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Synthesiology

English edition

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Development of methane hydrate production method

Toward the integrated optimization of steel plate production process

Information sharing platform to assist rescue activities in huge disasters

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MESSAGES FROM THE EDITORIAL BOARD

There has been a wide gap between science and society. The last three hundred years of the history of modern science indicates to us that many research results disappeared or took a long time to become useful to society. Due to the difficulties of bridging this gap, this stage has been recently called the valley of death or the nightmare stage (Note 1). Rather than passively waiting, therefore, researchers and engineers who understand the potential of the research should actively try to bridge the gap.

To bridge the gap, technology integration (i.e. *Type 2 Basic Research* – Note 2) of scientific findings for utilizing them in society, in addition to analytical research, has been one of the wheels of progress (i.e. *Full Research* – Note 3). Traditional journals, have been collecting much analytical type knowledge that is factual knowledge and establishing many scientific disciplines (i.e. *Type 1 Basic Research* – Note 4). Technology integration research activities, on the other hand, have been kept as personal know-how. They have not been formalized as universal knowledge of what ought to be done.

As there must be common theories, principles, and practices in the methodologies of technology integration, we regard it as basic research. This is the reason why we have decided to publish "*Synthesiology*", a new academic journal. *Synthesiology* is a coined word combining "synthesis" and "ology". Synthesis which has its origin in Greek means integration. Ology is a suffix attached to scientific disciplines.

Each paper in this journal will present scenarios selected for their societal value, identify elemental knowledge and/or technologies to be integrated, and describe the procedures and processes to achieve this goal. Through the publishing of papers in this journal, researchers and engineers can enhance the transformation of scientific outputs into the societal prosperity and make technical contributions to sustainable development. Efforts such as this will serve to increase the significance of research activities to society.

We look forward to your active contributions of papers on technology integration to the journal.

Addendum to Synthesiology-English edition,

"*Synthesiology-English edition" is a translated version of* "*Synthesiology", which is published quarterly, ISSN 1882-6229, by AIST.*

Papers or articles published in "*Synthesiology-English edition" appear approximately four months after the publication of the original* "*Synthesiology". Those published in Japanese are translated into English, so the views expressed in translated versions are exclusively those of the Japanese authors and editors. The Japanese authors are generally consulted regarding the translation of their papers, but are not responsible for the published English version.*

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Synthesiology Editorial Board

Note 1 : The period was named "nightmare stage" by Hiroyuki Yoshikawa, President of AIST, and historical scientist Joseph Hatvany. The "valley of death" was by Vernon Ehlers in 1998 when he was Vice Chairman of US Congress, Science and Technology Committee. Lewis Branscomb, Professor emeritus of Harvard University, called this gap as "Darwinian sea" where natural selection takes place.
Note 2 : *Type 2 Basic Research*
This is a research type where various known and new knowledge is combined and integrated in order to achieve the specific goal that has social value. It also includes research activities that develop common theories or principles in technology integration.
Note 3 : *Full Research*
This is a research type where the theme is placed within the scenario toward the future society, and where framework is developed in which researchers from wide range of research fields can participate in studying actual issues. This research is done continuously and concurrently from *Type 1 Basic Research* (Note 4) to *Product Realization Research* (Note 5), centered by *Type 2 Basic Research* (Note 2).
Note 4 : *Type 1 Basic Research*
This is an analytical research type where unknown phenomena are analyzed, by observation, experimentation, and theoretical calculation, to establish universal principles and theories.
Note 5 : *Product Realization Research*
This is a research where the results and knowledge from *Type 1 Basic Research* and *Type 2 Basic Research* are applied to embody use of a new technology in the society.

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Contents

Paleoclimate reconstruction and future forecast based on coral skeletal climatology

— Understanding the oceanic history through precise chemical and isotope analyses of coral annual bands —

Atsushi Suzuki

[Translation from *Synthesiology*, Vol.5, No.2, p.80-88 (2012)]

Global warming (due to increased carbon dioxide in the atmosphere) has attracted much attention. Yet, predicting trends in the Earth's climate remains difficult. A more sophisticated and accurate global warming model can be obtained by reconstructing climatic change since the Industrial Revolution, and other past periods of warming. To this end, a promising area of research in marine science is coral skeletal climatology, which offers a unique method for accurately reconstructing marine temperature and saline concentration over the past several hundred years, with a high temporal resolution (ca. 2 weeks) based on chemical and isotope analysis of long-lived coral skeletons. This method has been successfully applied to the Little Ice Age around the 18th century and the mid-Pliocene warming period of 3.5 million years ago. It can also be applied to biological and environment studies on massive coral bleaching events caused by unusually high oceanic temperature levels and other environmental issues such as ocean acidification.

Keywords **:** coral, climate, global warming, ocean, oxygen isotope ratio

1 Introduction

Observation records of the ocean and land at high resolution over a long time span are necessary in order to understand the climate change at a global scale. However, there are very few records of marine observation using measuring equipment before 1950. Therefore, the reconstruction of marine temperature, rainfall, and salinity over the past several hundred years using the annual growth bands from the skeletons of massive reef-building coral colonies has drawn attention (Figs. 1 and 2). The annual bands in the coral skeletons were discovered in 1933, but they became the subject of active research after 1995, and only recently the research has developed into "coral skeletal climatology" (Fig. 3). In this paper, I shall explain why the coral skeleton is excellent as a recording medium of the past global climate change, and describe the major developments where the latest analysis technology is being utilized to read the past records.

Under the title "Paleoclimate" in Chapter 7 of *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*[1] published in 2007, researches on climate changes from several years to several hundred thousand years were reviewed. In this report, there were many citations of the results of marine environment reconstruction at high temporal resolution (about two weeks) using indirect indices such as the oxygen isotope ratio of coral samples from the tropical and subtropical zones. It was shown that the sea temperatures of the recent two hundred years were clearly higher than the past period, through the records left in the extant large corals from several areas of low-latitude waters, and this is considered to be a major accomplishment of coral skeletal climatology. Figure 2 shows the research subjects used in the paleoclimate reconstruction and the positioning of the coral skeletal research.[1][2]

It is also an important issue to reconstruct the climate from the

Fig. 1 Massive colony of *Porites* (left) seen in the coral reef of Ishigaki Island, Ryukyu Islands and the x-ray positive photograph of a columnar sample (right)
In the x-ray photograph, the dark colored band corresponds to the high-density area, and the light colored band corresponds to the low-density area. One set of dark and light colored bands represents one annular ring.

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coral fossils from the Little Ice Age[Term 1] and the Medieval Warm Period, as well as the Holocene[Term 2] or the Pliocene[Term 3] Warm Period of 3.5 million years ago. The research method using the coral skeleton may also help clarify the coral bleaching events that are caused by abnormally high temperatures and ocean acidification phenomena.

In this paper, the research for reconstructing the past climate changes using the modern and fossil coral skeletons will be described, along with the examples of the latest research that is progressing through the combined evaluation of various indices, under the recent breakthroughs. Also, the methodology for enhancing the accuracy of global environment prediction will be discussed.

2 Knowing the temperature and salinity from the chemical composition of coral skeletons

Some of the massive colonies of the *Porites* corals that are distributed widely in the shallow waters of the tropical and subtropical zones continue to grow over the past several hundred years while secreting skeletons, whose main ingredient is calcium carbonate, at 1~2 cm thickness per year (Fig. 1). The skeletons consist of areas of high and low density layered on top of each other, and annular bands are thus normally formed. When a columnar sample is collected from a coral whose colony surface is alive, the year of skeleton formation can be known accurately by counting the annular bands. By cutting and analyzing the minute samples at 0.2~0.4 mm intervals along the growth axis of the skeleton, the paleoclimate can be constructed at high resolution of monthly or higher time units.

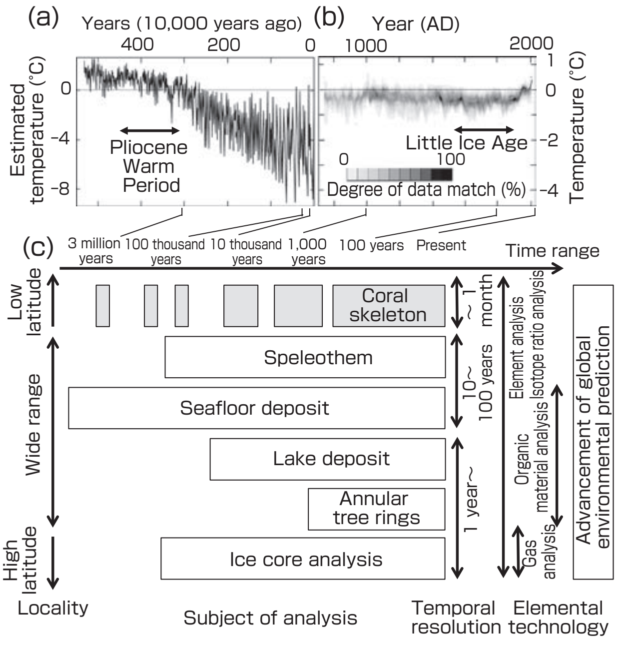

Fig. 2 Subject used in paleoclimate reconstruction and the positioning of coral skeletal research
(a) Estimation of temperature variation for the past 5.5 million years.[2] The past temperature can be estimated since the oxygen isotope ratio of the carbonate shell of the benthic foraminifers obtained from the core sample of deep seafloor deposits is a good index of global ice volume. It is an estimate of the temperature difference compared to present in the South Pole region, and the absolute value of the temperature difference differs greatly according to the latitudes and regions. (b) Temperature variation in the past 1200 years (from Fig. 6.10.c of Reference[1]). The deviation from the average value for 1961-1990 is shown and the degree of match among several researches is shown by darkness of color. (c) The producing range, analysis method, and temporal resolution of the subject used in the paleoclimate reconstruction using coral skeleton and others are presented schematically.

Oxygen isotope ratio is used frequently in the researches for the chemical composition of the coral skeletons. Normally, the oxygen isotope ratio is expressed as $\delta^{18}O$ by calculating the per mil (‰) of the isotope ratio in the sample ($^{18}O/^{16}O$) against the standard sample. The isotope ratio of oxygen in calcium carbonate and the isotope ratio of oxygen in seawater are given small letters c and w, and are expressed $\delta^{18}Oc$ and $\delta^{18}Ow$, respectively. The oxygen isotope ratio of calcium carbonate ($\delta^{18}Oc$) is dependent on the temperature when precipitation occurred and the oxygen isotope ratio of the seawater (correlated to salinity) (Fig. 4). To estimate the water temperature from the oxygen isotope ratio of the skeleton, it is preferable to use the relational expression obtained by comparing the oxygen isotope ratio of the upper part of the colony and the seawater temperature observation records. Also, to avoid the effect of skeletal growth rate on the chemical composition, the analysis should be done along the maximum growth axis of the colony where the growth rate is 5 mm y^{-1} or higher. In the area where the salinity variation is small throughout the year, the oxygen isotope

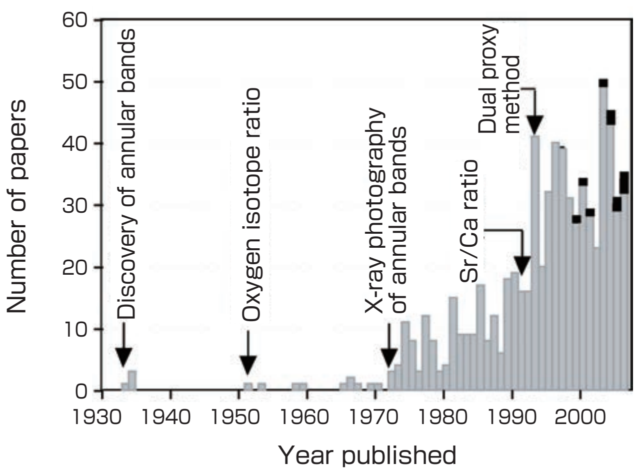

Fig. 3 Change in the number of papers on skeletal annular band of reef-building corals
From the number of papers listed in the Coral Banding Bibliography, AUSCORE on the website of the Australian Institute of Marine Science (http://www.aims.gov.au/pages/auscore/auscore-08.html). The papers contributed by AIST are marked as black bars.

ratio of the coral is a good index of the seawater temperature. For example, the oxygen isotope ratio of the corals from Ishigaki Island (Ishigaki-jima), the Ryukyu Islands corresponds well with the seawater temperature.[3]

For the coral skeletons, other useful indirect indices (proxies) have been found other than the oxygen isotope ratio. The strontium/calcium (Sr/Ca) ratio and uranium/calcium (U/Ca) ratio of the coral skeletons change according to seawater temperature only.

