Scenario in synthetic-type research: its role and description

— An investigation from *Synthesiology* papers —

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Synthetic-type research is conducted by private companies, public institutes, and universities to realize societal value by scientific and technological methods. *Synthesiology* is a scientific journal that enables authors to describe the processes and results of this kind of research. Editors specifically request authors to describe their scenario for synthetic-type research. In this paper, the characteristics of synthetic-type research are compared with those of analytic-type research, and the structures and properties of synthetic-type research scenarios are clarified. From the investigation of papers published in *Synthesiology*, we show that the scenario plays a central role in synthetic-type research and can be expressed using scientific languages.

Keywords : Synthesiology, paper, scenario, synthetic-type research

1 Introduction

Most people of today engaged in science and technology are strongly interested in how to effectively connect research and societal value for innovation. Much research is conducted by private companies, public institutes and universities, which is generally categorized into analytic- and synthetic-type research.

Analytic-type research is characterized as research whose major purpose is to discover knowledge elements and integrate those into a knowledge system after reducing nature and existence into their elements. Much of the research conducted at universities is of this type. Synthetic-type research is characterized as research whose major purpose is to create or produce things by integrating technical elements and synthesizing a goal. Much research conducted at private companies and public institutions is of that type.

Much synthetic-type research has been actually conducted in society so far. The writing format of the papers, however, has never been well established to express processes and results of such type of research. The journal of *Synthesiology* issued from 2008 is a new type of journal where processes and results of synthetic-type research are described.[1] The aim of issuing the journal is written in the Preface, "A journal of original papers of *Type Two Basic Research*,"[2] in Vol. 1, No.1 of *Synthesiology*. In accordance with this aim, this paper investigates the scenario that plays a central role in synthetic-type research.

Although the scenario of synthetic-type research is defined in Chapter 2, it may be said that the scenario is a kind of strategy to realize societal value by methods of science and technology, which is an important point for creating innovation. Authors describing processes and results of science and technology in the existing scientific journals, however, are not requested to describe the scenarios in their papers. The scenarios are not described often in the technical reports, "Giho," published by companies, either.

The Editorial Board of *Synthesiology* started the journal assuming that the scenario plays a central role in synthetic-type research and that it could be described by researchers verbally (using languages) and visually (using figures). Thus the editorial board requested the authors of the journal to describe scenarios in their own papers. This was an unprecedented attempt having never been made by the conventional scientific journals. *Synthesiology* has been published for eight years during which more than a hundred original papers have been issued.[1] We investigated those papers to see what role the scenarios played in synthetic-type research and how the scenarios were described verbally and visually. We attempted to see whether the assumption of the Editorial Board was valid.

In Chapter 2, characteristics of synthetic-type research are clarified in comparison with those of the analytic-type. Then the first hypothesis that the scenario plays a central role in synthetic-type research is presented.

In Chapter 3, the scenarios in synthetic-type research are described as having common and general characteristics. Then the second hypothesis that the authors of synthetic-

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type research papers can describe the scenario verbally and visually is presented.

In Chapter 4, investigations of papers issued in *Synthesiology* will show what role the scenarios play in synthetic-type research and how they are described verbally and visually. It is shown that there are different types of forms of expression of scenarios.

In Chapter 5, it is pointed out that the scenario can be effectively utilized for planning, implementation and evaluation of synthetic-type research.

See the paper, "Analysis of synthetic approaches described in papers of the journal *Synthesiology*,"[3] in Vo.5, No.1 of *Synthesiology* about the methodology of how technical elements are integrated and a goal is synthesized in synthetic-type research.

2 Synthetic- and analytic-type research

Science has developed very rapidly since the seventeenth century by understanding nature and existence by a method of reducing them into elements, i.e. the analytic approach. When we encountered complex issues like global environmental problems at the end of twentieth century, however, it became widely accepted that such issues could not be resolved only by the analytic approach.

Technology has developed very rapidly in the twentieth century with the endorsement of science. But it is evident that such technological development has not been conducted only by the analytic approach.

Consider the processes of synthetic-type research. Firstly, things or artifacts of societal value are identified to be realized. Secondly, goals of synthetic-type research are set to realize the societal value. Thirdly, the goals are broken down into technological requirements and elements. In this paper, research scenario (hereafter written just as "scenario") is defined as that which, after breaking down the goal of synthetic-type research into technical elements, expresses logical relationship between the goal and the technical elements and that among the technical elements. The scenario of synthetic-type research may include not only items of science and technology but also frameworks like legislative systems, societal customs, human networks and joint research that may affect research implementation.

Researchers implementing synthetic-type research will take the processes of selecting, developing, and integrating technical elements, and synthesizing to achieve the goal, and then realize the societal value.

In this chapter, we create a hypothesis that the scenario plays a central role in synthetic-type research. The hypothesis will be tested in Chapter 4 by investigating the papers issued in *Synthesiology.*

2.1 Processes of scientific research and technological development

In this subchapter, we define scientific research and technological development separately as different concepts, each having its own methodology. Figure 1 schematically shows processes and results of scientific research in the upper part and that of technological development in the lower part.

The target of scientific research is nature and existence. There are individual disciplines in academic societies like physics, chemistry, biology, electrical and mechanical engineering, and medical sciences. A university student of the field of science and engineering sets his or her discipline for study

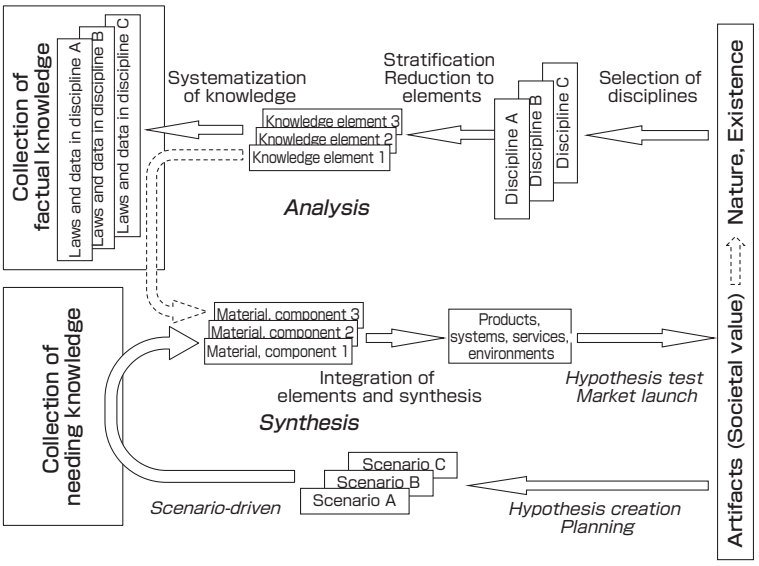

Fig. 1 Processes and output of scientific research and technological development

by selecting a department among others. A researcher also sets his or her profession by selecting a discipline. Each discipline has its own method of perspective and approach, based on which part of nature and existence is cut off in a specific aspect. A researcher finds pieces of knowledge of the discipline on the aspect cut off by stratifying phenomena and reducing them into elements. Discovered pieces of knowledge are systematized by relating them to each other, and then theories and formulas are established with the collection of data. In this sense the majority of scientific research is "analytic-type research" based on reducing into elements

The motivation of technological development is the will of a man to create something valuable for society. The value includes not only products and systems but also services and methods as well as protection and modification of the environment. As shown in Fig. 1 there are scenarios at the very beginning of processes to realize societal value.

