell technology, efficiency increase of fuel-cell technology, fuel-cell systems technology, small-scale and miniature fuel-cell technology, supply chain facilities for fuel-cells
  - Numerical data was based on averaging diverse data sets
  - The estimates of carbon dioxide emission decrease were calculated by the method used by the Ministry of Environment of Japan

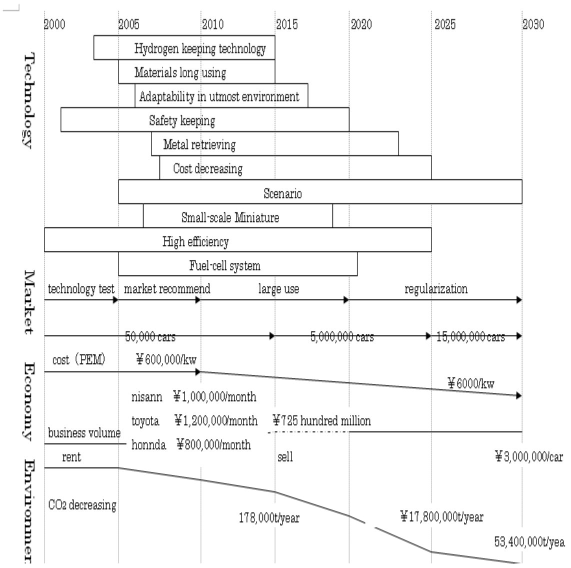

Fig. 7.12. An overlook roadmap for transportation oriented fuel-cell technology

- Step 3: This overlook roadmap was presented to researchers who are doing scientific research on transportation oriented fuel-cell technology at three universities: Osaka University (Osaka), Toyama University (Toyama) and JAIST (Ishikawa). These researchers were interviewed and expressed the following opinions about transportation oriented fuel-cell technology creation(similar for all three universities):
  - They would be interested most in advanced technology information
  - Related information on social and marketing aspects is not crucial for them; they have no time to get it even if they might be interested

- The development of transportation-oriented fuel-cell technology takes such long time because costs are high and related safety problems are difficult
- The time from technology to actual product development will also be long if useful implementation scenarios are not formulated
- Most helpful would be more detailed information on plans and actions of other researchers in academia, industry, and government who are developing transportation-oriented fuel-cell technology

Some examples of individual researchers' opinions are as follows:

- Researcher A said: it is not necessary to help researchers make research plans, because it is hard to say what future research topics will be; it would be useful, however, to develop some support that would help researchers find the most valuable research topics.
- Researcher B said: the overlook roadmap can give researchers a different perspective and review of the whole research field including technology, marketing, and social influences. However, for researchers who are doing scientific research and technology creation, the overlook is not enough. More detailed information is needed about technologies, research topics, patents, etc., including other information such as the availability of subsidies from government and industry.
- Researcher C said: forecasting is a useful way to support researchers in generating new ideas and new research topics for technology creation, but more useful would be more detailed information about what researchers in academia, industry, and government are doing now, what the relationships are among research topics, researchers, and technology, and among future scenarios.

- Step 4: Based on these opinions, a cooperation roadmap showing the relationship of current technology developments among the academia, industry and government was prepared, concentrating on vertical cooperation.

The best way to exchange information would be to organize regular meetings of researchers from academia, industry, and government to discuss current topics of reciprocal interest; however, this is not easy to do. Therefore, a new way of checking data available on the web, to discover relationships between several classes of data, was proposed. The datasets involved were collected from:

- Industry (46 datasets): Patents information
- Government (57 datasets): Subsidy projects information
- Academia (667 datasets): Research topics informatio.

The classes of data were selected as:

A. Technologies
B. Applications & Products
C. Research topics
D. Researchers
E. Scenarios

Relations between classes A and B are called AB, etc. Estimates of relations AB and BE can be found from industry datasets, AE and BE from government datasets, AC and CD from academic datasets. The proposed cooperation roadmap will provide information about the relationship between every two classes and relationships among all classes. Diverse methods can be used to interpret these relationships, e.g., critical technology components might be identified using literature-based discovery methods (Kostoff 2004). Researchers might also use such relationships in order to find:

- For each application technology, how many research topics are currently being explored by the academia, industry, and government
- Which two application technologies or two research topics have the strongest relationships
- Which are the hottest (most popular or newest) applications and research topics

Preliminary findings of this type are, e.g.:

- Around 25% of research topics subsidized by governments concern high efficiency energy technology
- Around 50% of researchers in this research field are working on catalysts.
- The newest highly subsidized research topic concerns organic and inorganic composite membranes.

Beside the determination of relationships, a good support mechanism responding to the needs of researchers would be to use text mining for data available on the web concerning current research on selected research topics and inform the research groups about the findings, e.g., by developing a portal for information about relationships and current research topics.

Step 5 of this study is not completed yet, but it involves obtaining feedback from researchers in academia, industry, and government on the cooperation roadmap, updating databases, repeating steps 2, 3, 4 as necessary, summarizing, etc.

Preliminary conclusions from this case study are interesting since they illustrate the deep difference in approaches by industrial and academic researchers. After surveying twenty industries, it was found that the roadmapping approach is widely used in industry as a tool for planning, forecasting etc. However, the interviews with technology researchers from three universities indicate that:

- They consider scientific research to be an individual activity
- Researchers in academia do not have the organization or definite purpose that they have in industry
- They have, however, great pride in their own ways of performing research
- They believe that they do not have enough time to worry about additional information, such as the social aspects of technology developments;
- For financial reasons, it is difficult for specialists to gather frequently and organize discussion groups.

Based on these characteristics of technology creation in academia and in industry, new types of cooperation roadmaps were developed, but their effectiveness still needs to be tested.

7.6 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; later, roadmapping was widely adopted by government agencies, consortia and academia.

Roadmapping can be also regarded either as a tool of knowledge management, or as a kind of knowledge creation process. While concentrating on using information technology, the latter interpretation, this chapter identified the following general types of support for roadmapping:

- *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*

This chapter also identified other optional supports, such as simulations and gaming or idealized design for stimulating intuition during roadmapping.

Examples of the development of roadmapping principles and tools for academic research were given; experience with their application shows that roadmapping is more useful for junior than for senior researchers. This is an important conclusion for graduate education and research institutes such as JAIST. Moreover, a case study which uses roadmapping to support fuel-cell technology creation has identified some reasons for the slower adoption of roadmapping in academia than in industry: the reason might be the essentially more individualistic character of academic research. This indicates the need to develop more specialized support tools both for academic research and for cooperation between industry, the academia, and government. It also re-confirms the need for new prescriptive approaches to more complex technology creation programs, such as the *Nanatsudaki Model* suggested in Chapter 2 of this book.