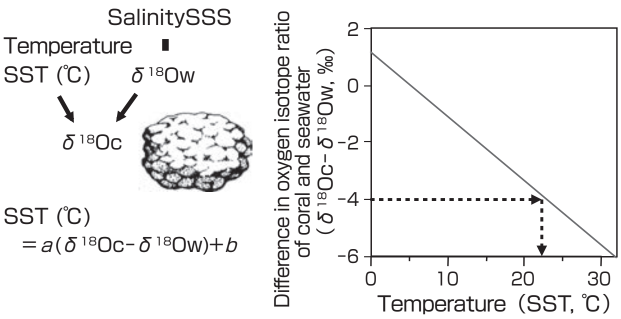

Fig. 4 Oxygen isotope ratio (δ^{18}Oc) of the coral skeleton and sea surface temperature (SST)
The oxygen isotope ratio is expressed as δ^{18}O by calculating the per mil (‰) of the isotope ratio (^{18}O/^{16}O) in the sample against the standard sample. The oxygen isotope ratio in calcium carbonate is expressed with a small letter c. By calculating the relational expression by comparing the oxygen isotope ratio of the surface of the coral colony and the seawater temperature observation record, the seawater temperature at that time can be estimated from the oxygen isotope ratio of the past skeletons. Strictly speaking, it is affected by the oxygen isotope ratio of seawater (δ^{18}Ow), but this can be neglected in the marine region with small variation in sea surface salinity (SSS). The salinity[Term 4] is expressed without units according to the convention of oceanography.

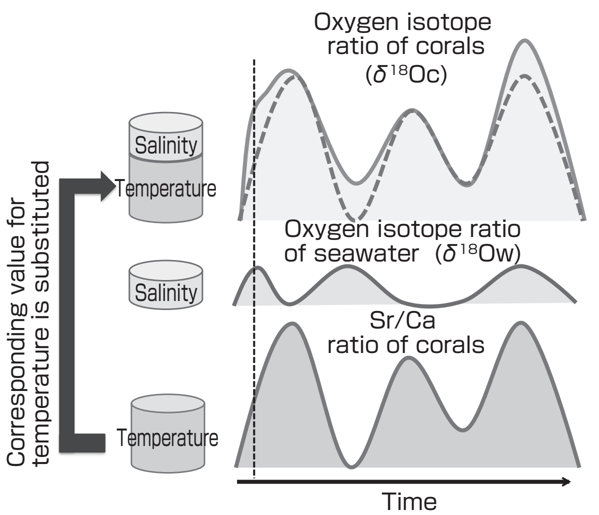

Fig. 5 Conceptual diagram of the dual proxy method using oxygen isotope ratio and Sr/Ca ratio of the coral skeleton
The reconstruction of the seasonal variation of temperature and salinity is presented.

The oxygen isotope ratio of coral skeletons is dependent on both the seawater temperature and salinity (more accurately, the oxygen isotope composition of seawater), while the Sr/Ca ratio is dependent only on temperature. Therefore, by estimating the temperature from the skeletal Sr/Ca ratio, and then subtracting the variation by temperature from the variation of the skeletal oxygen isotope ratio, the difference will indicate the variations of the oxygen isotope ratio composition of the seawater or the variations in salinity.[4] This is the dual proxy method using oxygen isotope ratio and Sr/Ca ratio of the coral skeleton (Fig. 5). The U/Ca ratio can also be used instead of Sr/Ca ratio.

3 Near past climate change in Ishigaki and Chichi Islands reconstructed from coral skeletons

The long-length coral research in the Northwestern Pacific region around Japan has not been done actively compared to overseas. Our research group conducts chemical analyses of the long columnar samples of *Porites* that are over 100 years old from Ishigaki Island (Ishigaki-jima,24° N, 124° E) of the Ryukyu Islands and Chichi Island (Chichijima, 27° N, 135° E) of the Ogasawara Islands (Fig. 6).

In the Pacific, a rapid change in the climate condition called the regime shift is known to occur,[5] and the event of 1988/1989 is notable in the Southern Ryukyus.[3] Before this regime shift, the seawater temperature during winter in the shallow waters of the coral reef of Ishigaki Island was sensitive to the Siberian High, and good correlation was seen with the monsoon index (pressure difference between Irkutsk and Nemuro) that indicates the strength of the monsoon. The

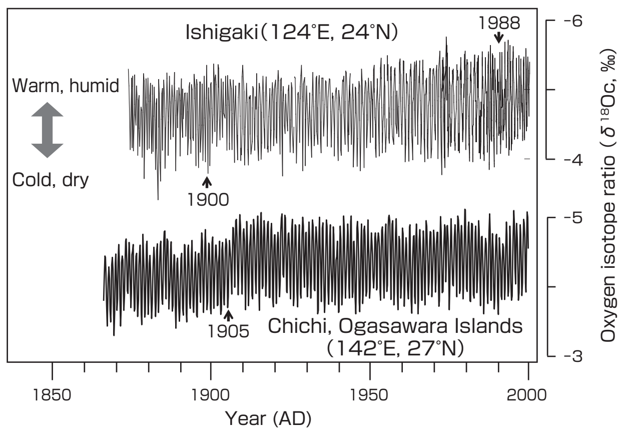

Fig. 6 Oxygen isotope ratio record of the coral skeletons collected from Ishigaki Island, Ryukyu Islands and Chichi Island, Ogasawara Islands[6][7]
The seasonal variations of temperature, etc. can be reconstructed at 1~2 month temporal resolution. The low temperature period at about 1900 for the Ishigaki coral discussed in this paper, the regime shift in 1988/89, and the salinity shift at around 1905 for the Ogasawara coral are marked with arrows.

oxygen isotope ratio of the Ishigaki coral skeletons in winter is determined by temperature, and the minimum winter temperatures reconstructed from the oxygen isotope ratio for 1971~1987 showed good correlation with the monsoon indices that express the strength of the seasonal winter winds. In contrast, the seawater temperature of Ishigaki after the regime shift decreased its correlation with the monsoon index. Instead the correlation with the southern oscillation index (SOI) became clearer than the monsoon index. This is an interesting phenomenon where Ishigaki that is categorized as the subtropical zone seemed to shift to the tropical zone. A period of low seawater temperature was observed in the coral sample from around 1900.[6] January 1902 was recorded as the winter with prevailing powerful Siberian Highs, and this was the year when the tragic incident occurred where the entire regiment of the Imperial Japanese Army was lost at Mt. Hakkoda during the winter training.

On the other hand, the reconstruction of temperature and salinity for about 130 years using the coral records at Ogasawara was the first true application of the dual proxy method[7] in the Northwestern Pacific region. For this coral sample, the U/Ca ratio, which is considered to be an excellent index of seawater temperature as in Sr/Ca ratio, was analyzed (Fig. 7). The good match of the reconstruction results of temperature and salinity by the combinations of oxygen isotope ratio and either the Sr/Ca or U/Ca ratio demonstrated the high reliability of the coral records (Fig. 8). The reconstructed seawater temperature corresponded with the Pacific Decadal Oscillation.[8] What was more interesting was that a rapid decline in salinity was observed around 1905-1910. The change in estimated salinity[Term 4] was about 1, and while the adequacy of scale remains under question, it was the most notable change in the coral records over 130 years. No sign such as diagenic alteration was observed in the skeleton during this period. The cause of salinity decrease at the beginning of the 20th century in Ogasawara was assumed to be caused by the decreased evaporation volume due to the weakening of the Ogasawara High caused by the decline of the westerlies at the time. The relationship with the low temperature event shown in the coral record of Ishigaki Island is also interesting.

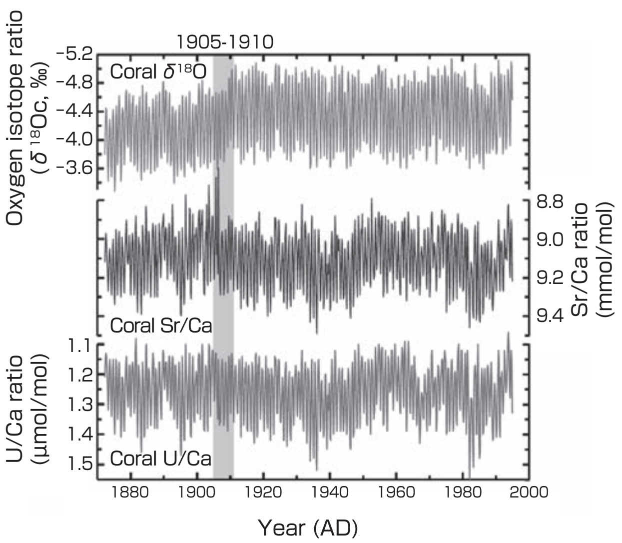

Fig. 7 Variation of oxygen isotope ratio, Sr/Ca ratio, and U/Ca ratio of the corals from Chichi Island, Ogasawara Islands[7]

The time from 1905 to 1910 when rapid increase in oxygen isotope ratio was seen is shaded.

4 Reconstruction of El Niño by fossil corals of the Pliocene Warm Period

El Niño phenomenon that occurs every few years in the equatorial Pacific region plays an important role in the current climatological system. With the progression of global warming, how will El Niño-Southern Oscillation (ENSO) change in the future? The *Fourth Assessment Report of the IPCC* predicts a frequent occurrence of powerful El Niños[9] but there is much opposition. The investigations of coral skeletons were conducted actively to address this issue.[1] Through the analysis of coral records over 500 years including the period before the Industrial Revolution, it was found that the strength of El Niño was correlated to the average seawater temperature, and El Niño was active as the temperature increased. This indicates that ENSO is affected by average global climate conditions, and implies the possibility that ENSO may change due to future warming. Also, correlation

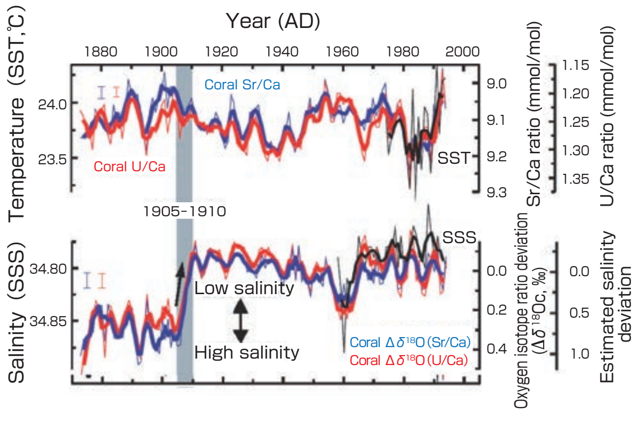

Fig. 8 Variations of sea surface temperature (SST) and sea surface salinity (SSS) reconstructed from the coral from Ogasawara Islands[7]

For salinity, the amount that contributed to the salinity variation of the oxygen isotope ratio calculated by dual proxy method from the coral skeleton is converted to salinity, by using the relationship of oxygen isotope ratio and salinity of the seawater in the Northwestern Pacific region (increase of salinity 1.0 equivalent to increase of oxygen isotope ratio 0.42 ‰). The deviation is labeled as estimated salinity deviation from the recent value (right axis). The results of the two combinations of oxygen isotope ratio with Sr/Ca ratio (blue line) and with U/Ca ratio (red line) are shown. The measured temperature and salinity are also shown (black line). The region of 1905 to 1910 when rapid decrease in salinity was observed is shaded.

was observed between the past seawater temperature and the strength of ENSO for the several warm periods observed during the Middle Holocene[Term 2] (about 6,000 years ago) and the Last Interglacial period (about 120 thousand years ago). These are in accord with the hypothesis that ENSO is affected by the average global climate conditions.