Scenario making in the planning stage before implementation could be said to be hypotheses creation. Based on the scenarios or in scenario-driven ways, researchers of synthetic-type research select necessary materials, make components and elements, and synthesize target products, systems, services and environment. Since this process is a "synthetic" like process, the technological development could be said to be "synthetic-type research."

Demonstrating whether a synthesized artifact realizes the societal value targeted beforehand could be said to be hypothesis testing. In the case of private companies, realization of targeted societal value could be tested by introducing products or services into the market. In the case of research institutions and universities, realization of societal value could be tested by the reaction of society and industry to applied patents, proposed joint projects, manufactured prototypes, established databases and their disclosure for public use, published technical standards, developed metrological standards and reference materials and calibration services, developed geological maps and their publication, and developed risk evaluation methods and their applications.

When a synthetic-type research is conducted in the way shown in Fig. 1, success of the project of synthetic-type research depends on the quality of the scenario. This point is the first hypothesis created by this paper.

2.2 Interaction between scientific research and technological development

This subchapter describes the interaction between scientific research and technological development from historical examples in which research is connected effectively with societal value.

While science was born in the seventeenth century in western Europe, technology is supposed to have been born far beforehand around the time of the birth of human beings. Technology, which historically emerged way beforehand, and science, a newcomer, are basically different in nature, so effective interaction between the two may not be easy. Various attempts including those based on governmental science and technology policies are now being practiced around the world.

Interaction between science and technology began in the nineteenth century. A typical example is the relation between the invention of the steam engine and the development of thermodynamics. As shown by the upward broken-line arrow at the right hand side of Fig. 1, science recognized the artifact, the steam engine, as an existence and took it in as a research target. Resulting pieces and system of knowledge affected technological development to promote various thermal engines as shown by the downward broken-line arrow at the left hand side of Fig. 1. This is an example where science took results of technology in and then the technology was developed greatly by the endorsement of science. The science of neutrons and nuclear fission is strongly related to the technology development of nuclear weapons and power plants. Various discoveries in solid state physics and the invention of electronic devices including transistors are related in a similar manner.

An example in the twenty-first century may be nanotechnology. While nanoscience was a kind of observation science using electron microscopes at the beginning, the technological invention of scanning tunneling microscopes enabled not only observation but also manipulation of atoms, which led to processing and manufacturing various objects and structures at the nanoscale. Conversely, this stimulated science research to promote nanoscience. Nanotechnology is rapidly developing with the endorsement of nanoscience.

There may be similar relationship between life science and medicine and agriculture.

2.3 Attributes of synthetic-type research

Attributes of synthetic-type research compared with that of the analytic-type are shown in Table 1. The attributes of analytic-type research have been clarified over a long history of the establishment of science. The attributes in Table 1 for the analytic-type research can be considered accepted by all scientists. But the attributes of synthetic-type research have not been fully investigated because such type of research was defined quite recently.[1] Thus the following comments on the attributes of synthetic-type research are those of the authors of this paper at the present moment. (It is expected that they will be clarified in the course of time.)

The attributes in Table 1 are explained one by one.

Table 1. Attributes of analytic- and synthetic-type research

Category	Analytic-type research	Synthetic-type research
Methodology	Analysis	Synthesis
Action	Discovery and investigation of the truth	Invention and production
Knowledge	Factual knowledge	Needing knowledge
Motivation	Intellectual curiosity	Will to realize societal value
Scenario	Peripheral	Central
Discipline(s) involved	A single disciple	Plural disciplines
Uniqueness of solution	A unique solution	Plural equivalent solutions
Important characteristics	Consistency and systematization of knowledge	Societal value
Originality	Originality of factual knowledge	Originality of element selection and goal synthesis
Novelty	Novelty of factual knowledge	Novelty of element selection and goal synthesis
Evaluation	Peer review by experts	Merit review by beneficiaries

As the research names indicate, the methodology of research is analysis for analytic-type research and synthesis for the synthetic-type. The research conduct is discovery and investigation of the truth for the former, but is invention and production for the latter. The knowledge obtained is factual knowledge for the former about what the truth is, but is needing knowledge for the latter about what and how to do.

The motivation of obtaining knowledge is intellectual curiosity for analytic-type research, but is the will to realize societal value for synthetic-type research. The scenario of research is a peripheral interest and is not regarded as important for the former, but is regarded as most important for the latter being the central interest. The discipline involved in research is likely to be single for the former where specialization is usually intensified, while the disciplines involved are generally plural for the latter where necessary elements are taken in from many disciplines.

The solution is unique for analytic-type research where scientists believe that there should be a single solution of the truth. If there remain possible plural solutions for an issue, scientists continue to conduct research until a single solution remains. But there usually could be plural solutions for an issue for synthetic-type research that are equally important. The excellence of solutions depends on the societal environment and other relevant technologies, and has the possibility of varying with time.

The important characteristic is consistency among and systematization of knowledge for analytic-type research, but is societal value of research results for synthetic-type research. The originality is to create new elements of factual knowledge that the research adds on the system of existing knowledge for the former, but is to create new ways of selecting and structuring elemental technology for the latter.

The evaluation of research is made by experts being in the closest specialty to the authors for analytic-type research so that they can correctly evaluate consistency, systematization, and originality. This is called a peer review. However, for synthetic-type research, the evaluation of research is made by those who receive merit from the research results including researchers and engineers who receive merit from synthetic-type methods themselves. This is called a merit review. Reviewers of disciplines different from the author are usual.

3 Structures and properties of scenarios

In this chapter the characteristics of scenarios are generally investigated highlighting internal and stratified structures. Based on this investigation a second hypothesis that authors of synthetic-type research can describe the scenario verbally and visually is created. This hypothesis will be tested in Chapter 4.

