Research and development of systems science and technology

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The Center for Research and Development Strategy (CRDS) of the Japan Science and Technology Agency (JST) established the Systems Science Section to review what should be promoted in the area of systems science and technology. As the research disciplines are becoming finely segmented, systems aim to achieve integration, and there is a common theme shared with *Synthesiology*. We interviewed Principal Fellow Hidenori Kimura who leads the Systems Science Section.

***Synthesiology* Editorial Board**

Participants of the roundtable discussion

Hidenori KIMURA	Principal Fellow, CRDS-JST
Naoto KOBAYASHI	AIST (Senior Executive Editor, *Synthesiology*)
Motoyuki AKAMATSU	AIST (Executive Editor, *Synthesiology*)

Akamatsu

I think the systems science and technology that Dr. Kimura is promoting is close to *Synthesiology* in the sense that both aim for full utilization of science and technology in society. I would like to ask about the systems science and technology, the relationship between *Synthesiology* and systems technology, and the technology needed to solve the future social issues.

Kobayashi

Although the evaluations of the East Japan Earthquake and the nuclear power plant accident have not been completed at this point, and it seems too early to address them in this discussion, I think they heavily reflect the problems of systems.

Kimura

Although it is not clear how much of the facts is known at this point, one of the issues raised was robots. There were projects (1983~1990) for advanced robots for hazardous environment in the fields of oceanography, space, disaster, and nuclear power. The question is "Was the reason why these robots were not deployed because of some technological problem or human problem?" The researches are gravitated toward elemental technologies. It has become clear that "such things can be done" is not enough, and this is one example where the systems technology is important.

Kobayashi

In the nuclear power plant accident, I think there were problems in all three systems including the system of hardware, the system of interaction between hardware and humans, and the system of human groups of how people should respond including politics. In that sense, it is very important to extract the issues as systems and to take measures accordingly.

Systems science and technology exists for problem solving

Akamatsu

What is the background for bringing up systems science and technology at JST? Why systems science and technology now?

Kimura

I think you can call today the "age of systems". Currently, we are struggling within our systems. Therefore, I thought it was important to lay a path as a science here. If you consider "systems technology" as the tool to analyze, design, and implement the systems and "systems science" as the organization into universal science of artifacts, systems science and technology is the way to construct and develop a large-scale system in a complex society.

Kobayashi

That means that systems science and technology is science and technology to solve problems. In *Synthesiology*, we set the objective, write the scenario to achieve the objective, and select the synthesis methods to achieve the objective. It is not simply a combination of elements. I think that is the characteristic of science in this field. On the other hand, Dr. Kimura and Dr.

Yoshikawa frequently mention “design science”. Does systems science and technology fall in that realm?

Kimura
I certainly think it is one of the design sciences.

Akamatsu
So, it is “systems technology” first. You say the systems technology is needed for problem solving, the systems science is its base, and the system exists originally for problem solving.

Kobayashi
Since problems cannot be solved with elemental technologies alone, we must have systems. It is said that Japan is weak in systems science and technology and systems thinking, but I think Japan had been doing well in the world for over hundred years since the Meiji Period. Why are we said to be weak in the field of systems?

Kimura
I think we are very strong in a certain phase, and once the Japanese systems science and technology shined brightly. For example, we successfully built the shinkansen (bullet train) system from 1960s to 1970s, the Dendenkosha Information Processing System (DIPS) of the former Nippon Telegraph and Telephone Public Corporation, and the integrated production management that enabled 10 million ton annual production of ironworks. These could not have been achieved without well-developed systems thinking.

Kobayashi
Taking the example of my field of specialty, Japan became advanced relatively early in optical communication technology. That was because the R&D capabilities of the individual technologies such as fiber, semiconductor material, and optical device were high, and the performances of the products were excellent. That allowed us to create the network and system faster than anyone else in the world. It is very interesting that, from the 1960s to early 1980s, we were able to create the shinkansen and the optical network that were not catch-up technologies.

Kimura
Back in those days, the systems technology was indeed very powerful in theory and practice. When I was a student, the guys who were good in math were considered to be the big ones. There were many systems science departments in the universities, and I think it matched the spirit of the era. However, since the 80s, the emphasis shifted to the deep exploration of elemental technologies.

Kobayashi
Does that mean that the academia of the world headed in that direction?

Kimura
I think it was only Japan. The word *monozukuri* (manufacturing) appeared in the beginning of the 1990s, so it was around that time. Although my analysis is not complete, one factor is arrogance. The Japanese manufacturing industry dominated the world, and elemental technologies became prominent. I think there was a feeling that we won because of our excellence in elemental technologies.