The Pliocene Warm Period at about 4.6 million to 3 million years ago is considered to be most similar to the climate condition that may be caused by global warming (Fig. 2a). Although the Jurassic and Cretaceous Periods of the Mesozoic Era,[Term 5] about one hundred million years ago when the dinosaurs existed, were also warm periods, the positions of the continents were totally different and simple comparison with the modern climate cannot be made. For the Pliocene Warm Period, a hypothesis has been proposed that the temperature gradient in the equatorial Pacific that caused El Niño disappeared, "permanent El Niño" where the seawater temperature of the entire region remained high occurred, and El Niño that occurred every few years ceased. On the other hand, there is a hypothesis that El Niño existed in the past, the temperature gradient between the east and west of Pacific increased, and El Niño occurred more powerfully and more frequently. The two hypotheses are based on the analysis of the core samples of the deep seafloor deposits with temporal resolution of several thousand years to several ten thousand years, and it was difficult to directly observe the El Niño phenomena that occur at several year intervals.

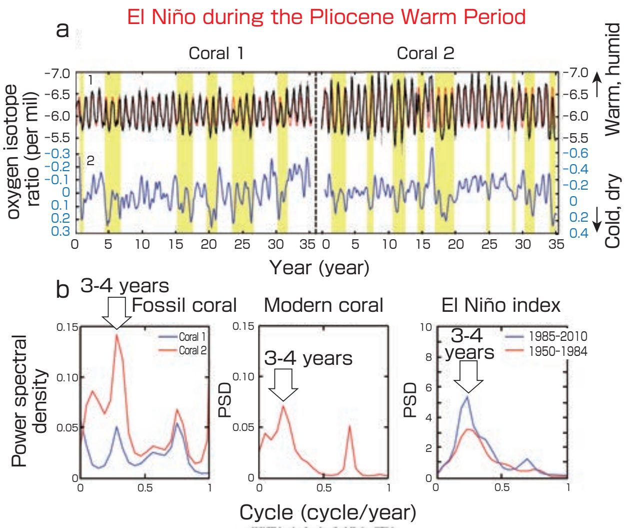

Fig. 9 (a) El Niño during the Pliocene Warm Period recorded in two fossil coral colonies[10]
This shows the annual variations for about 35 years for the two coral colonies (Coral 1 and Coral 2) in different periods about 3.5 million years ago. Black line is the variation of oxygen isotope ratio, red line is the seasonal pattern of average oxygen isotope ratio within the period, and blue line is the anomalies calculated by subtracting the average seasonal pattern from the oxygen isotope ratio variation. The period shaded by yellow color is estimated to be El Niño.
(b) Power spectral density[10]
The power spectral density shows at which cycle the variation is great in the chronological data, and offers a guideline for detecting the period variation ingredient. From left are the power spectral densities for oxygen isotope ratio of fossil corals (blue line = Coral 1; red line = Coral 2), oxygen isotope ratio of a modern coral, and El Niño index (Nino 3.4 index = anomalies for temperature of tropical Pacific; blue line = 1985~2010; red line = 1950~1984). There is a common peak at 0.3 cycle/year (3-4 year cycle).

The author's research group discovered well-preserved fossil corals from the strata that corresponded to the warm period in Luzon Island, the Philippines, and succeeded in analyzing and obtaining the record of seawater temperature variation that is the oldest direct evidence of El Niño.[10] The corals secrete aragonite skeleton, but with passage of time, this changes into stable calcite depending on the temperature and pressure conditions on the earth surface. Normally, after 100 thousand years, the production of unaltered coral fossils is extremely rare. However, in this stratum, the coral fossils are surrounded by mudstone that is an impermeable stratum, and this is effective in preserving the primary aragonite skeletons. The oxygen isotope ratio composition (index of temperature and salinity) was analyzed for the two colonies of coral fossils collected, and the seasonal variation of the atmosphere and marine environment for 70 years and the chronological variation patterns were extracted (Fig. 9a).

The marine region around the Philippines is strongly affected by El Niño, and it is known that the variation pattern of the oxygen isotope ratio of extant corals is an excellent record of the variation pattern of the current El Niño. When the results of analysis of the extant and fossil corals using the same method were compared, it became clear that the El Niño occurred at about the same cycle in the Pliocene Warm Period as the present (Fig. 9b).

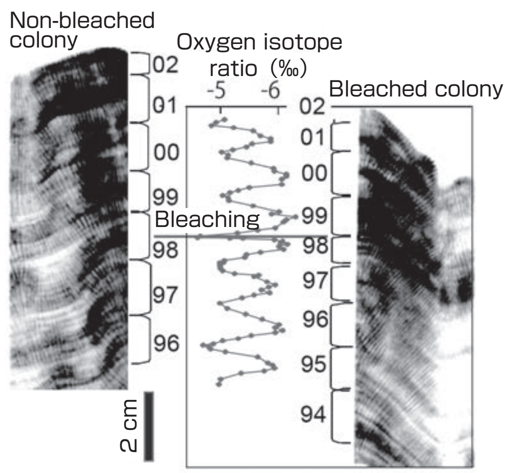

Fig. 10 Effect of large-scale bleaching event of August 1998 observed in the *Porites* skeleton of Ishigaki Island
The x-ray photograph of the skeletons of the bleached colonies and of those that did not undergo bleaching, and the oxygen isotope ratio profile along the growth axis of the bleached coral skeleton
The samples were collected in September 2002.

This result refutes the possibility of the permanent El Niño theory that states that El Niño will not occur in global warming which has been the major way of thinking. Also, it strongly indicates that El Niño will continue to persist on the warmed earth. This result will provide new hints to predict El Niño and its effects in the future global warming.

5 Coral bleaching phenomenon and decreased biological diversity of coral reef caused by abnormally high seawater temperatures

The coral bleaching phenomenon that occurred in the Great Barrier Reef of Australia in the southern hemisphere at the beginning of 1998 shifted to the northern hemisphere with the passage of seasons, and coral bleaching at a scale unseen before occurred in the coral reefs around the Ryukyu Islands in August 1998.[11] Although the biological and biochemical researches for coral bleaching were done actively particularly on the relationship between the coral and symbiotic algae, here, the focus will be on the coral skeletons. When the corals are bleached, what records are left in the skeletons?

In the coral reef off the coast of Yasurazaki in the east coast of Ishigaki Island, there is a massive colony consisting of three fused *Porites* colonies. It was observed that during the large-scale bleaching event in 1998, bleaching was seen in one colony while bleaching did not occur in the adjacent two colonies.[12] A jump that corresponded to the bleaching period was observed in the oxygen isotope ratio profile analyzed at high resolution along the growth axis of the skeleton, and this was interpreted as the halt of coral skeleton growth for a few months immediately after bleaching.[13] Columnar samples were collected again from these colonies in September 2002, four years after the large-scale bleaching event, and x-ray images were taken for observation. It can be seen that the growth speed significantly declined in the skeletons during 1998 only (Fig. 10). As the global warming progresses and high seawater temperatures occur frequently, the growth of coral skeletons is inhibited and the environment may become unsuitable for growth. On the other hand, if the high seawater temperature condition is resolved in a short time, some of the corals such as the *Porites* can recover from bleaching and may be able to survive. The evaluation of the effect of abnormally high temperatures on the coral and the coral reef ecosystem is an important research topic.

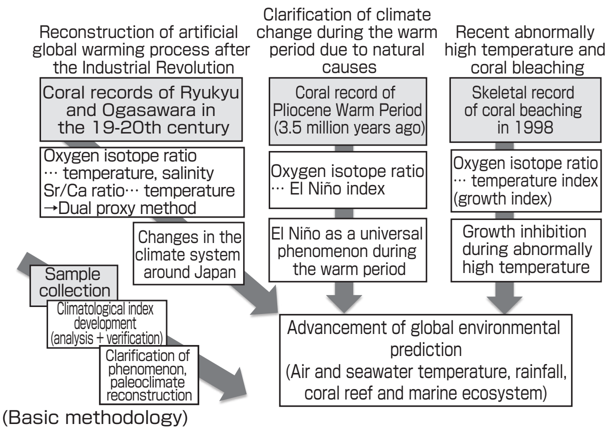

Fig. 11 Basic methodology of the coral skeletal climatology (lower left) and the development of three researches addressed in the paper

The meaning and interpretation of the indices used and the scenario of contribution to the final goal are presented for the three studies addressed in the paper, "Near past climate change of Ishigaki and Ogasawara reconstructed from coral skeleton," "Reconstruction of El Niño by fossil corals from the Pliocene Warm Period," and "Coral bleaching by abnormally high temperature."

6 Effect of marine acidification phenomenon on the coral reef

Marine acidification is recently gaining attention as a new global environmental issue.[14] The carbon dioxide released into the atmosphere by human activity migrates into the ocean to reduce the pH of seawater and the saturation of carbonates, and negatively affects the development of marine organisms and calcification of coral and foraminifers.[15][16] It is reported that in the skeletal analysis of the 328 colonies of *Porites* collected in 69 marine regions of the Great Barrier Reef, the calcification rate that had been stable for the past 400 years rapidly changed and decreased 14 % after 1990, and the relationship with marine acidification was indicated.[17] The boron isotope ratio (ratio of ^{11}B and ^{10}B) in the coral skeleton is an excellent index of seawater pH,[18] and the reconstruction of the changes in past seawater pH using the long-length coral samples and fossil corals is an important future topic of research. The analysis of boron isotope ratio is measured using the thermal ionization mass spectrometry (TIMS) or the multi-collector inductively coupled plasma mass spectrometry (MC-ICP-MS), and the introduction of such high-performance

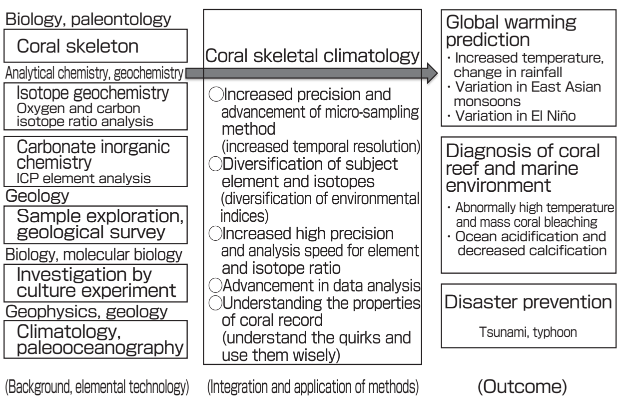

Fig. 12 Scheme of research development for coral skeletal climatology

This scheme shows the elemental technologies of the research, the basic fields, the integration of the methods that compose the body of the coral skeletal climatology and its application to the actual subject, and the social demands to which the outcome may contribute.

analysis devices is essential in the advancement of research.

7 Summary and future prospect

It was shown that the coral skeleton is excellent as a medium recording the past global climate changes, and that the attempts to read the record of climate change have advanced by using the state-of-the-art technology (Fig. 11). The necessity for coral skeleton research is expected to increase in the future as the global warming prediction becomes advanced. Also in the *Fourth Assessment Report of the IPCC*, the decrease in rainfall is predicted in the subtropical zone according to the climate model, but its accuracy must be raised.[9] The reconstruction of the past salinity oscillation that is closely related to rainfall, along with seawater temperature, is an immediate concern. This can be met by the composite index method using oxygen isotope ratio and Sr/Ca ratio as exemplified by the coral skeletons of Ogasawara. This method can be applied to fossil corals, and there is an example of investigation of coral fossils from the last ice age in the East China Sea.[19] The *Fifth Assessment Report of the IPCC* is scheduled for publication around 2013. Until then, it is necessary to promote the pH reconstruction by boron isotope ratio analysis and the analysis of climate change by the dual proxy method of oxygen isotope ratio and Sr/Ca ratio, and to reflect the results in the *Fifth Assessment Report*. Therefore, further promotion of coral skeletal climatology is needed.

On the other hand, there are points that need to be clarified, such as the basic mechanism of why the climatological factors such as seawater temperature are recorded in the chemical and isotope compositions of the coral skeletons.[20] In addition to the geochemical methods, it is necessary to conduct culture experiments[21][22] and molecular biological methods[23] to clarify the biological mechanism. The researches that transcend the conventional disciplines may allow application to the prediction and evaluation of calcification inhibition of marine organisms that may be caused by the future marine acidification (Fig. 12).