3.1 Internal structures

While the processes of synthetic-type research are described in Fig. 1 using specific terms as materials, components, elements, we attempt to describe internal structures of scenarios using more general terms. It should be noted that a scenario is defined as “that which, after breaking down the goal of synthetic-type research into technical elements, expresses logical relationship between the goal and the technical elements and that among the technical elements.” It is supposed that the definition leads deductively to the internal structure of the scenario as shown in Fig. 2. Figure 2 is a kind of basic tool to be used for describing the scenario where the author(s) can establish the logical relationship between the research goal and technical elements

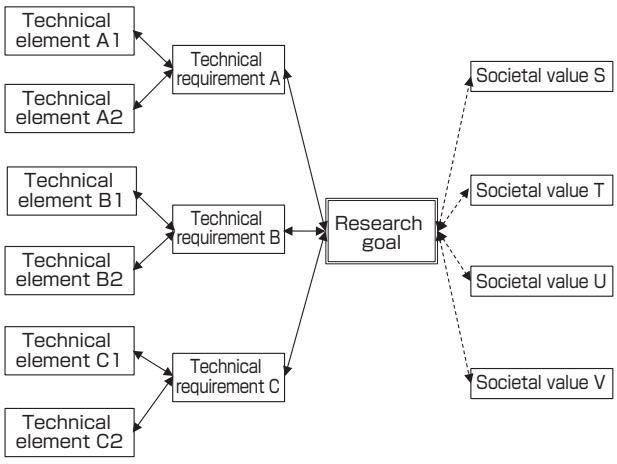

Fig. 2 Internal structure of scenario

When we follow the arrows in Fig. 2 from right to left, this is the process of scenario making. Assuming societal value in synthetic-type research, a researcher sets up a goal of research, which is an expected output of the research project. The goal of research is making goods, delivering services, and establishing methodology. (Those may be called generalized products.)

Next the goal of research is broken down into technical requirements. The technical requirements are often specific performances, characteristics, safety, expected life span, and manufacturing methods for production. Finally the technical requirements are broken down into technical elements. The technical elements are the basic units of the scenario.

When we follow the arrows in Fig. 2 reversely from left to right, this is the process of scenario implementation of synthetic-type research. Firstly, taking into consideration the technical requirements, the researchers seek technical elements and select the most suitable ones for the research project. If critical technical elements are unavailable, the researcher attempts to develop new techniques. Next, the researcher attempts to achieve the goal of research by integrating the technical requirements. Finally, whether the achieved goal of research meets the societal value set in the scenario making is verified and evaluated.

3.2 Stratified structure

Synthetic-type research could be of different sizes. The scenario could be at different levels, e.g. from a small and simple scenario like at the very beginning of a research project to a large and complex scenario like at the final stage of a project. A large-size scenario may be composed of small-size scenarios as shown in Fig.3. Those scenarios have the same internal structures independent of the size, i.e. there is similarity. A larger-size scenario embraces smaller-size scenarios.

In stratified structures, a goal of smaller-size research could contribute to a larger-size one as one of the technical elements. Thus scenarios may be said to have similarities having fractal structures.

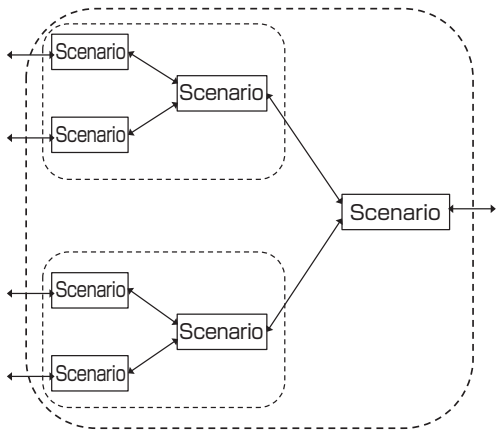

Fig. 3 Stratified structure of scenario

Table 2. Extracted instruction to write *Synthesiology* papers

	Item	Requirement
1	Research goal	Describe the research goal ("product" or researcher's vision).
2	Relationship of research goal and society	Describe the relationship of research goal and society, or its value for society.
3	Scenario	Describe the scenario or hypothesis to achieve the research goal with "scientific words."
4	Selection of elemental technology(ies)	Describe the elemental technology(ies) selected to achieve the research goal. Also describe why the particular elemental technology(ies) was/were selected.
5	Relationship and integration of elemental technologies	Describe how the selected elemental technologies are related to each other, and how the research goal was achieved by composing and integrating the elements, with "scientific words."

Assuming the internal and stratified structures of scenarios, researchers of synthetic-type research can describe the logical relationship between the goal of research and technical elements in terms of science and technology. This is a second hypothesis the present paper creates.

4 Description of scenarios in *Synthesiology* papers

The Editorial Board of *Synthesiology* requests authors to describe their own scenarios in the papers. In this chapter, we investigate how the scenarios are described by the authors. Then the two hypotheses created in Chapter 2 and 3 will be tested.

4.1 Request for description

Table 2 shows an extracted instruction in the Editorial Policy[4] of *Synthesiology* about how to write *Synthesiology* papers. The third item, "Scenario," characterizes the journal. Thus the Editorial Board requests authors of *Synthesiology* papers to describe their own scenarios.

4.2 Common characteristics

We found some common characteristics of scenarios regardless of discipline by reading the papers published in *Synthesiology* and by interviewing the authors.

4.2.1 Birth of a scenario

An "idea" or a "flash of thought" of a researcher could provide an opportunity for the birth of a scenario at the early stage of research even if it develops into a large-scale project. The idea or the flash of thought may change to a "possibility"

and could grow into "conviction" in the researcher. Then discussions of a scenario with his or her colleagues may promote expressing the scenario verbally and improving the logic of the scenario, which helps it to evolve so that a third party can understand.

Thus a prototype of a scenario is grown within a researcher's head at an early stage without expressing in a language and improving the logic. His or her research colleagues could join a collective activity of research only after the stage of expressing the scenario in a language. There is no means to communicate the scenario to others before the stage of expressing in a language when the scenario remains just as an idea that is hard to express.

4.2.2 Change of a scenario over time

The scenario develops step by step for improvement as the research progresses and the research group discusses. It is usual with the *Synthesiology* papers for the author(s) to describe scenarios of the time when the author(s) writes the paper or the "last" version of the scenario which he/she reaches in the end.

The *Synthesiology* authors often describe scenarios changing over time as the research project develops. Then a few scenarios are described in the paper with a stratified structure as shown in Fig. 3. The project started later takes in the results and experiences of the project started earlier where the later one sets up the goal that is closer to the societal value.

4.2.3 Large-scale scenarios

In the case of large-scale projects where many researchers are involved, the scope of research becomes quite wide with stratified scenarios. Research groups are formed for individual areas of technical requirements usually with several researchers involved for each area. Experts would be individually involved for each technical element. Stratified scenarios as shown in Fig. 3 are usually made.

4.2.4 Describing scenarios in language

The following was found from interviews to the authors of *Synthesiology* papers. When researchers are actually conducting research, they may conceive their own scenarios in an intuitive or unconscious manner. Such scenarios are not often left on record and have no written documents. In such cases some authors realized that they had actually conceived intuitive scenarios unconsciously when they started writing the *Synthesiology* papers. There were more than a few papers in *Synthesiology* where intuitive scenarios were written in language probably for the first time.