Akamatsu
I guess we did not recognize that the real reason for the “win” was systems technology. If the criterion for the “win” is set to be exporting overseas, the reason would necessarily become elemental technologies.

Kimura
Taking the example of iron, the integrated ironworks with annual production of 10 million tons was built in Japan for the first time in the world in the middle of the 1960s. The United States Steel Corporation produced about 5 million tons, and Japan doubled that capacity. The reason why it was held at 5 million tons was because the system was so complex. Iron and steel are produced by order, so they are single production products. The production line had to be dedicated to individually ordered products, and this was managed by visual inspection. Complete computerization of this process not only raised the production scale but also dramatically improved the quality. However, the contribution of the systems technology was not acknowledged. This was reflected in personnel evaluations. The systems people never became board directors! They said that the Japanese iron conquered the world because of its excellent quality as a material and the iron industry

Dr. Naoto Kobayashi

Dr. Hidenori Kimura

would essentially be a material industry. I think this thought was prevalent in other industries as well.

Akamatsu
Although the value was in the manufacturing system, people emphasized the elemental technology of the "product", and thought that the value lay therein.

Kimura
There was no room to recognize our arrogance and we failed to capture the reality and prepare for the next. People thought that Japan would continue to rule the world, and also thought that the Japanese style management conquered the world.

When the Japanese industry shifts

Kobayashi
I've heard that the manufacturing industries have been gravely hit by this earthquake and disaster, With the Oil Shock in the early 1970s, the rapid economic growth of the heavy industries led by iron, steel, and shipbuilding ended, and the main players of industry shifted to automobiles and electric industries. With the current state of automobiles, we don't know whether the EV (electric vehicle) will become the mainstream in the future. I feel that the Japanese industry must make the shift after the East Japan Earthquake, and this may be the time to reexamine systems science and technology once again.

Akamatsu
When something goes wrong, people tend to seek out the culprit of the supposedly man-made disaster, but that is very dangerous. Reducing the matter to a personal fault is similar to the thinking of reducing the matter to an element. As we recover from the earthquake, we are not looking at the situation systemically if we reduce the problem to who made the mistakes.

You mentioned the shinkansen system as an example where the systems technology truly shined. Mr. Shima, the head engineer of the former Japan National Railways, managed the technological development of the shinkansen. He said, "We did only ordinary things. One must think ahead and thoroughly." I think he thoroughly thought about what things were needed to run the shinkansen and carefully built the needed things. The people who excelled at the time thought and made things in terms of systems very routinely. However, they did not advocate, "This is the system," and it was not communicated. At the time, the word "system" was used as in the context of something like the "computer system," and the use in the sense of systemic way of thinking did not diffuse. I don't think it was incorporated well in education.

Dr. Motoyuki Akamatsu

Kimura
The word "system" was not really used very often. However, the shinkansen and NTT's DIPS were very state-of-the-art. The 10 million ton integrated production of iron and steel was the victory of systems technology, and stood at the top of the world. Although there might have been arrogance, we need to work hard to achieve them again.

Akamatsu
When looking at the past to learn, we reduced our challenges to elements since we thought we were winning by elemental technologies. Unless we state that the challenge is the system, nothing can be solved even if we emphasize problem solving.

Strategic research for systems construction is necessary – Do not proceed blindly

Kobayashi
That the "challenge is the system" is a very good analysis. When you say system, there are systems with which we design certain structures from the beginning and then built them robustly, and there are those where partial optimization is done in the autonomous decentralized style. These differ according to how the issues are solved. Are there many methodologies for designing the system?

Kimura
We should not fall into partial optimization. If you are autonomously decentralizing, you must intend to design a system of autonomous decentralization from the beginning.

We proposed that the "research for systems construction strategy is necessary". This was proposed late in the discussion of the Systems Science Section, CRDS, and is an essential factor lacking in Japanese science and technology. I am a researcher in the field of control, and in designing a control system, we don't blindly implement the controller for a large plant. The plant is thoroughly analyzed in a model-based study, the model is created, the model is put in the computer, the parameters are optimally designed, the simulations for whether these are okay are done repeatedly, and finally, if all goes well, it is implemented. That is the cardinal rule.

However in Japan, demonstration research is started right away. While the basic research for elemental technology is done thoroughly, people think that basic research is not necessary for systems. Of course, demonstration research is

necessary for confirmation at a certain phase, but aren't there things that must be done beforehand? If a demonstration is done, that only means that things turn out a certain way for a certain scenario. If the environment changes, a different story may unfold. We must carefully build the systems construction strategy, and all sorts of different scenarios must be considered. That is how it is done overseas in most cases.