The 2011 off the Pacific coast of Tohoku Earthquake (Great East Japan Earthquake) occurred on March 11, 2011, and major damages occurred due to the tsunami to the Pacific coast of the Tohoku and Kanto regions. The re-evaluation of the past tsunami damages throughout Japan is an urgent issue. Particularly, the tsunamis of the Jogan Earthquake that struck the Tohoku region in 869 and of the Meiwa Earthquake that occurred in the South Ryukyu region in 1771 are gathering attention due to the similarities to the earthquake in 2011, in the height of the tsunami and the scale of casualties. The methods of coral skeletal climatology can be applied to disaster research by looking at the *Porites* boulders pushed ashore by the tsunami. The author's research group applied the radiocarbon dating method and the coral skeletal climatology method to the *Porites* boulders scattered on the east coast of Ishigaki Island, Southern Ryukyu, and demonstrated that these were washed ashore by the Meiwa tsunami.[24][25] The contribution to the research on the Meiwa tsunami, which was a historical earthquake-caused tsunami in the Okinawa region, has high social demand from the perspective of regional disaster prevention.

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Terminology

Term 1: Little Ice Age: the period of cold climate that occurred from about the mid 14th century to the mid 19th century. Concerning the degree of temperature decrease and regions, there is much that remains unknown.

Term 2: Holocene: the most recent of the geological time divisions (epoch) and includes the present age. It covers from about 10 thousand years ago when the last ice age ended to present.

Term 3: Pliocene: one of the geologic epochs of the Cenozoic Era. It covers the period from about 5 million years ago to about 2.58 million years ago. The first humans such as Australopithecines appeared during this epoch.

Term 4: Salinity: there is a long history of revisions of the analysis methods and expressions of the salinity of seawater.[26] "Practical salinity" was defined as the salinity measurement of seawater using electric conductivity became common, but this value is based on the conductivity ratio of the standard seawater and sample water, and is given no unit.[27] This expression is used widely to present. Recently, to precisely calculate the physical quantities such as the density of seawater from salinity, "absolute salinity," in which the weight of the dissolved matter is assessed accurately, had been proposed, and this is given the unit g kg^{-1}.[28] The conversion equation from "practical salinity" to "absolute salinity" has also been proposed. In this paper, practical salinity will be called salinity and handled as a quantity without unit.

Term 5: Mesozoic Era: a geological time between the Paleozoic and the Cenozoic Eras. It started about 250 million years ago and lasted till about 65 million years ago. The Mesozoic is composed of the Triassic, Jurassic, and Cretaceous Periods. This was the age of the dinosaurs.

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Discussions with Reviewers

1 Overall comment (1)

Comment (Shigeko Togashi, AIST)

This paper evaluates the effect of climate change caused by human activities necessary for the realization of sustainable society. To increase the prediction precision of the future, the paper shows that breakthroughs occur by the introduction of new geochemical indices in the analysis of past climate change left in the coral skeletons. The future direction is stated, and I think it is appropriate as a *Synthesiology* paper.

Please provide a diagram of outline that shows other topics in paleoclimatology addressed in IPCC, and indicate where the coral skeleton research is positioned in that realm. I also think you should clarify the relationships between the factors of climate change and the indices that comprise the elemental technologies to analyze those factors.

Answer (Atsushi Suzuki)

I added Fig. 2 to explain the various subjects used in the paleoclimate reconstruction and the positioning of the coral skeleton research. I also summarized the research materials and analysis methods used in paleoclimate reconstruction, other than those concerned with coral skeletons. I presented the reconstructed map of temperature (seawater temperature) for the entire targeted geologic time, and attempted to present the overall trend.

2 Overall comment (2)

Comment (Koh Naito, Center for Service Research, AIST)

This paper presents a synthetic approach that attempts a multifaceted modeling of a complex natural phenomenon by combining the data of careful chemical analysis. This approach is new, and in particular, the attempts to understand quantitatively the natural phenomenon, which used to be modeled qualitatively, was only started in the 1990s. I think this approach is expected to contribute greatly to the future society. In that sense, this area of study is highly interesting to the researchers and practitioners outside the geoscience field. Therefore, your effort of trying to use as few technical terms as possible greatly helps the readers.

In that sense, please create a table that provides supplementary explanation for the geologic time categories such as “Pliocene,” “Holocene,” “Mesozoic,” “Jurassic,” or “Little Ice Age,” to enhance understanding by the readers outside the field.

Answer (Atsushi Suzuki)

For the geological time category, I created a terminology section at the end of the paper to provide supplementary explanation. I added the descriptions in the text for “Little Ice Age,” “Holocene,” “Pliocene,” and “Mesozoic.”

3 Composition as a *Synthesiology* paper

Comment (Koh Naito)

To enhance overall understanding, I recommend that you create a single diagram that shows what the data used in the paper mean and their correlations, and add this to the end of the paper. Although the reader can understood the points as one reads through the paper, it will help the reader outside the field to read through and then review the overall argument and structure using such a diagram at the end.

Answer (Atsushi Suzuki)

I added new diagrams in the revision.

Figure 11 is an attempt to present the meaning and interpretation as well as the correlations of the data of the three studies addressed in the paper, “Near past climate change of Ishigaki and Ogasawara reconstructed from coral skeleton,” “Reconstruction of El Niño by fossil corals from the Pliocene Warm Period,” and “Coral bleaching by abnormally high seawater phenomenon." Figure 12 is a table that summarizes the scheme of the research development of coral skeletal climatology. I hope Figs. 11 and 12 will allow the readers to overview the overall structure of the coral skeletal climatology on which we are currently working.

4 Emphasis on the composite evaluation of various indices

Comment (Koh Naito)

When one reads your discussion, the understanding of the natural phenomenon is emphasized. To clarify the synthesiology as an integrated approach, I think you should emphasize the importance of accurately understanding the phenomenon by composite evaluation of various indices that you mentioned in the summarizing chapter.

Answer (Atsushi Suzuki)

As you mentioned, it is extremely important to evaluate the indices with advantages and disadvantages in a composite and integrated manner and to accurately reconstruct the past climates, in the paleoclimate reconstruction by geochemical method using coral skeletons. I emphasized this point in the introduction and the discussion.

5 Breakthroughs by the introduction of new geochemical index

Question (Shigeko Togashi)

The former Fig. 2 is a citation of AUSCORE, and I think it is a good graph that shows how breakthroughs occur by the introduction of new geochemical index. Can you add the contributions of the AIST research groups to this graph?

Answer (Atsushi Suzuki)

In the revision, former Fig. 2 became Fig. 3. I altered the histogram to show the papers of the AIST research groups.

6 Scale of past temperature variations recorded in the fossil corals

Comment (Shigeko Togashi)

To clarify the breadth of the past time scale, please show the approximate temperature changes after the Pliocene, where the observation of the temperature variations recorded in the modern corals can be applied to fossil corals.

Answer (Atsushi Suzuki)

I added the reconstruction diagram of the temperature for the entire geological time scale after Pliocene to the newly added Fig. 2a, and attempted to show the overall trend in an easily understandable manner. This temperature reconstruction was done by estimating the temperature differences with the current temperatures in the South Pole region, based on the oxygen isotope ratio of the carbonate shell of the benthic foraminifers obtained from the core samples of deep seafloor deposits. Therefore, please note that the absolute value of the temperature differences may differ greatly according to latitudes and regions.

Development of methane hydrate production method

- A large-scale laboratory reactor for methane hydrate production tests -

Jiro NAGAO

[Reprint from *Synthesiology*, Vol.5, No.2, p.89-97 (2012)]

Natural gas hydrates off the shores of Japan are valuable resources for the country. To utilize these resources, it is necessary to establish a gas production technology and investigate suitable conditions for extraction of methane from methane hydrate reservoirs. While core-scale dissociation experiments yield reproducible results on how methane hydrate dissociates under various conditions, a production test at a real gas field would provide information about the type of dissociation phenomena occurring in a geological reservoir field. The performance of natural gas production from methane hydrate reservoirs is dependent upon the size and characteristics of reservoirs, such as temperature and permeability. In other words, while a core-scale dissociation test in a laboratory can demonstrate the heat transport process, dissociation in an actual reservoir is dominated by the material flow process. Thus, I believe that it is important to couple data obtained from core-scale tests with the results of field-scale tests by using a large-scale laboratory reactor in which dissociation experiments can be conducted under similar conditions to the actual reservoir. In this paper, I report the goals of the Methane Hydrate Research and Development Program being conducted by the Ministry of Economy, Trade and Industry, Japan, and describe the research objective of a large-scale laboratory reactor for methane hydrate production tests at MHRC (Methane Hydrate Research Center) of AIST (National Institute of Advanced Industrial Science and Technology).

Keywords : Methane hydrate, the Methane Hydrate Research and Development Program, MH21 Research Consortium, gas production method and modeling, large-scale laboratory reactor

1 Introduction

In Japan, most of the fossil fuels used as primary energy sources are imported from overseas. As natural gas is a relatively environmentally clean energy resource compared with crude oil or coal, its demand is increasing worldwide. Methane hydrate is a crystalline material comprised of methane and water molecules under high-pressure and/or low-temperature conditions. The crystalline structure of methane hydrate is shown in Figure 1. Methane hydrate is naturally distributed in permafrost and subsea environments, which are believed to contain huge amounts of potentially extractable natural gas, of which methane is the main component (thus comes the term 'methane hydrate'). The existence of methane hydrate has been confirmed in offshore areas of Japan (Figure 2), particularly in the Nankai Trough, by means of observations made by bottom simulating reflectors (BSR).[1]-[3] Therefore, it is believed that methane hydrate will become a valuable domestic energy resource of Japan once its production technique is established. To this end, the Ministry of Economy, Trade and Industry (METI) launched the Methane Hydrate Research and Development Program, and the Research Consortium for Methane Hydrate Resources in Japan (MH21 Research Consortium) was established. In the eastern Nankai Trough area, sedimentary core samples were obtained by the MH21 Research Consortium aboard the research vessel JOIDES Resolution. Laboratory analysis of sedimentary core samples taken from the eastern Nankai Trough area revealed that the concentration of methane hydrates is very small and methane hydrates exist within the pore spaces of sandy sediments. Kida *et al.* summarized the chemical characteristics of these sediment samples.[4]

Fig. 1 Crystalline structure of methane hydrate
Water molecules form "cage" structures, and methane gas molecules are captured in the water cages.

Several methods have been proposed for recovering natural gas from methane hydrate reservoirs, including depressurization, thermal stimulation and inhibitor injection.[5] The depressurization method decreases the reservoir pressure

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below the equilibrium pressure of methane hydrate formation at the reservoir temperature. This method appears to be a cost-effective solution for producing natural gas from methane-hydrate-bearing layers.[6] On the basis of numerical simulations of gas productivity, this method is considered to be predictable and effective for producing gas from the reservoirs consisting of alternating layers of sand and mud. However, hydrate dissociation is a very complex process of coupling heat and mass transfers with the kinetics of hydrate dissociation. Therefore, to understand the dissociation process of methane hydrate existing within the pore spaces of sandy sediments, dissociation experiments on methane-hydrate-bearing cores in a laboratory would be useful.[7]-[10]

The performance of gas production strongly depends on the size and permeability of the samples. Heat transfer is a predominant factor in dissociation experiments on methane-hydrate-bearing cores performed in a laboratory (of the order of a few centimetres), whereas mass transfer dominates the dissociation process in an actual reservoir field (of the order of a few 100 m). This difference in the dominant factors between core-scale experiments and field-scale production is responsible for the difference in gas production behaviours. To overcome this problem and to establish gas production conditions at a reservoir field, it is necessary to conduct methane hydrate sedimentary core production experiments on a larger scale. Thus, AIST recently developed and introduced a large-scale apparatus for methane hydrate laboratory production tests, which can conduct gas production experiments under conditions similar to those at actual natural methane hydrate reservoir fields. In this paper, I first present an overview of the Methane Hydrate Research and Development Program.[11] Then I describe the problems in conducting research issues such as methane hydrate production experiments at a laboratory scale, actual field production tests and numerical prediction of productivity, and finally, I report the advantage and certification of a large-scale reactor developed recently to overcome such problems.