When researchers did not record their scenarios in a written form, it seemed considerably hard for them to recall the scenarios from the past and reproduce the processes of developing the scenarios. As the scenarios change and develop over time, the past scenarios are likely to disappear from the researchers' memory.

4.3 Various forms of scenarios

It is supposed that the internal structure of the scenarios the *Synthesiology* paper authors have is basically like Fig. 2. However the forms of scenarios were quite different from author to author about what aspects of the logical relationship between technical elements are emphasized. Some scenarios described in the *Synthesiology* papers are summarized in Reference [5]. We categorized those forms into four types.

4.3.1 Logical relationship between technical elements

About 50 % of the *Synthesiology* papers illustrate the logical relationship between technical elements in a similar form to Fig. 2. In these papers technical elements and technical requirements are logically related and a goal of research is achieved by integrating them.

An example of this type is the paper, "Investigation of the distribution of elements of the whole of Japan and their applications," in *Synthesiology* Vol. 3, No.4.[6] The scenario is illustrated in Fig. 4. The goal of research was to investigate distribution of elements on the surface of the earth crust of the whole of Japan and to make a map of element distribution (a kind of geochemical map) and open it to the public. To understand environmental pollution by toxic substances like arsenic, mercury, cadmium etc. and to seek the origin of the pollution were also intended.

Because the geochemical map is a kind of database, the scenario set five technical requirements for the database of basic characteristics, completeness, reliability, user convenience, and operability. A certain level of quality is required for each necessary condition for the geochemical

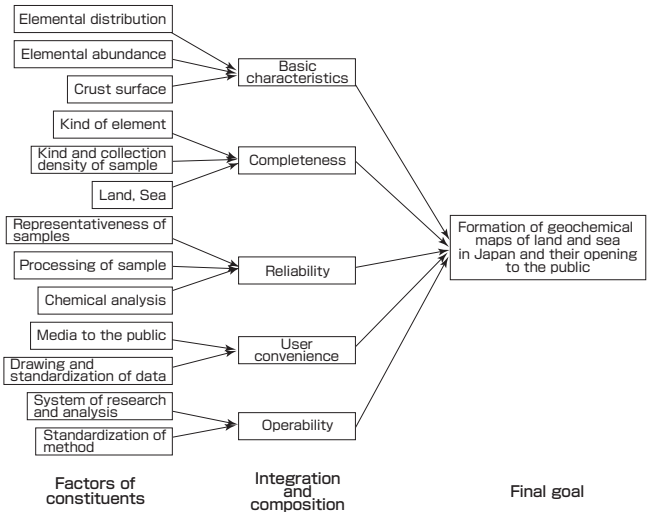

Fig. 4 Formation of the geochemical map of Japan and a scenario for opening access to the public
(From N. Imai, *Synthesiology*, Vol.3, No.4 [6])

map to be used widely by society. Then thirteen technical elements were set as shown in Fig. 4 to meet the quality of technical requirements. Actual research activities were the development of the technical elements, field work and chemical analyses of samples.

The biggest issue of this project was the completeness of the database. Under the restrictions of the number of participating researchers and time frame of research, the sampling density of one for 10 km square had to be selected. The biggest issue was whether the geochemical map of such low density sampling would be accepted by society. However low density sampling was decided. The project was started so that the technical elements and technical requirements were achieved within the preset time frame. In this way the element distribution map of the whole of Japan including both of land and sea was completed. At present this geochemical map is being used widely, overcoming the problem of sampling density.

4.3.2 Cyclic relation among technical elements

About 12 % of the *Synthesiology* papers illustrate the cyclic relationship of logic among technical elements, where time variation of the research project is incorporated in the scenario. Industries and societal sectors are allocated as partners of research. Research results obtained are provided to the partners step by step, and research is developed gradually by using information obtained from the partners. The *Synthesiology* paper, "Technologies for the design and retail service of well-fitting eyeglass frames,"[7] in Vol.1, No.1 is a typical one, the scenario of which is shown in Fig. 5.

The shapes of the face and the head are quite different according to individuals. Taking this into account, the goal of this research was set to establish a framework for an eyeglass shop so that the shop can provide customers with eyeglass frames best-fitting to individual head shapes of eyeglass users.

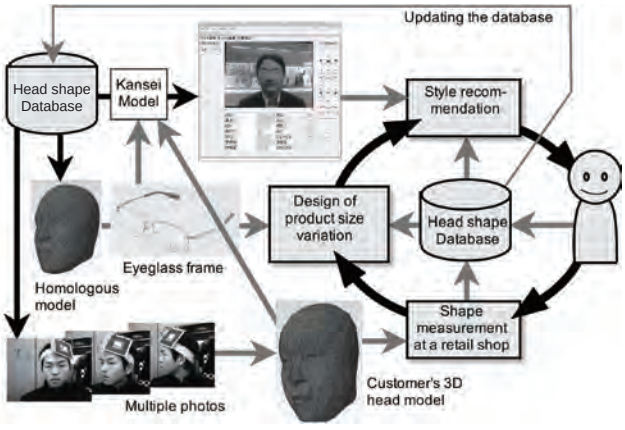

Fig. 5 A system to produce eyeglass frames according to the "Finding well-fitting products" approach
(From M. Mochimaru *et al.*, *Synthesiology*, Vol.1, No.1 [7])

Four technical requirements were set. They are the head shape database composed of many people, head shape measurement of customers at retail shops, design of eyeglass size variation, and style recommendation service. The head shape database is the center of this research because containing as much head shape data in the database is the key to providing customers with better eyeglasses.

This scenario is characterized by the cyclic flow of actions and data that circulate across technical requirements under the collaboration between researchers and the retail shops and customers, i.e., their partners. The head shape database becomes larger and better as more customers visit the shop. The scenario of the synthetic-type research is quite unique where actions and data circulate around a database across technical requirements.

4.3.3 Selection of technical elements

When a researcher of synthetic-type research sets up technical requirements and technical elements, the best elements are selected from existing ones and, if appropriate elements are not found, new ideas have to be created. About 13 % of the *Synthesiology* papers illustrate the processes of element selection. Those papers actually describe decision making processes of the authors where possible choices of elements are compared and evaluated from scientific and technological points of view on merits and demerits.

The *Synthesiology* paper, "Mass preparation and technological development of an antifreeze protein,"[8] in Vol.1, No.1 is a typical one. The scenario is shown in Fig. 6 where choices from various possible elements and the authors' decision processes are described.