Akamatsu
I think it involves the question of funding. We can get money for making something, while it is hard to get money for designing the system or doing simulation. It tends to be easier to get funding for elemental technologies. The scenarios for why this research is necessary or what it would lead to are treated as unimportant, but rather, we cannot get approval unless we present some performance index, such as "if we build this device the speed will become several times faster".

Kimura
I think that is a major negative tradition of the administrative organization.

Science and technology that meet social expectations

Kobayashi
The academic journals evaluate highly the addition of some new fact based on the world's academic criteria. In *Synthesiology*, of course, new knowledge is necessary, but we emphasize the selection of the elemental technologies and why they were selected, how they were synthesized, and the final goal is the practical use of the research result in society. As the essential items of the paper, we require the research objective and relevance to society, the scenario, how the elements were selected and integrated, and what were attempted for realization. I think it has similarities to the discussion of the R&D for systems science and technology.

Akamatsu
When one writes the scenario for *Synthesiology*, one must see the subject or the research topic as a system. We focus on what kind of structure the elements have.

Kimura
The systems science and technology claims that a single whole function is achieved by integrating the individual elements with various functions, but this can be achieved only by someone with a highly systemic mind.

The Science Council of Japan has expressed grave concern about the fact that the Fourth Science and Technology Basic Plan is a problem-solving type. There is a question about where the scientist's autonomy will go if the problems are given. In the problem-solving science and technology, how should autonomy of scientists and engineers be protected? Dr. Yoshikawa called the connection of the research objective and society as the "science and technology that meet the social expectation". This is one major issue.

Kobayashi
I think one must first consider the strategy. The topics for problem solving can be set by the researchers themselves, and how they should be approached can also be set freely. This way of thinking is important. For example, when research is considered as layered in relation to society, whether it be basic or applied, if we can create a research strategy that we all agree upon in any layer, the research result can be evaluated according to the relationship with the research strategy. That is my way of thinking. Therefore, the important point is to incorporate the "connection between the research object and society" within the research strategy.

Kimura
Science and technology cannot be separated simply into curiosity-driven and project-oriented. Strategies always exist within the scientific research, and in a certain sense, even pure science and technology attempt to solve problems.

Akamatsu
There is curiosity before a research topic is born, and it becomes a research challenge because it is interesting. To solve that challege is to systemically think and break down the structure of the topic that the researcher thought would be interesting. Many people may not be aware of that, though.

Kimura
I don't think there's any research without curiosity.

Education and law needed for systems construction strategy

Kobayashi
Before, there were solid systems in Japan as exemplified by the shinkansen and DIPS, but you indicated that the systemic thinking or the potential for thinking about the systems has decreased. What is necessary for us now?

Kimura
The Basic Act on the Promotion of Core Manufacturing (Monozukuri) Technology was established in 1999, the Institute of Technologists was established, and this law formalized the yearly production of the Manufacturing Basic White Paper. When the technology of the world was shifting to systems and software, or shifting "from things to action", Japan was going against that flow. Therefore, in this age, I think we should make something like a basic act on the promotion of core systems technology.

Akamatsu
Maybe it is education. If a graduate student in a doctorate course

does nothing but study some theme given by the professor, it will be difficult to understand the topic as a system.

Kobayashi
There are many people with PhDs at the core of policy making in the international institutes and foreign governments. There are extremely few administrators with PhDs in the central government ministries and agencies of Japan. I think we need to fortify the PhD courses and change the university education itself. When we talk about education, the teachers must change, too. It would be better if they could teach that the elemental technologies are of course important but it is important to systemize them. I hope we can steer toward that direction.

Spiral is important for both synthesiology and systems science and technology

Akamatsu
Yes. To design a system is also to determine the order by which the system should be operated, and I think there are many things that can be solved by first designing it and then operating it. Spiral is created as the system interacts with the real world.

Kimura
That is certainly true. We are investigating why the systems failed to work in the East Japan Earthquake. I have a feeling that the greatest point is that the concepts of disaster prevention and rescue were not linked together. The spiral was not working. On the other hand, there are many laws such as the Special Measures Act and Disaster Relief Act, and these laws state the protocols of how to establish headquarters when a certain disaster occurs and what to do next. Yet the situation changes from moment to moment. People move and the environment changes and the system itself must be updated accordingly.

When a disaster strikes, one can make the primary damage prediction by understanding the scale of the earthquake and the epicenter. As more information is gathered, the damage predictions can be fine-tuned, and we must also decide what kind of relief system should be created based on the predictions. This must be done in a spiral way.

Akamatsu
While there may be disaster prevention for times of normal situations, the spiral movement does not work properly if there is a lack of disaster prevention against the aftershocks that may occur after the main earthquake.