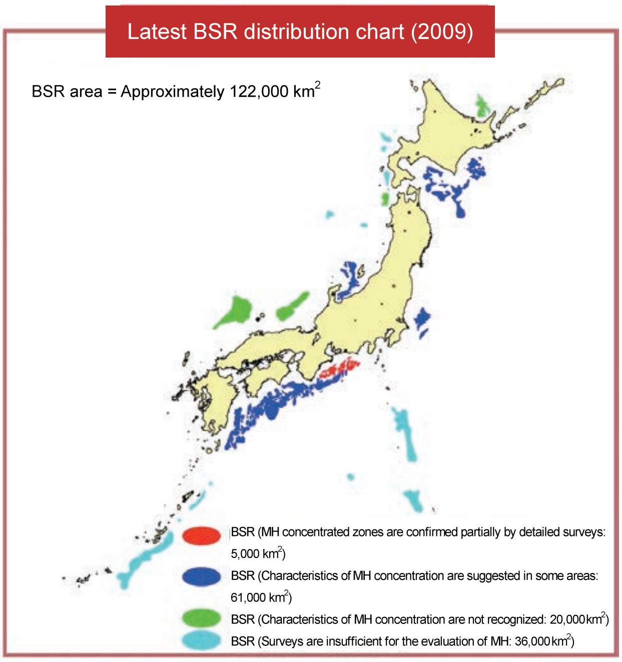


Fig. 2 Methane hydrate distribution off the shores of Japan calculated by observing bottom simulating reflectors

Red: MH concentrated zones are confirmed partially by detailed surveys (5,000 km^2), Blue: Characteristics of MH concentration are suggested in some areas (61,000 km^2), Green: Characteristics of MH concentration are not recognized (20,000 km^2) and, light blue: Surveys are insufficient for the evaluation of MH (36,000km^2). Total BSR area is approximately 122,000 km^2. (Copyright@MH21 Research Consortium)

2 Overview of Japan's Methane Hydrate Research and Development Program

The Methane Hydrate Research and Development Program has a three-phase approach.[11] At the starting period of this program, since AIST had high potential in gas hydrate chemistry, the Methane Hydrate Research Laboratory (now Methane Hydrate Research Center: MHRC) joined as a conducting member of research on the production method and modeling. In phase 1, from FY 2001 to 2008, the MHRC performed laboratory experiments on methane-hydrate-bearing cores taken from the eastern Nankai Trough, where the methane hydrate reservoir consists of alternating layers of sand and mud. The experiments showed that methane hydrate existed within the pore spaces of sand layers. Details of physical properties such as absolute permeability, porosity, methane hydrate saturation, thermal conductivity and sedimentary strength were also obtained. To evaluate gas production performances from methane hydrate reservoirs, a numerical production simulator called MH21-HYDRES was developed. Through laboratory experiments and numerical simulations using MH21-HYDRES performed by the MHRC, MH21 Research Consortium revealed that the depressurization method was determined to be the optimal production method for use in a methane-hydrate-bearing layer, which is the main sedimentary structure in the eastern Nankai Trough. For the first time, the validity of the depressurization method was verified by means of an onshore gas hydrate production field test conducted in March 2008 in a permafrost zone in Canada.

In phase 2, from FY 2009 to 2015, the use of methane hydrate extracted off the shores of Japan will be evaluated as a highly reliable energy resource. In addition, although it has been known that the depressurization is a useful method for gas production from methane hydrate reservoirs by laboratory characterization of core samples, the technical difficulties of commercializing gas production from methane hydrate reservoirs will be studied, where the commercialization will be inducted by public and private sectors in phase 3 from FY 2016. The MH21 Research Consortium has set up four research groups: the Research Group for Field Development Technology, the Research Group for Production Method and Modeling, the Research Group for Resource Assessment and the Administrative Coordination Section. The Research Group for Field Development Technology, coordinated by the Japan Oil, Gas and Metals National Corporation (JOGMEC), will implement offshore production tests, characterize the methane hydrate resource field, investigate offshore development systems, analyze the findings of a second onshore gas hydrate production test and implement long-term tests. The Research Group for Resource Assessment coordinated by JOGMEC will evaluate methane hydrate distribution off the coast of Japan and investigate methane hydrate systems. Within the Administrative Coordination Section, an R&D team that assesses environmental impacts has been organized to analyze environmental risks and investigate appropriate countermeasures, develop technology to measure the environmental impact, assess environmental impacts in offshore production tests and make a comprehensive assessment of the environment and optimize the assessment methods used for developing methane-hydrate-bearing layers.

The MHRC at AIST coordinates the Research Group for Production Method and Modeling. The aim of this group is to establish an economical and efficient gas production method by developing technologies for advanced production methods, evaluating technologies for productivity and production behaviour and evaluating technologies for sedimentary characteristics. Research activities related to each of these R&D issues are described below.

(1)Development of technologies for advanced production methods

As mentioned above, the depressurization method can be applied to a methane-hydrate-bearing layer consisting of alternating layers of sand and mud. In such a case, the higher the initial reservoir temperature, the higher the rate of methane gas production and recovery.[12] As gas hydrate dissociation is an endothermic reaction, the gas production rate gradually decreases as the reservoir temperature decreases. Therefore, to guarantee continuous gas production by maintaining reservoir temperature at a certain range, the development of a combined production method coupling depressurization with the other production methods is being investigated. Furthermore, to ensure long-term stable methane gas production, factors that reduce permeability of the methane-hydrate-bearing reservoir should be quantitatively analyzed, e.g. impact of sand production,[13] skin formation and flow obstructions resulting from methane hydrate reproduction.

(2)Development of evaluation technologies for productivity and production behaviour

In order to provide reliable predictions of productivity and production behaviours for various reservoir characteristics, the MH21-HYDRES production simulator will be upgraded. To enhance the sensitivity and accuracy of gas production behaviour, analytical models and/or routines relating to issues such as permeability of the reservoir, thermal characteristics and consolidation properties will be developed.[14] To evaluate production damage, the calculation parameters will be justified through the verification of onshore gas hydrate production tests and offshore production tests. To evaluate production behaviours in a wide area and over a long-term period, three-dimensional reservoir models that consider discontinuity, faults and heterogeneity of the reservoirs will be developed and loaded into MH21-HYDRES. On the basis of these results, a comprehensive evaluation of the production method will be performed and an optimized economical system according to the reservoir characteristics will be developed.

(3)Development of evaluation technologies for sedimentary characteristics

To assess environmental impacts such as the stabilization of production wells, the probability of landslides and the risk of methane gas leakages from methane-hydrate-bearing sediment layers during gas production, evaluation routines called COTHMA will be developed for the sediment deformation simulator. Through a comprehensive evaluation of the mechanical properties of deep-water unconsolidated sedimentary layers by using COTHMA, the geo-mechanical stress around wells and border areas as well as long-term sediment deformation will be ascertained.

3 Development of a large-scale laboratory reactor for methane hydrate production test

To commercialize gas production from a methane hydrate reservoir, the technical issues described above need to be investigated. In addition, optimal production conditions that are adaptive to prevailing methane hydrate reservoir characteristics need to be ascertained. For this purpose, production tests in reservoir fields, core analyses and predictions of gas production and geo-mechanical properties obtained using MH21-HYDRES and COTHMA will yield important results, particularly when coupled with the results of investigations of the methane hydrate reservoir structure. Field production tests will yield real productivity data on real methane hydrate reservoirs, which will enhance the accuracy of numerical simulators. However, it is difficult to conduct reproducible tests under various production conditions. Numerical simulations can provide a prediction of the productivity and the stability of a methane hydrate sedimentary layer. In addition, by introducing parameters into the numerical calculations, suitable conditions of gas production for various reservoirs can be predicted. However, these parameters are obtained from methane-hydrate-bearing core analyses, and the obtained results will be evaluated and fine-tuned through comparisons with results from the real field production tests. A dissociation experiment on methane-hydrate-bearing cores in a laboratory is useful for determining chemical and structural properties and understanding dissociation behaviour of methane hydrate distributed within pore spaces. However, because of the size of methane-hydrate-bearing cores (of the order of a few centimetres), heat transfer becomes a predominant factor. As mass transfer dominates the dissociation process in an actual reservoir field, the difference in dominant factors between core-scale experiments and field-scale production would result in a difference in gas production behaviours. As mentioned above, these R&D concepts have advantages and disadvantages and are closely related to each other, as shown in Figure 3.

To overcome the above problems, AIST developed a large-scale laboratory reactor for methane hydrate production tests. Especially, to design this reactor, we have focused on solving the problem of predominant factors on hydrate dissociation, and a numerical analysis by MH21-HYDRES has been performed.[15] From this analysis, we cleared that mass transfer dominates the dissociation process for sandy sample having over 1m-size. Furthermore, taking into account the research activities of the Research Group for Production Method and Modeling, the reactor was designed by considering the technical issues, as presented in Figure 4. As stated above, three main research activities need to be conducted by the Research Group for Production Method and Modeling. Although it has been determined that the depressurization method is economically suitable for gas production from methane hydrate reservoirs off the shores of Japan, detailed conditions and procedures for depressurization remain unknown. Thus, AIST designed the large-scale laboratory reactor to aid the development of technologies for advanced production methods and to analyze the impact of sand production, skin formation, and flow obstructions. To achieve these goals, in the reactor, highly sensitive temperature and pressure sensors with a wide range and fluid flow metres are arrayed to examine a range of production conditions so that a higher gas production rate and a higher recovery rate can be obtained. To evaluate the sand production phenomenon, a sand screen is fitted to a well tube. The overall volumes of the high-pressure vessel and line tubes are estimated to reduce data error enabling comparison of the results with those of numerical predictions obtained by MH21-HYDRES. Thus, evaluation of mechanical properties can be avoided. To verify the deformation of sandy samples during gas production, it is necessary to position mechanical sensors at many locations for measuring changes in stress and confinement pressure. For this purpose, holes need to be configured in the sides and bottom of the vessel, which is a complex task.

A schematic diagram of the large-scale laboratory reactor is shown in Figure 5. The steel high-pressure vessel has an inner diameter of 1000 mm and a height of 1500 mm. The vessel consists of three chambers, and its volume and weight

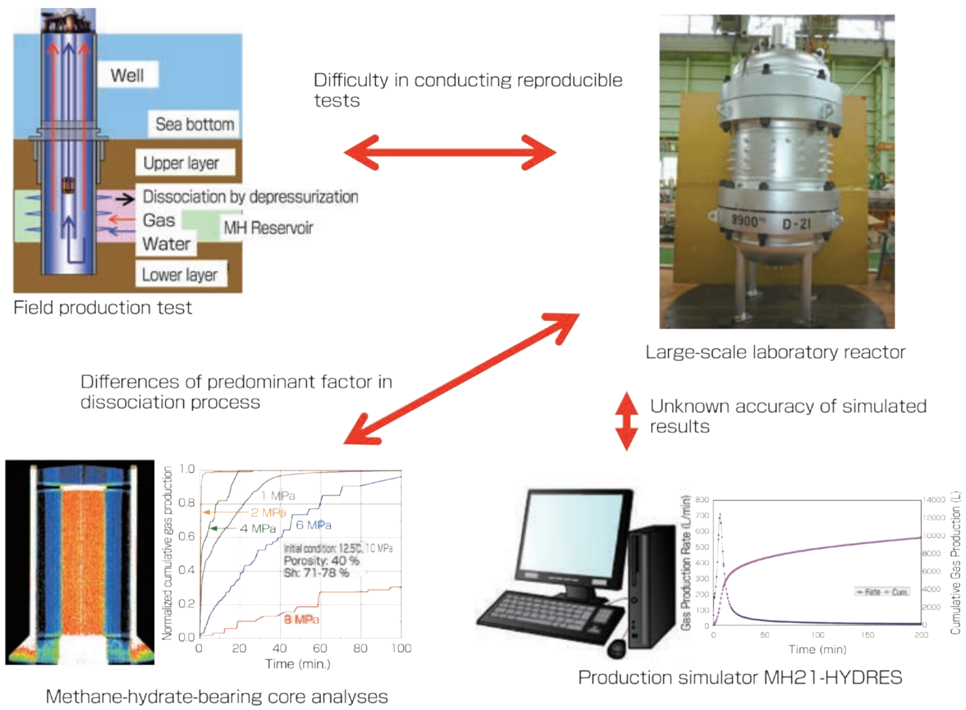


Fig. 3 Large-scale laboratory reactor for resolving disadvantages of production tests, core analyses and production simulations
These issues are the main research concepts for establishing gas production methods and evaluating conditions in methane-hydrate-bearing layers.

are 1710 L and 9900 kg, respectively. This is four times larger than the large-scale production reactor LARS developed by the SUGAR Project in Germany.[16] The objective of the SUGAR Project is to clarify the characterization of CO_2 geological storage and methane gas production using the reaction heat of CO_2 hydrate generation in the methane hydrate reservoir. Our vessel can be loaded with core samples of sand with a diameter of 1000 mm and a length of 1000 mm. An inner plate is placed on top of the methane hydrate sedimentary sample to exert an overburden pressure of up to 16.5 MPa; this pressure is similar to that in a subsea environment. The overburden pressure is supplied by injecting water into the space between the upper chamber and the inner plate. A production well is simulated using a steel pipe with a diameter of 100 mm and a length of 1000 mm with 32 holes drilled along its length; the pipe is placed at the centre of a sandy sample layer. A sand screen can be placed over the holes to terminate sand production. A total of 50 holes in the sides and 19 holes in the bottom of the vessel are provided to allow the insertion of gas, water and temperature and pressure sensors. The position of sensors can be adjusted depending on the characteristics of the sand sample and the production conditions. To simulate conditions of a methane hydrate reservoir at the eastern Nankai Trough area, the vessel is placed in a large cabinet that can control the temperature of the high-pressure vessel from −5 to 20 °C.