An antifreeze protein has the effect that the freezing temperature of its water solution is depressed below 0 degree Celsius. It is known that such proteins exist in creatures living in the cold regions of the earth. Industrial applications of antifreeze proteins were highly desired, but the difficulty was the lack of amount of purified antifreeze proteins for practical use. The authors' scenario was to take the following

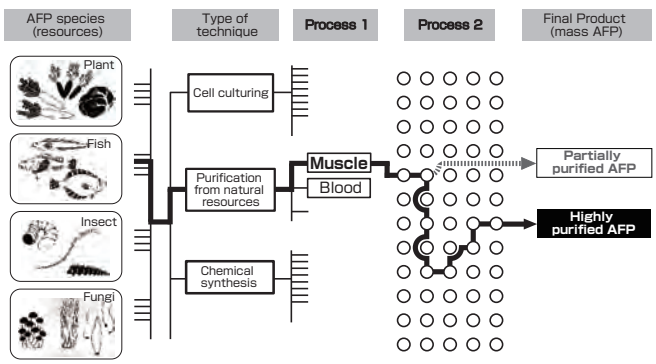

Fig. 6 Procedure for obtaining mass amount of AFP
(From Y. Nishimiya *et al.*, *Synthesiology*, Vol.1, No.1 [8])

choices to overcome the difficulty. First of all, the authors chose fish from among many kinds of creatures containing antifreeze proteins in their bodies. Secondly, they made the choice of purification of antifreeze proteins from natural resources (fish) instead of cell culturing and chemical synthesis. Thirdly, they made the choice to purify antifreeze proteins from muscles of fish instead of blood. These choices were made based on both the authors' scientific knowledge and intuition. This resulted in the success of the production of purified antifreeze proteins to a practically sufficient amount from the muscles of small fish unloaded at the ports in Hokkaido. Now the authors and private companies collaborate for industrialization.

The *Synthesiology* paper tells us that the important points in research are the positions of not necessarily prioritizing the current trend and of respecting basic research to get scientific knowledge necessary for making choices.

4.3.4 Changes over time

The scenario sometimes can be changed greatly including modification of the research goal when synthetic-type research itself evolves in an unexpected way, societal environment of the research changes, and a new technical element affecting the research emerges.

It is rather natural that the scenario of a long-term synthetic-type research changes during implementation. About 20 % of the *Synthesiology* papers illustrate how the scenario changed.

Figure 7 is an example of such a paper illustrating a series of scenarios about a real-time all-in-focus microscope from the early stage of the research to the industrialization stage.[9] An idea of a new microscope emerged from a scientific interest, the idea evolved during the implementation of research and, the research goal was clarified and specified step by step through the development of new technical elements and through communication with a collaborative company. The *Synthesiology* paper describes the whole story of a long project, where we can understand the dynamism of synthetic-type research.

4.4 Difficulties in scenario description

There are some *Synthesiology* papers where scenarios are not described explicitly. There may have been the following reasons behind that.

A) The key point of the writing form of *Synthesiology* papers was not well explained to the authors by the Editorial Board. This led to the authors writing their *Synthesiology* papers without fully understanding how to describe the scenario specifically.

B) Individual members of the Editorial Board had more or less different ideas on the form of the scenario of *Synthesiology* papers because it had not been well established.

C) Review criteria for the reviewers were not well established. This might not have guided the authors well on how to specifically describe their scenarios.

Circumstances of A) to C) seem to have been unavoidable because the study of the writing form of synthetic-type research papers just started ten years ago, and is still continuing. As it took a very long time from the seventeenth

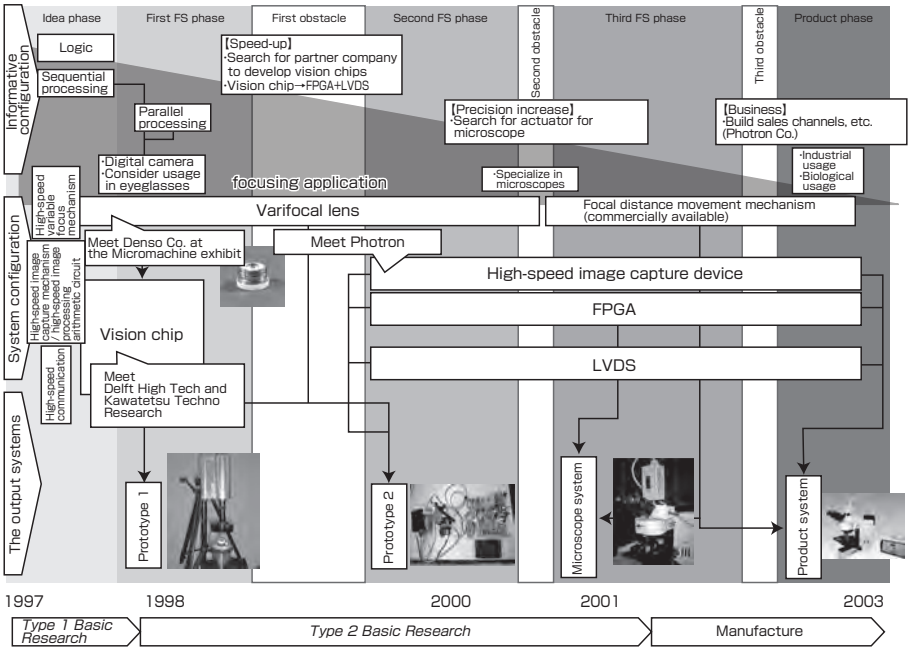

Fig. 7 Our struggle (Twists and turns) for synthesis
(From K. Ohba, *Synthesiology*, Vol.2, No.4 [9])

century for the form of analytic-type research papers to be well established, it is understandable that the writing form and review criteria of synthetic-type research papers are not well established at the moment. This problem will be resolved step by step through further publishing of *Synthesiology* papers and through experiences of writing papers on synthetic-type research.

4.5 Hypotheses testing

The Editorial Board of *Synthesiology* requested the authors to describe their own scenarios of synthetic-type research, based on two hypotheses that the scenario would play a central role of synthetic-type research and it would be possible to describe the scenario verbally and visually.

Almost all *Synthesiology* papers mention scenarios explicitly or implicitly. In most cases specific chapters, sections and columns are allocated for scenario description. The scenarios cover the whole of research and describe logical relationship of research contents.

Most of the *Synthesiology* paper authors quote their own past papers published in other refereed journals. The scenarios of *Synthesiology* papers are written in a way that goes right through their past papers. The scenarios usually reveal the relationship among those papers. It is supposed that the scenarios are like an axis running through a series of their past papers. Interviews to some of *Synthesiology* paper authors were also supportive showing that writing *Synthesiology* papers was a good chance for the authors to review a series of their own research and reconfirm the essence of the research.

The scenarios of the *Synthesiology* papers vary widely in scale from a large-scale project involving a whole technical field to a small-scale one of just one researcher. However the importance of scenarios in synthetic-type research, whatever the scale, seems equivalent.