Kobayashi
As Dr. Kimura said, it is important to repeat the modeling process where the analysis, simulation, and synthesis are done.

Kimura
Yes. In synthesiology, does the spiral course continue after the research is completed?

Akamatsu
We haven't gotten to that stage yet. The ability to evaluate the research when it is sent out to society is necessary. When the spec requirement arises, we must look ahead and not stop at mere acceptance of spec. When one spiral course is run, the limiting condition changes completely from the first layer and redesigning must be done. Running the spiral course involves such redesigning.

Kobayashi
For social implementation, we must involve the industry. Therefore, I hope the people of industry who did the actual implementation look back at how they did it and write a paper on the methodology.

Systems science and technology is the promoter of fusion of humanities and sciences

Akamatsu
The activities of the Systems Science and Technology Committee finished last year, and a proposal was submitted. What do you think is the most important factor for the discipline to grow or to promote this way of thinking?

Kimura
I think it is necessary to incorporate the systems science and technology into innovation. One must make specific proposals and then build up actual results. Since there is no section in the Ministry of Education that is in charge of this, we are discussing this matter.

Kobayashi
If we consider science and technology as a system, I think the systemization of various fields and businesses becomes necessary. It has been said that the fusion of humanities and sciences is necessary at the universities, but it is not going well. Compared to the professors of sciences, the professors of social sciences are not too willing. However, considering the systems for the future, it will not be about science and engineering only.

Kimura
I think there is a possibility that the systems will be the promoter of the humanities-sciences fusion. Systems are becoming major topics in humanities. There is a hot debate going on in the social sciences on what is a social system.

Kobayashi
Are there any examples of successful efforts in humanities-sciences fusion or systems science and technology in the United States, Europe, or Asia?

Kimura
The International Institute for Applied Systems Analysis (IIASA) of Austria was established in the early 1970s, and it has both the sciences and the humanities researchers. After the publication of *The Limits to Growth*, the IIASA was established with enthusiastic support of the United Nations to seek themes where people could collaborate together during the Cold War. This institute has spent considerable effort on the population problem and CO_2 reduction. It created the Regional Acidification Information and Simulation (RAINS) model, and this is one of its successes. China has its stronghold in systems science. There is the Institute of Systems Science in the Chinese Academy of Sciences, and it is very big. Also, there are economists and social scientists as well as physicists at the Santa Fe Institute, which is the leader of complex systems. There is no research institute for systems science in Japan.

Kobayashi
I hope we get successful cases like the shinkansen. It doesn't have to be of that big a scale.

Kimura
I really hope so, too. What I wish to propose is the systemization of the rescue organizations and the implementation of high-tech in the rescue system. Since the East Japan Earthquake, the Japanese science and technology has lost authority in the world. We must create a universal rescue system, and show the rest of the world how the rescue and relief operation should be done.

Akamatsu
We can see which items will function and which will not if we have such a system. By systemization, we should be able to make a decision when the situation changes. I hope we can carry out the recovery process systemically.

Kobayashi
I think the systems science and technology and *Synthesiology* overlap in several areas. We have recently become aware that the spiral movement and feedback are very important in our discussions of the *Synthesiology* papers. As Dr. Kimura says, rather than having a rigid design from the beginning, it is important to have the system revolving.

Kimura
In Japan, once the plan is made, it cannot be changed. It is necessary to ensure temporal evolution by correcting this shortcoming.

Akamatsu
I think "problem research" is the keyword. One tends to think that the problem is given, but that's not true. One has the ability to spontaneously come up with a problem, and it can be solved only by breaking it down into a system. Since synthesiology seeks the methodology for creating the scenario, I think the aim is very similar.

Kimura
In the future science and technology, the systems science and technology and synthesiology will increase their weights. How is *Synthesiology* taken at AIST?

Akamatsu
I don't think its awareness is high. However, we started an education program called the Innovation School three years ago, and use *Synthesiology* as one of the texts. We talk to the young researchers who just received their doctorates about how to grasp the scenario of the research, how to build the research, and from which perspective things should be seen. The young researchers respond quite positively.

Kimura
I guess it is gradually spreading. In JST, the understanding of systems science and technology is still low. There are many people who say, "Why do research on systems?" or "Isn't it something anyone can do?" However, the systems science and technology was added to the list of promotion subjects in the Fourth Science and Technology Basic Plan, so I think something will start to happen.

Kobayashi
For science and technology, analysis must be done thoroughly by a model, simulated, and then valuable money can be invested. I hope the systems science and technology will diffuse widely.

This roundtable discussion was held at the Center for Research and Development Strategy (CRDS) of the Japan Science and Technology Agency (JST) in Chiyoda-ku, Tokyo, on April 22, 2011.

Profile

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