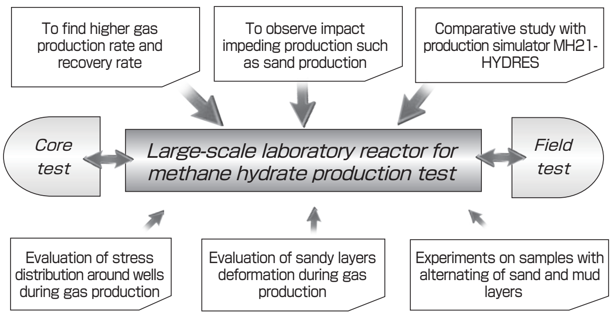


Fig.4 Relationship between the experimental issues on large-scale laboratory reactor and the roles of research teams of the Research Group for Production Method and Modeling

Evaluation of production behaviours such as (1) enhancement of production rate and recovery rate and (2) analysis of impact impeding production are the main experimental issues on a large-scale laboratory reactor. Also, various production conditions to obtain a higher gas production rate and recovery rate can be examined. The experimental results are compared with those from small scale core experiments and analyses of MH21-HYDRES, which is a numerical model of a large-scale laboratory reactor. Finally, the results will be compared to production results of real field tests which will be held in FY2012. However, research regarding geo-mechanical characterization has not been conducted. To achieve relatively uniform methane hydrate formation within the pore spaces of a sandy sample, the positions of the perforations cannot be adjusted for experiments on samples with alternating layers of sand and mud.

Holes in the sides and bottom of the vessel for the insertion of gas and water are connected to a CH_4 gas supplier and pumps that supply pure water into the sandy sample layers, respectively. The production well is connected to a gas and water separator. Real-time observations of the rate of the production of gas and water as well as the amount of fine sand particles can be performed under various temperature and pressure conditions.

Pure water is injected into the high-pressure vessel via the holes in the sides of the vessel and the centre pipe. Once the designated amount of pure water has been filled in the vessel, sand particles are added to the pure water, and vibration is applied to ensure homogeneous accumulation of sand particles. After the vessel is filled with wet sand particles, the inner plate is positioned above the sand sample layer, and the top chamber is closed. Pure water is injected into the interior of the top chamber to apply overburden pressure to the sandy sample layer by pressurizing the inner plate. To adjust the water content, water in the sandy sample layer can pass through the holes in the bottom of the vessel.

For the formation of methane hydrate in the sandy sample layer and control of the confinement pressure, the flow rate of CH_4 is adjusted. CH_4 is continuously supplied via holes in the sides of the vessel. The temperature of the cabinet is decreased below the equilibrium temperature of methane hydrate formation. By calculating the injected volume of methane gas and the initial water content, the end of the methane hydrate formation can be estimated. After methane hydrate formation, pure water is injected into the pore spaces of the sandy sample layer because natural gas hydrate reservoirs are usually saturated with water.

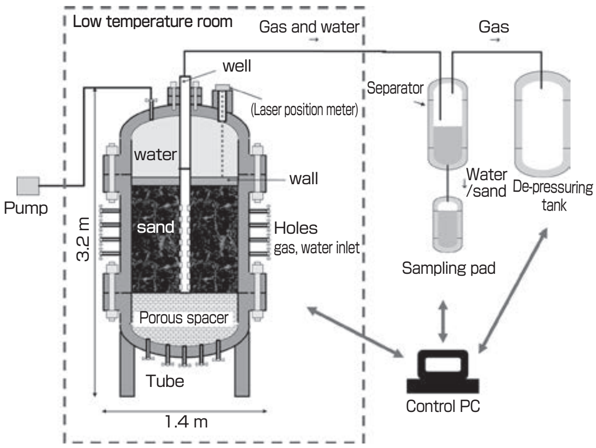
The top of the centre pipe is connected to a backpressure regulator. To examine the depressurization method, the pressure value of the regulator is adjusted to a designated pressure. After adjustment, gas and water flow out through the centre pipe, which may contain fine sand components. The centre pipe is connected to the gas-water separator, and each line tube is connected to a fluid flow metre that measures water and gas volumes during the experiment. To evaluate the sand production phenomenon, a water flow line is connected to the accumulation chamber to collect the fine sand particles.

Figure 6 shows the predictions of water and gas production by the MH21-HYDRES production simulator using the results of depressurization experiments conducted in the large-scale laboratory reactor. The results show the water and gas production behaviours when pressure is decreased from 10 to 3 MPa. The parameters for the numerical simulation were temperature of 10 °C, pressure of 10 MPa, permeability of sandy sample layer of 1000 mD,[17] initial effective permeability of 26 mD,[Term1] hydrate saturation of 60 % and water saturation of 40 %. From these results, gas production shows a peak during the first period, indicating that mass transfer is predominant in the dissociation process. Gas production experiments conducted using depressurization to ascertain the relationship between the degrees of reduction in pressure and the gas production rate have been underway. The obtained results will be compared with those obtained from a numerical simulation study conducted using the MH21-HYDRES production simulator. This study will contribute to the first field production test to be conducted off the shore of Japan in FY 2012.

Acknowledgements

This study was financially supported by the Research Consortium for Methane Hydrate Resources in Japan (MH21 Research Consortium) to carry out the Methane Hydrate R&D Program conducted by METI. I thank Dr. Hideo Narita, Dr. Yoshihiro Konno, and Dr. Hiroyuki Oyama of AIST for their valuable suggestions in the preparation of this manuscript.

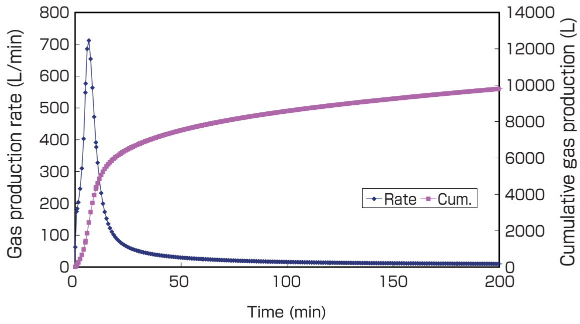
(a) High-pressure vessel of the large-scale laboratory reactor



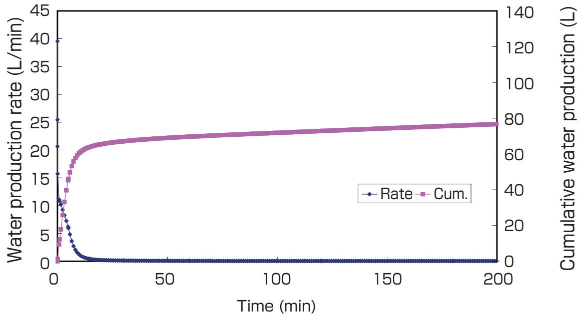
(b) Schematic flow diagram of the large-scale laboratory reactor

Fig. 5 Schematic illustrations of the large-scale laboratory reactor

To aid the development of technologies for advanced production methods and to analyze the impact of sand production, skin formation and flow obstructions, the highly sensitive temperature and pressure sensors with a wide range and fluid flow metres are arrayed to side holes of the vessel. To evaluate the sand production phenomena, a sand screen is fitted to a well tube. Water and fine sand are collected in a sampling pod arrayed to the water/gas separator. The overall gas volume is measured at de-pressuring tank arrayed to the water/gas separator. All measured data were collected in a PC automatically.



(a) Gas production behaviour



(b) Water production behaviour

Fig. 6 Predictions of gas and water productions based on depressurization experiments in the large-scale laboratory reactor using the MH21-HYDRES production simulator

A peak during the first period in gas production behaviour indicates that mass transfer is predominant in the dissociation process.

Terminology

Term 1. Darcy (D): a traditional unit for permeability. The SI unit for pearmeability is m^2. 1D is ca. 10^{-12} m^2.

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Discussions with Reviewers

1 General construction of the manuscript

Comment (Hiroshi Tateishi, AIST)

For the development of the gas production technology from methane gas hydrate reservoirs, this manuscript first explains the overview of Japan's Methane Hydrate Research and Development Program, and then the development of the apparatus for methane hydrate production tests carried out by the author is described. The construction of the manuscript is rather unusual, because the experimental results from the apparatus have not yet been obtained at present. In spite of this fact, the manuscript is acceptable after revision because publication of such type of manuscript is requested from the outside. From the standpoint of the journal, *Synthesiology*, the manuscript lacks issues as pointed out in the following comments. From the viewpoint of "synthesis," there is a dual structure of synthesis: one is micro-level technology synthesis to integrate elemental technologies toward the development of the apparatus which is the main purpose of the present manuscript, and the other is macro-level system synthesis to integrate the results obtained with the apparatus toward the development of the production system. For the revision of the manuscript, please take these points into consideration.

Answer (Jiro Nagao)

Concerning the development of a large-scale laboratory apparatus for the optimization of production conditions toward commercial utilization of methane hydrate, the outline of the program, the R&D issues of the Research Group for Production Method and Modeling of MH21 Consortium coordinated by the MHRC at AIST, and the important issues to be analyzed with this apparatus have been described. In response to the reviewer's comments, the author has added and revised the description in the text and the reference. However, the development of the production system depends not only on the production method, but also on the economic evaluation of methane production including the combination of machines in production tests at the sea bed conducted by JOGMEC. Thus, it is difficult to consider the validity of the production system based only on the tests with the large-scale apparatus. Therefore, the author has not described the development of the production system in this paper.

2 The role of MHRC

Comment (Hiroshi Tateishi)

In the latter half of "2. Overview" section, the goals of R&D issues in phase 2 at MHRC are explained. However, the description is sudden and difficult to understand for the readers since the relevance of phase 2 with phase 1 is not explained. Brief explanation for the following points is required: why MHRC is assigned for this part of R&D, what kind of results MHRC obtained in phase 1, and how the results obtained in phase 1 are connected to phase 2.

Answer (Jiro Nagao)

The author has added the following explanation. At the start of the program, the Methane Hydrate Research Laboratory of AIST (the present Methane Hydrate Research Center) participated in the MH21 Consortium as the research supervisor of R&D of production method & modeling in phase 1 since the laboratory had high level knowledge on methane hydrate engineering. The foregoing explanation has been connected to the subsequent description of implementation challenges and the research results. It has been found that depressurization is effective for the gas production method from the methane hydrate resource as a research result in phase 1. The finding is linked to the research purpose of phase 2 (technology advancement toward commercialization).

3 Development of 1m-size test apparatus

Comment (Hioshi Tateishi)

1. I can understand the logic that thermal decomposition is dominant in cm-size samples whereas mass transfer is dominant in the actual 100m-size bed, therefore a test filling the gap in between is required. Yet it is difficult to judge the adequateness of the specifications of the apparatus since no quantitative explanation is given on the scale boundary that separates the dominant factors. It seems difficult to set a strict boundary, but explanation is required such as, "Since critical scale is around this level because of such and such reasons, a 1m-size apparatus is adequate enough."

2. Since the explanation of the specifications of the apparatus is simply listed, it is not clear where the focus is. For example, if the author arranges the explanation in the order of main items to test with the apparatus, technological issues and required functions to achieve the issues, the ways to clear the issues, the readers can understand the idea more easily. Especially, the manuscript lacks the explanation of originality of the MHRC.