From the *Synthesiology* papers, one can say that, if the scenarios were deleted from the papers, those papers would become just collections of research results obtained from the past papers. It would lack the essence of the authors' intentions, i.e. the axes across a series of their past research. Thus it could be said that what characterizes the *Synthesiology* papers is the scenario.

Thus, with respect to the first hypothesis, it could be said that the scenario plays a central role in synthetic-type research.

More than half of the *Synthesiology* papers illustrate the scenario or something equivalent to that using one or two figures. Those figures show on what scenario the authors conducted synthetic-type research, and the overview of the logical relationship between the research elements. Detailed logical relationship between the research goal and technical elements is also described in the text of *Synthesiology* papers.

In *Synthesiology* papers, the authors describe scientific and technological items and frameworks at a certain balance, although different according to individual papers. While some papers describe only scientific and technological items, others stress frameworks. The most typical framework is collaborative research. The reason is that much synthetic-type research has been conducted in a collaborative way between public institutes and private companies, most of which can result in success. It is supposed that the difference of emphasized items comes from the authors' view on what the most important factor was for success of research.

It was noted in Subchapter 4.3 that the scenario is described in various forms. Figure 4 shows that the internal structure of the scenario shown in Fig. 2 can be used as is as a descriptive form of logical relationship. Figures 5, 6 and 7 emphasize specific aspects of logical relationship between elements. In these cases technical elements and technical requirements are described in more detail in the text and other figures.

All the scenarios described in *Synthesiology* papers are original creations in the sense that they are described for the first time by the authors. The example of a scenario shown in Fig. 5 further indicates that a new methodology of research was created by inventing a cyclic relationship between technical requirements. High originality is recognized in the scenario itself.

Round-table discussions were held twice with the authors of *Synthesiology* papers and members of the Editorial Board to talk about their experiences of writing *Synthesiology* papers.[10][11] There is an author of a *Synthesiology* paper who submitted an article to *Synthesiology* again that reviews hisSynthesili synthetic-type research as a whole.[12] The round-table discussions and the article also support the second hypothesis.

Thus, with respect to the second hypothesis, it could be said that the scenario can be described verbally and visually throughout all disciplines and all scales of projects, although in quite different forms from author to author.

5 Applications of scenarios

Since the scenario plays the central role in synthetic-type research, it would be reasonable to expect that the scenario is useful in various aspects of such type research. Possibilities in scenario use will be discussed below in planning, implementing, and evaluating synthetic-type research. It is suggested that there may be possibilities that the speed of synthetic-type research for innovation could be remarkably increased in society through disclosing and sharing of

scenarios.

5.1 Planning of a research project

A project plan can be made based on a scenario rearranged to meet limitations of resources such as time period, budget, manpower, and equipment. The scenario can be used as follows.

5.1.1 Setting-up of research goals

When a project planner sets up the purpose of a research project, the planner can integrate the societal value in the scenario into the project. There is an option of taking the societal value as is in the scenario, focusing on a specific value in the scenario, or adding some other value to the scenario.

5.1.2 Application to a roadmap

A project planner can add time priority to the scenario and develop it into a project roadmap.

5.1.3 Development of technical elements

A project planner can make an implementation plan of a project by selecting necessary elements from the scenario. If there is a lack of technical elements necessary to achieve the goal, the project planner identifies them and makes a decision whether to develop them internally or to outsource development.

5.1.4 Communication with potential stakeholders

If a project planner communicates with potential stakeholders like private companies similarly interested in the scenario, the project planner can receive feedback concerning the scenario from the potential stakeholders for improvement. When a private company is further interested in research implementation, the project planner and the company can discuss in detail the possibilities of collaborative research identifying each other's roles in the scenario.

5.1.5 Estimate of resources

A project is applied by a planner for endorsement or funding to its own organization or research funding agencies. The application could be improved if the project planner estimates necessary resources (manpower, equipment, money, and time) correctly based on the scenario.

5.2 Implementation of research projects

5.2.1 Framework formation for research implementation

According to individual roles of scenario elements, the project leader can specify participating researchers appropriately. The project leader can select external partners, if necessary, to establish collaborative research of a larger formation.

5.2.2 Formation of participating researchers

The project leader ensures that all the participants in the research project share the scenario and understand their individual positions and roles. In the case of industry-academia-government collaboration, individual participants can clearly recognize through the scenario their own roles and relationship to each other in the project beyond the formation.

5.2.3 Changes of a research project and formation

When a research project has to be changed halfway by an interim evaluation etc., the project leader can change the research project in a consistent and flexible manner if he or she makes changes based on the scenario.

5.3 Evaluation of research

5.3.1 Evaluation of research projects

A research evaluator of research funding agencies etc. can evaluate an applied project based on the scenario of synthetic-type research. The decision of adoption or rejection of a research project is made appropriately through reviewing the scenario in terms of rationality, innovativeness, and feasibility, as well as validity of resource requirements.

When an interim evaluation of a research project is made halfway, a research evaluator can evaluate the progress of the project in comparison with the original scenario and can appropriately evaluate a proposed change of the project due to environment changes based on the scenario.

At the final stage of a research project, a research evaluator can appropriately evaluate processes and output of a project based on the scenario.

5.3.2 Evaluation of the scenario

The success of synthetic-type research strongly depends on the quality of the scenario because it plays a central role in such type research. Thus it would be important to evaluate the quality of the scenario in terms of rationality, innovativeness, and feasibility. It should be noted here that not all synthetic-type research directly reach societal value. As shown in Fig. 3 a small-size scenario allocated at a lower position reaches societal value through some other larger scenarios. So the validity of the "chain of scenarios" to reach the societal value should also be evaluated.

The evaluation of the scenario should be made from the following points of view.

a) Is the assumed societal value appropriate from the viewpoint of the present and future society and industry?

b) Is the research goal targeted effectively and inevitably for the realization of the assumed societal value?

c) Is the scenario described appropriate from the viewpoint

of the targeted research goal? Has the realization of societal value been well considered in the scenario?

d) Does the scenario show clear superiority over others from the viewpoint, for example, of the possibility of a breakthrough?

e) Are the technical requirements broken down necessary and sufficient from the viewpoint of the research goal?

f) Are the identified technical elements necessary and sufficient from the viewpoint of technical requirements?

g) Are the identified technical elements available?

h) If there are unavailable technical elements, are the possibilities of self-development or outsourcing to other organizations well considered?

5.3.3 Improvement of evaluation quality

A project plan of synthetic-type research is usually described in an application form submitted to a research funding agency. The project plan is evaluated for the decision of adoption or rejection. Research output of a project is described in a final report after finishing all research activities. The application and final report are submitted to the same agency, but separately at different times. Thus it would not be very easy for the project leader to check the validity and rationality of the research over the whole period from the application to the finish. It would require considerable effort for a funding agency to evaluate in a coherent manner a research project over the whole period. A research evaluator could evaluate the processes and results of research more appropriately if a scenario is available at the application time and if a scenario reviewed or revised is available at the interim time.