3. The author briefly explains the large-scale production apparatus LARS developed by the SUGAR Project in Germany. Since only the size is mentioned, it is difficult to understand the significance of the comparison. Please describe the purpose and design concept of the LARS and explain the difference of the two apparatuses, LARS and the apparatus of MHRC.

Answer (Jiro Nagao)

1. In order to design our apparatus, we have focused on solving the problem of predominant factors of hydrate dissociation. The sample size dependence of the rate-determining step has been investigated by using the production simulator, MH21-HYDRES. Another study shows that in the case of permeability of 10 mD order, the mass and heat transfers become comparable at the sample size of 0.5 m (Konno *et al*. Proc. Offshore Technology Conference 2010, 20591 (2010)). On the basis of the study and the analysis, we have judged that mass transfer dominates the dissociation process with an apparatus of over 1m-size. We have added the explanation in lines 3-8 on page 93 and reference No.15.

2. On designing the apparatus, we have set the most important R&D issues to be investigating the dependence of productivity of the depressurization method on the permeability of the sample and finding the most suitable depressurization conditions, and analyzing quantitatively the impact of sand production, skin formation, and flow obstructions. The explanation of the functions prepared to clear the issues, their technological issues and the ways to clear the issues have been added to the manuscript.

3. It was described in a paper that the objective of the SUGAR Project is to clarify the characteristics of CO_2 geological storage and that the apparatus was introduced to carry out the methane hydrate decomposition using the reaction heat generated in the formation of CO_2 hydrate. The explanation of the objective has been added to this manuscript. However, the author has not obtained the accurate information on the design concept of the apparatus and cannot explain it.

Toward the integrated optimization of steel plate production process

— A proposal for production control by multi-scale hierarchical modeling —

Kiyoshi NISHIOKA[1,4] * , Yasushi MIZUTANI[2], Hironori UENO[3], Hirofumi KAWASAKI[1] and Yasunori BABA[4]

[Translation from *Synthesiology*, Vol.5, No.2, p.98-112 (2012)]

Integrated optimization of production in the steel industry to simultaneously minimize lead time and improve productivity is a real challenge. Lean manufacturing, recognized as a leading successful example of such optimization, is characterized by synchronization of time scale of production with that of the mainline. However, in the steel industry, it is inherently difficult to implement synchronization and reduction of production time to the same degree as in the automobile industry. This difficulty motivated our method for integrated optimization of production at the plant level in the steel industry, by modeling the production control as a multi-scale hierarchical structure in time. This paper describes an attempt to systematize production knowledge in industry by a synthesis of practical knowledge (of shop-floor engineers) and company experiences.

Keywords : Steel industry, integrated optimization, production control system, multi-scale hierarchically structured model, lean production system

1 Introduction

Integrated optimization in production control for manufacturing an unlimited variety of products with zero defect, using minimum resources, in the minimum manufacturing lead time[Term 1] and with zero stock, is the ultimate goal of *monozukuri* (manufacturing). Generally, production control is classified largely into pull- and push-types.[1][2] The pull-type production control is used for the type of manufacturing for which in upstream processes optimal parts and intermediate goods are provided sequentially to the requirement of downstream processes or customers and is applicable to assembly industries. One such industry is the automobile industry, which gave birth to the lean manufacturing system, one of the major successes of the 20th century. In contrast, in push-type production control, instructions for production are given to feed parts and intermediate goods starting from the entrance of processes and to channel them from the upstream processes to those of downstream. It is applicable to many industries including process industries such as steelmaking and chemical. The issue here, where push-type production control is concerned, is how the integrated optimization of production can be achieved, while simultaneously realizing the minimization of manufacturing lead time and the improvement of efficiency (productivity).

This paper analyzes examples of relevant cases of Kimitsu Works of Nippon Steel Corporation, and studies how the concept or methodology of the lean production system originally derived from pull-type production control is made applicable to the manufacturing processes of the steel industry that has a process structure suited to push-type production control. In the Plate Mill of Kimitsu Works, the production control system was remodeled to realize integrated optimization in a process industry resulting, in the early 2000s when demand rose sharply due to the rapid expansion of the Chinese economy, in a substantial shortening of manufacturing lead time thanks to the reduction of in-process stock (Fig. 1) and in the faster expansion of production compared with other plate mills in Japan (Fig. 2). How could optimization at the level of the entire plate mill be achieved, where the manufacturing flow is complex and the constraint hurdles are quite high? This paper explains how the innovation of the production control system on the shop floor was realized, and what the steel industry, a process industry, can learn from the lean production system, by identifying and modeling the realized production control system as a multi-scale hierarchical structure.

2 Manufacturing of steel plates

The manufacturing processes in a steelworks[Term 2] consist of producing pig iron at the blast furnace that consumes raw materials of iron ore, coal, etc., then producing steel by refining iron at the converter. Steel thus produced is molded into slabs (oblong sheets of steel) on the continuous casting

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line, and rolled to become steel plate products. Steel plates are produced based on orders received and on elaborate production planning. Each plate weighs about 3 tons and is manufactured from a large lot of 300 – 400 tons per one converter vessel by dividing them into small tonnage for each plate. Steel plates as products are used widely as important components of various structures including ships, buildings, bridges, construction/ industrial machinery, offshore structures for drilling offshore oil/ liquefied natural gas, etc., and they must comply with a huge variety of standards. They have characteristics that differ from other steel products. For example, their places of use are rigorously specified and each one of them is delivered in a particular specified size.

Steel plates are manufactured based on orders received and the orders are diversified and small in each lot, which explains why their manufacturing processes are complicated. First of all, in the rolling processes, plates of various sizes are manufactured, and during these processes, their metallurgical microstructure is controlled to meet varieties of specifications in their material properties. After rolling, in the finishing processes, various works are conducted including the correction of defects occurring in the upstream processes and supplementary treatments (heat treatment, coating, etc.).

By incorporating material quality (*Tsukurikomi*) during the rolling process, the thermo-mechanical control process (TMCP) was developed in Japan during the 1980s and for the 30 years that followed, TMCP played the role of one of the state-of-the-art core technologies for manufacturing high quality steel plates in Japan. The schematic illustration of the steel plate rolling processes is illustrated in Fig. 3.

TMCP enables the production of as-required steels of whichever microstructure and property by controlling the

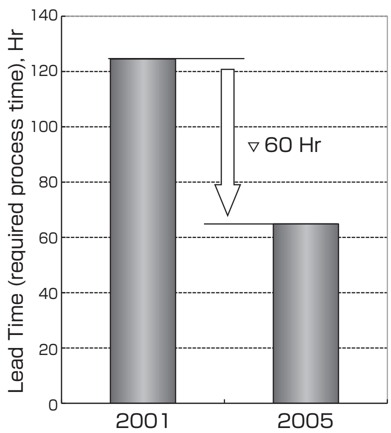

Fig. 1 Shorter production lead time in the Plate Mill of Kimitsu Works

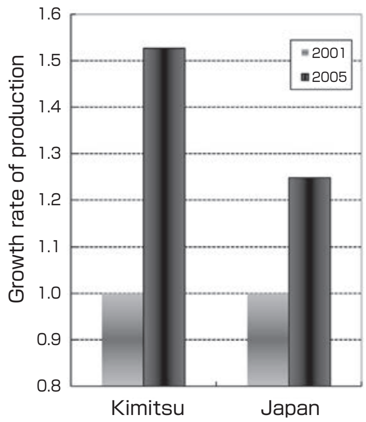

Fig. 2 Comparison of production growth rates of plate mills in Japan
(Source: Monthly Steel Statistics Report of Secured Orders of Steel Products (ordinary and specialty steel products), The Japan Iron and Steel Federation)

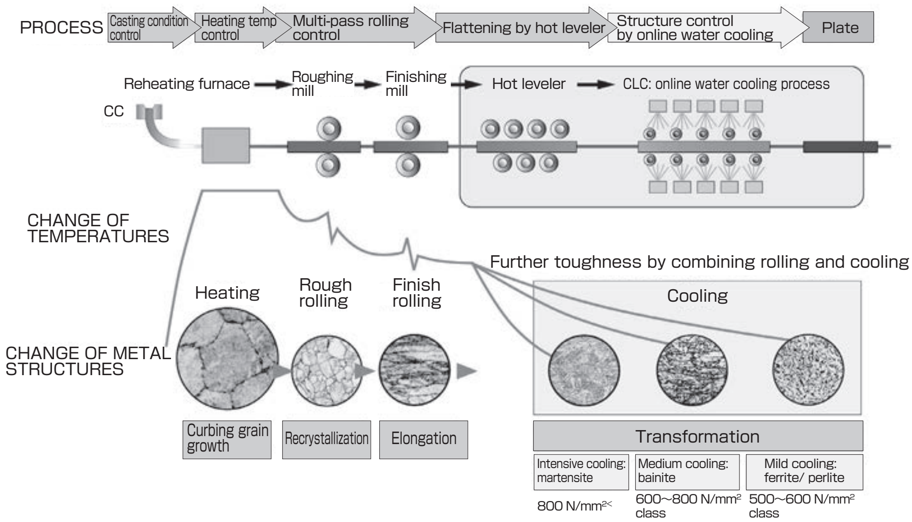

Fig. 3 Microstructure control of steel plates and TMCP technology[3]

cooling speeds after rolling, and it has been a fundamental technology in the development of new quality steel plates in recent years. However, it is difficult to manufacture TMCP steels that maintain the correct shape and the uniform cooling of a huge steel plate with several meters in length and width. Furthermore, where the manufacturing of high-quality steels is concerned, processes such as heat treatment, coating, etc. are implemented, causing problems of increased loads (process capacity vs. volume of required processing) in the finishing processes, lowered integrated production capacity, prolonged manufacturing lead time, and increased inventory, etc.

3 Comparison with the automobile industry's lean production system

What kind of production control system is the automobile industry's lean production system? Firstly, as is typical of the automobile industry, the effective use of time on the assembly line was set as an objective. To achieve this, various methodologies conceptualized as automation, just-in-time, etc. were invoked, thus eliminating *muda* (waste) on the shop floor thoroughly, and a production system that could respond flexibly to the changes of market trends and production processes was completed.[4]-[7] The essence of this production system is the pull-type production control that makes the upstream processes provide the final market with whatever the downstream needs in the exact amount required and at optimal timing.[2][8] In some of the assembly industries, mostly among electric equipment manufacturers, systems other than the assembly-line system, for example, the cellular manufacturing system, have been introduced.[9] These share their objective of adopting the lean production system in that they also control time effectively.

Now let's determine why this production system that has been successful in assembly industries has not worked well in the steel industry. When considering the reasons, it becomes necessary to understand that the structures of processes between assembly industries and process industries are intrinsically different. The lean production system is based on the assumption that the mainline is fully leveled evenly, and it will become effective when synchronized with sub-lines. In contrast, the steel industry has had as given the integrated processes of the blast furnace-converter-rolling mill, and has pursued the improvement of efficiency by constructing larger equipment/ facilities. A plate mill is located in the midst of a push-type process structure whose upstream processes pursue economies of scale, and application of the lean production system was difficult because it assumes the existence of a pull-type process structure that pursues minimization of stock and production lead time by coordinating each work process in order to satisfy the needs of the downstream processes.

In the steel industry, to improve efficiency, it is important to group together as many individual orders as possible, so that their manufacturing lot size in the upstream processes of the semi-finished product – steelmaking is increased. As a result, it used to be considered essential to have a process "to group orders into a larger lot", i.e., to manufacture steel in a large lot in the upstream processes and to divide it in the downstream processes to meet individual orders. The pursuit of scale in the upstream processes leads to the production of intermediate goods with common steel types and sizes, and because the production lot is normally larger than the delivery lot of products, it also contains the intermediate goods of products that differ in delivery timing; this flows down the downstream processes spasmodically. Such process structure causes stock to increase, and shortening the production lead time simply by studying the lean production system was difficult.