The success of a research project is judged by its output in quality and quantity. Papers published in refereed journals are used as objective evidence. However, it should be noted that, even if a paper of synthetic-type research is submitted, most academic journals expect authors to write papers in the form for analytic-type research and reviewers of papers apply the review criteria for such type research.

At the moment there are very few refereed journals that receive papers of synthetic-type research. The first reason is that submission of synthetic-type research papers is beyond expectations to most of the refereed journals. The second reason is that researchers of synthetic-type research do not know how to describe processes and results of such type research well. The third reason is that reviewers of most of the refereed journals do not have clear review criteria for synthetic-type research.

Appropriate research evaluations would be made if more and more papers of synthetic-type research are published in many refereed journals including *Synthesiology* where processes and results of such type research are described. Submission of synthetic-type research papers is strongly encouraged.

5.3.4 Evaluation of researchers

It would become possible to find good researchers who can conduct synthetic-type research well and to evaluate such capabilities when many scenarios become open to the public. Also researchers of synthetic-type research can know themselves what capabilities should be obtained for innovation creation.

The following is the basic capabilities required for researchers of synthetic-type research.

a) Capability of assuming new societal value

b) Capability of targeting a research goal to meet societal value

c) Capability of describing an entire scenario from the research goal to the technical elements

  c-1) Capability of breaking down the technical requirements into performance, characteristics, safety, risk etc. to achieve the research goal

  c-2) Capability of identifying technical elements necessary and sufficient to meet the technical requirements

  c-3) Capability of recognizing the strength of technical elements his/her research group owns, and finding/selecting excellent technical elements that preceding researchers own

  c-4) Capability of finding/selecting technical elements useful to his/her own purposes that have been already realized in other disciplines

  c-5) Capability of developing key technical elements that have never been realized

6 Conclusions

We investigated more than a hundred *Synthesiology* papers. It was confirmed that the scenario plays a central role in most of the *Synthesiology* papers. The scenario description is the greatest characteristic of *Synthesiology* papers that is different from other scientific journals. About two thirds of the *Synthesiology* papers describe the scenario or something equivalent visually using figures. It was also confirmed that the scenario can be described verbally and visually.

Although the skill of describing the scenario varies from paper to paper, the form of the scenario will be refined in the future as experiences are gained. This time the hypotheses were tested within the limited materials of more than a hundred *Synthesiology* papers. In the future, the testing is expected to become more reliable if more synthetic-type research papers follow.

It was a surprise that the *Synthesiology* papers were described in an intelligible manner to reviewers and readers of the journal whose disciplines are different from that of the authors. While almost all papers published in the contemporary scientific journals are not intelligible to those whose disciplines are different from those of the authors, it is remarkable that the *Synthesiology* papers are comprehensible. If the writing form of synthetic-type research papers becomes more refined, *Synthesiology* papers will become more understandable to readers.

Interviews to the *Synthesiology* paper authors revealed that the discussion with reviewers was quite useful to the authors. Discussions with reviewers were open to the public readers with the real names of reviewers revealed, which was a new attempt. The discussion with reviewers is considered quite helpful for the readers to understand the papers better because the reviewers ask important matters that the authors may have missed.

In the early 2000s, AIST conducted "*Full Research*" which is composed of *Type 1 Basic Research*, *Type 2 Basic Research* and *Product Realization Research* in a concurrent and coherent manner.[13] *Type 2 Basic Research* and *Product Realization Research* may be equivalent to synthetic-type research while *Type 1 Basic Research* to analytic-type research.

Results of synthetic-type research are usually published in the journals of industrial associations and the reports of individual companies (Giho). But the scenarios, i.e., the present central issue, are not fully described there. If a researcher of synthetic-type research wants to submit a paper to scientific journals, the researcher has to write a paper in the form of analytic-type research so that the materials have to be considerably rearranged to meet the review criteria of journals for analytic-type research. In this environment it is quite difficult to describe scenarios of synthetic-type research in the existing scientific journals.

The scenarios of synthetic-type research will be widely shared in and become important assets of society if scenarios are published more not only in *Synthesiology* but also in other journals. When a scenario is shared by different disciplines, then it is expected that a new collaborative research region is temporarily created that may be thought of as a new converging discipline. When a scenario is shared by industry-academia-government collaboration, then it is expected that a new collaborative research region is temporarily created that is across different organizations. Generally there are many difficulties in collaboration between different disciplines and between different organizations. If a common scenario were to be shared and understood by all the participants, then the level of collaboration and the speed of research would be remarkably increased.

Sharing scenarios between different disciplines and organizations benefits not only organizations implementing research but also the funding agencies through appropriate evaluations and more effective funding.

The importance of synthetic-type research will be increased in the innovation age. There probably were excellent scenarios behind the creation of excellent societal value. It is expected that research and societal value are connected more efficiently by disclosing and sharing scenarios as societal assets. Sharing scenarios will inspire researchers and research groups in industries, universities, and governments. The frameworks of research in society will possibly evolve into a new stage where research is remarkably accelerated for innovation.

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Discussions with Reviewers

1 General comment

Comment (Hiroyuki Yoshikawa, Japan Science and Technology Agency)

I consider that this paper is useful for quality improvement of *Synthesiology* papers to be submitted in the future and for better understanding of the readers of this journal because it deals with important issues on the papers published in *Synthesiology*. The submitted *Synthesiology* papers contain original knowledge about synthesis obtained during actual research. The authors of synthesiological papers have to seek a logical structure of writing a paper themselves while those of general scientific papers can write papers in a traditionally established way. In this sense it is valuable that the logical structure of a paper is examined by surveying the submitted papers.

This paper may be considered as the analysis of evidence because evidence was obtained from detailed survey of about a hundred published papers. If so, this paper would firstly describe revealed facts and secondly present analyzed results, which would show what the synthesiological papers are like. Then this paper would become like an analytic-type paper, which may not be very suitable for the journal of *Synthesiology*. Instead, however, the authors of this paper actually created hypotheses on the writing form of synthetic-type research papers having been in the position of planners of the journal. The hypotheses have been tested, and plenty of new contents have been obtained that were not clear at the planning stage of the journal. So this paper can be considered as contributing much to the writing of *Synthesiology* papers in the future. I highly respect the authors' will of not writing the paper like an analytic-type research one. It impresses me.

It is suggested to the readers of this paper to see Kobayashi's paper in Vo.5, No.1, *Synthesiology*.[3]

Comment (Noboru Yumoto, AIST)

The first version of the manuscript described the methodology of synthetic-type research in comparison with that of the analytic-type and how to make a scenario of synthetic-type research referring to the published *Synthesiology* papers. However, it is thought that this paper does not develop its original contents sufficiently to be accepted as a research paper of *Synthesiology*.

It was highly evaluated that the authors made an effort to widely revise the first manuscript to clarify the hypotheses and their test in the second version. It is very valuable to test the

two hypotheses because they have been assumed at the start of *Synthesiology*; the first being that the scenario plays a central role in synthetic-type research and the second being that it would be possible for the authors to describe the scenario verbally and visually in their papers. However I think that it is necessary to consider carefully the fact that all the authors of published *Synthesiology* papers were requested to describe the scenario, which may have given a potential bias to scientific testing of the hypotheses.

I think that, as explained in the authors' answer to the second round review, examinations are important from the viewpoint of hypotheses testing why there are some papers that do not describe scenarios clearly. Inclusion of such examinations in the text of this paper is requested.

Answer (Akira Ono)

The first version of the manuscript emphasized too much how to make scenarios. So it was revised not to emphasize it because every scenario is an original creation of the authors of *Synthesiology* papers and because it is actually difficult for a third party to instruct the authors on how to make their scenarios. The authors of this paper also thought that the first version lacked a clear description about creating and testing hypotheses. So Subchapter 4.5 "Hypotheses testing" was newly introduced to describe it in more detail.

While synthetic-type research actually has a long history, the writing form of such type research papers had never been investigated until ten years ago, when *Synthesiology* was issued for the first time. On the other hand, the writing form of analytic-type research papers has been developed over a long time since the seventeenth century, and has become common knowledge accepted by all scientists. Compared with that, the writing form of synthetic-type research papers is far from established, and its verification has never been universally demonstrated. It will take much more time to demonstrate the two hypotheses thoroughly. Thus we made revisions to the manuscript from the viewpoint of what can be said from the several-year experience we have had with *Synthesiology*.

We would like to tell our thoughts on a potential bias that the *Synthesiology* paper authors may have received. The Editorial Board actually attempted to instruct *Synthesiology* paper authors in advance for better writing, for example, by introducing scenarios having been described in the past published papers. But we think that the essential points of hypotheses testing are, regardless of Editorial Board instructions, the questions of whether the scenario "intrinsically" played a central role in synthetic-type research and of whether it was "intrinsically" possible for the researchers to describe scenarios verbally and visually. The contents of scenarios are entirely original of the authors, which are not anything resulting from the instructions of the Editorial Board. The hypotheses testing was done not through whether a chapter for scenario description is set or not but through investigating the "intrinsic" validity of the hypotheses by reading the *Synthesiology* papers.

The authors' consideration was described in a new Subchapter 4.4 "Difficulties in scenario description" about why there were some papers that did not describe the scenarios clearly.

2 Difference between analytic- and synthetic-type sciences

Comment (Hiroyuki Yoshikawa)

Figure 1 illustrates the difference between the analytic-type sciences and synthetic-type ones, but the relation to the general explanation is not easy to understand. The general explanation is like this: While in analysis, one creates (derivation of laws) and develops (collection of knowledge) a discipline to explain nature and existence, in synthesis, one creates methods to get existences (products, services, and methods) or actually creates them to realize given expectations or value. The analysis and synthesis have parts in common logically, but the logics appear in different orders. The scenario of synthesis is hypothesis creation while the discovery of laws is hypothesis in the analysis. However, the processes of hypothesis creation are not supposed to be written in papers of the analysis. The synthetic-type science papers are different from general scientific ones on the point that the scenario is highlighted and explained. That is the difference of the analytic-type sciences and the synthetic-type ones. Please add a figure that explains the difference visibly.

Answer (Akira Ono)

We agree with your view on the hypothesis creation in the synthetic-type sciences. Figure 1 was replaced with a revised one which shows more clearly the suggested relationship between the analytic-type sciences and the synthetic-type ones.

3 Internal structure of scenarios

Question (Hiroyuki Yoshikawa)

Figure 2 is explained in this paper as showing the scenario making processes of synthetic-type research with the arrows from right to left, and the scenario implementing processes of such type research with the arrows in the other direction. The explanation could be read like this. "Relation figures like Fig. 2 already exist probably with huge data of technical requirements and elements, from which appropriate elements are carefully selected to integrate and synthesize products of real existence." My question is the following. In the published *Synthesiology* papers, were relation figures like Fig. 2 formulated places of scenario making given by existing data? Or, in most of the cases, were relation figures like Fig. 2 actually created in the processes of scenario making without such data? If the goal of *Synthesiology* is to establish general formulation of scenarios, it is suggested to emphasize that the individual *Synthesiology* papers are examples of evidence, collection of which may lead to a general form of Fig. 2.

Answer (Akira Ono)

Figure 2 illustrating the internal structure of a scenario and the logical relationship was deduced by the authors from the definition of the scenario at almost the same time as the issuing of *Synthesiology*. Figure 2 is a basic form explaining the logical relationship between the research goal and technical elements in the scenario.

We agree that in many cases relation figures like Fig. 2 were created without existing data by the *Synthesiology* paper authors in the processes of scenario making. If we look at the *Synthesiology* papers in detail, none of the scenarios appear similar. This means that the logical relationship describing their scenario in the most appropriate way is not necessarily the same as Fig. 2. Examples are shown in Subchapter 4.3 "Various forms of scenarios." We think that Fig. 2 could be instructive for researchers of synthetic-type research to describe their scenarios, but the most appropriate forms may be different from author to author. It will be useful to collect examples of forms of scenarios and categorize them.

4 Definition of the scenario and its role

Comment (Hiroyuki Yoshikawa)

Please define the scenario clearly. While the importance of the scenario is explained sufficiently in this paper, what the scenario does is not. When reading this paper, I began to feel that my understanding had not improved of what a scenario is and why it is necessary to write a scenario. This paper provides many explanations about the role of the scenario stating its usefulness,

but it does not lead to the absolute necessity of the scenario. On the other hand this paper mentions the necessity of the scenario to some extent using examples in Chapter 4. In Section 4.2.4 "Describing scenarios in language," for instance, it is said that the scenario description is necessary as record keeping. However, verbalization of the scenario is not just for records but is needed to help discover logical relationship between the technical elements which is intrinsically part of societal value and research goals but is not expressed. If a positive explanation could be clearly given why the scenario written in language is necessary, the significance of this paper as well as of synthetic-type research could be better understood.

Answer (Akira Ono)

Since the definition of the scenario was not clear in the first version of manuscript, it was revised, and the definition was given at the beginning of Chapter 2 as "that which, after breaking down the goal of synthetic-type research into technical elements, expresses logical relationship between the goal and the technical elements and that among the technical elements."

We think that the reason why the scenario has to be described in language is to make clear the logical relationship between the research goal and technical elements and that among the technical elements themselves. If the scenario described in language lacks this, the scenario would remain just as an idea or a flash of thought which may not lead to discussions and collaboration with other people. We hope that the readers of this paper understand the necessity of the scenario better. Revisions were made throughout the paper based on this thought.