4 Efforts made for integrated optimization in manufacturing steel plates

4.1 Past efforts

The Japanese iron and steel industry, amid the long-running structural economic depression after the 1973 oil shock, reproduced on a diminishing scale and promoted rationalization, concentrating its efforts on improving labor productivity. Where the fields of shipbuilding, buildings, bridges, tanks, line pipes, etc. are concerned, i.e., major customers of steel plates, they realized weight saving, higher functionality and combined characterization, demanding the steel industry to deliver products, for example, with higher strength and toughness, or high environmental-resistance. New structural steels with additional functions were developed using the TMCP technology, but steels by accelerated cooling had lower rolling efficiency[Term 3] compared with steels for general use. Furthermore, as the application of the TMCP technology advanced, the load of the correction (flattening) process[Term 4] became heavier and the state of heavy load in the finishing processes became increasingly commonplace as the product mix shifted to a mix of more sophisticated products. In such a situation, the necessity of reinforcing the finishing capacity became increasingly recognized, but it was a common understanding that, where steel plate manufacturing was concerned, it was difficult to improve the integrated efficiency of the plant as a whole. Solving the bottleneck problem in the production system had not been prioritized as a management objective of high priority, partly because the shorter production lead time could not demonstrate a short-term profit improvement effect.

Furthermore, because the upstream processes of ironmaking-steelmaking occupy a significant part in the cost structure of an integrated steelworks, steelworks management with a cost-oriented consciousness tended to be more interested in them.

As a result, actions to deal with the problems of increasing in-process stock and of smaller order lot sizes resulting from the highly sophisticated product mix tended to wane. Under the circumstances where operation under chronically excessive in-process stock was accepted as the norm, the bottlenecks in the finishing processes surfaced when demand increased and delivery delay due to substantial prolongation of the manufacturing lead time occurred. Situations arose where adjustment of the amount of orders to be received was required, which used to be dealt with symptomatically by, for example, increasing the number of workers in the bottleneck process.

4.2 Management innovations that enabled integrated optimization

In order to realize production control that enables optimization at the level of each individual plant, there has to be a series of management innovations that makes it possible. During the many years when Japanese crude steel production stagnated, Nippon Steel continued its long-term efforts to streamline its management. During the 1990s, under the strong leadership of top management, it made innovations in terms of its organization/ management structure, aiming to fortify its competitiveness. The core innovations made were the individual product-type-wise management that contains the integration of production and sales,[10] and the drastic integration/ restructuring of organizations was realized by streamlining head office functions and compressing hierarchies.[11] The organizational reform at the corporate level effectuated in 1997 authorized middle management such as plant superintendents to make independent and centralized decisions on shop floor operations, giving them the opportunity to work as entrepreneurs. Kimitsu Works used to have an organizational structure where one department oversaw production scheduling etc. of the whole company and supported each division that manufactured individual products. However, as a result of the organizational restructuring, all the categories concerning the production of steel plates, of production scheduling, quality control and equipment maintenance that used to be overseen overall at headquarters were placed under the management of the Plate Mill. Under this new structure, the Plate Mill superintendent initiated the innovation of the control structure for plate production. Based on the understanding that it is integrated optimization at the level of individual plants that creates the power to maintain the product competitiveness for a long period of time, the management paradigm of the production control shifted substantially from the conventional system that aimed at enhancing productivity at the level of each facility to one that aims at shortening the manufacturing lead time through the curtailment of in-process stock. This was the start of the challenge to apply the lean production system developed in a pull-type industry to the plate manufacturing that is intrinsically compliant with the push-type industry.

4.3 Actions taken by middle management on the shop floor

The rolling process greatly affects the quality and cost of a plate mill. Therefore, the superintendent, aiming first to enhance the rolling efficiency, worked on the development and application of a support model of production control. Then, to solve the predicted problem of insufficient capacity of the finishing processes that would occur once the rolling efficiency was enhanced, he worked on enhancement of the efficiency of each one of the finishing processes in addition to the bottleneck processes (flattening process, etc.). The finishing processes used to be positioned as subordinate processes to rolling and their equipment was maintained mainly based on the breakdown maintenance (BDM). However, the superintendent changed it to the total productive maintenance (TPM), under which the functions of equipment maintenance and manufacturing work together in unison, aiming to keep the equipment/ devices functioning properly whenever required.

Furthermore, the optimization of plant management as a whole required a series of supporting activities by the staff related to the integrated optimization. Among all the problems, the reduction of in-process stock in the finishing processes works in opposition to the enlargement of production lot sizes in the preceding processes, and may become a short-term cost-push factor. This means that the reduction of in-process-stock in the finishing processes gives rise to problems that the efficiency enhancement of individual equipment alone will not solve, thereby requiring “Heijunka” leveling for allocating even process loads at the planning level. The designing of production lot sizes (material procurement design) is the responsibility of scheduling staff, but at the time, there was no system capable of conducting material design that took into consideration the even distribution of loads in the finishing processes. In order to solve this problem, engineers who were familiar with the shop floor operation and knowledgeable also in system development were deployed to the production scheduling group and a support system was developed for leveling the loads of finishing processes evenly from the perspectives of cost, efficiency and manufacturing lead time. Technical details describing the way in which the above was achieved in a time series are mentioned in the following chapter.

5 Innovation in the production control system of the Plate Mill

5.1 History of support system development

Production control schedule and schedule types are classified into the primary schedule (overall production), secondary schedule (reference production) and detailed schedule (order of manufacturing), and for each type, the planning elements are organized by the time scale of plan, units of scheduling and frequency of modifying the plan, product categories, and subjects matters covered by the planning.[12]

Regarding the support systems of production control, MRP (material requirements planning) was introduced by General Electric in the mid-1950s, and since then for reinforcing the limitations of early MRP, support systems such as MRP Ⅱ, ERP (enterprise resource planning) and APS (advanced planning and scheduling) have been developed. Regarding their deployment and diffusion, the results of application of MRP and APS to simple and stabilized manufacturing processes have been reported. However, there is still no report on the result of their application to complex manufacturing processes where production volume changes frequently.[12]-[21] This reflects the fact that in the assembly industries where the pull-type production control represented by the lean production system is effective, the plan is reviewed in multi-phases and the accuracy of the plan of parts ordering, etc. are automatically improved as the time of actual production approaches.[12] Therefore, there has not been much need to build a comprehensive model/ support system that dynamically and organically connects plans with different time scales.

In contrast, in the steel industry, a typical process industry, for operating integrated and continuous large-scale production facilities, an enormous amount of information for equipment control and production control has to be handled. Therefore, it introduced a production control system supported by large-scale computers ahead of other industries.[13] The production control system in the steel industry, corresponding fundamentally to the push-type production control system, prioritized the optimal control of the processes of intense heat and high temperatures, responses to the production fluctuation of upstream processes, and the maximization of each manufacturing lot size by integrating order information. Therefore, only very limited energy has been spent for supporting planning and scheduling for achieving the integrated optimization in terms of the manufacturing lead time and the in-process stock of intermediate goods. Furthermore, the sophistication and diversified specifications of recent products increased the complexity of the production control of plate manufacturing. Since large-scale production was carried out combining orders of various steel types whose processes to be completed were different, it was nearly impossible to determine at the very start of manufacturing the completion processes of individual intermediate products, and it was extremely difficult to predict and control manufacturing lead time.

To realize the pull-type production control under such an environment, it is necessary to dynamically realize the optimization of manufacturing lot sizes and manufacturing lead time in all the processes by developing a model capable of defining comprehensively the influence of the size of manufacturing lots on the efficiency of each process and the manufacturing lead time, and by deploying support systems. In the steel industry where production fluctuation and variation are substantial, applying the existing MRP, APS, etc. was practically impossible, so we developed a series of models and introduced them to the shop floor operation one by one.

5.2 Development of a new set of production control systems

(1) Efficiency model

For improvement in the efficiency of rolling processes (for rolling processes, tonnage of slabs rolled per hour), the rolling processes that are the mainline in plate manufacturing were always the most important elements. Conventional evaluation implemented concerned mainly the reinforcement of individual pieces of equipment, but investment in the reinforcement in a short cycle means a large extra load in terms of management, and this is not easy to achieve. To overcome the issues of heavier load in rolling as a consequence of expanding TMCP technology application and the lower efficiency caused by diversified products, we began concentrating our efforts on enhancing the efficiency of the entire rolling processes arranged continually, directly, and in tandem. The efficiency of each process in rolling varies greatly depending on product specifications. Moreover, friction of the preceding and subsequent material processing (idle waiting time accrued due to the difference in the preceding and subsequent processing time) frequently occurs, changing sequentially the bottleneck processes of the materials being processed. The importance of bottleneck countermeasures is clearly indicated in the theory of constraints (TOC),[14] but because it is difficult to apply simple bottleneck countermeasures to rolling processes, we developed a new efficiency model that enables quantitative evaluation of the lowering of efficiency attributable to the friction between individual rolling processes. The development of this efficiency model was based on the assumption that the TOC is applicable also to the solution of problems in complex and continued processes like rolling processes.

(2)Manufacturing lead time model

Thanks to the efficiency model, the optimization of process design and appropriate equipment reinforcement of bottleneck processes were realized and the production efficiency of the rolling processes improved dramatically. This, however, verified the lack of capacity in the finishing processes, resulting in the increase of in-process stock caused by the fluctuation in the amount to be processed. To deal with this, we worked on the efficiency improvement of each process throughout the finishing processes, and with the help of a research and development crew, developed a logistics simulator using a simulation tool for modeling discrete event systems, in an attempt to reduce in-process stock and shorten the production lead time. However, we did not succeed in obtaining a satisfactory result. The simulator assumes as given the parameters of daily manufacturing lot sizes, product mix, processing capacity of each finishing process, equipment utilization rate, etc., and has as its objective the fine-tuning of the priority order of processing, which we consider was the fundamental cause of this failure to obtain a satisfactory result.

We learned again through the study of the existing cases of the lean production system and also from understanding the limitations of the logistics simulator that it is most important to realize leveled production, together with an appropriate investment in bottleneck processes. Therefore, to ensure the enlargement of manufacturing lot sizes and the leveling of loads on finishing processes simultaneously, we worked on the development of a production lead time model capable of describing comprehensively the relationship between the manufacturing lead time variation and the success rate of delivery time, as well as the relationship between the product mix and manufacturing lot sizes and between the manufacturing lead time and the amount of stock.

(3)Required time/ in-process stock model

The above undertaking identified the relationship between the manufacturing lead time of each product type whose estimation used to be difficult and the corresponding time required to complete each process. However, even at this stage, it was not fully understood how the required completion time of each process is determined and which control factors played a part therein. In contrast, for the analysis of waiting time for cases where there is a variation in the frequency and intervals of events and in the intervals of processing, the queuing system theory was applicable.[12] The development of a model capable of describing the required completion time and in-process stock volume of each process became possible by the development of a required time/ in-process stock model based on the queuing system theory.

5.3 Development of an efficiency model

We have already explained that the plate production is classified largely into the upstream rolling processes and the downstream finishing processes. The rolling processes are comprised of heating, rolling, cooling, etc. and each one of these processes is arranged continuously, in direct connection and in tandem. In contrast, the finishing processes are comprised of heat treatment, ultra sonic testing (UST), coating, gas cutting, cold leveling (CL), oil-press leveling (OL), surface grinding, etc., and each process is arranged independently and in juxtaposition.

Like the plate rolling processes where many types of steel mix and flow, changing greatly the efficiency of each process and where the processes are arranged continuously, in direct connection and in tandem, the efficiency of each process changes in response to the process conditions of each material, and the bottleneck processes change sequentially. In association with this, the friction of preceding and subsequent processes occurs frequently, changing greatly the efficiency of the plant as a whole. In contrast, if the processes are arranged independently, it is possible to stock in a sufficient amount between processes as a buffer, and the friction of inter-process processing rarely occurs, resulting almost uniquely in the efficiency of each process by the process conditions of each material.

In order to overcome the issues of heavier load in rolling as a consequence of having expanded the application of TMCP/ accelerated cooling technology and of diversified products, the most important issue is to reduce the inter-process friction of processes in rolling caused by the diversification of process conditions associated with the diversification of steel types and by the smaller lot sizes to be processed. We therefore attempted to develop an efficiency model that enables quantitative evaluation of the lowering of efficiency attributable to the friction between individual processes of rolling, by determining the efficiency of each process according to the process conditions matching the material specifications and to the processing lot sizes, and at the same time by identifying bottleneck processes.

Each one of the rolling processes has various factors that work against better efficiency. For example, the heating process has the temperature at the start of heating, heating conditions, etc.; the roughing process has the temperature to extract a slab after heating, rolling sizes, etc.; the finishing rolling process has the TMCP temperature, weight of the slab to be rolled, etc. We developed a rolling efficiency model

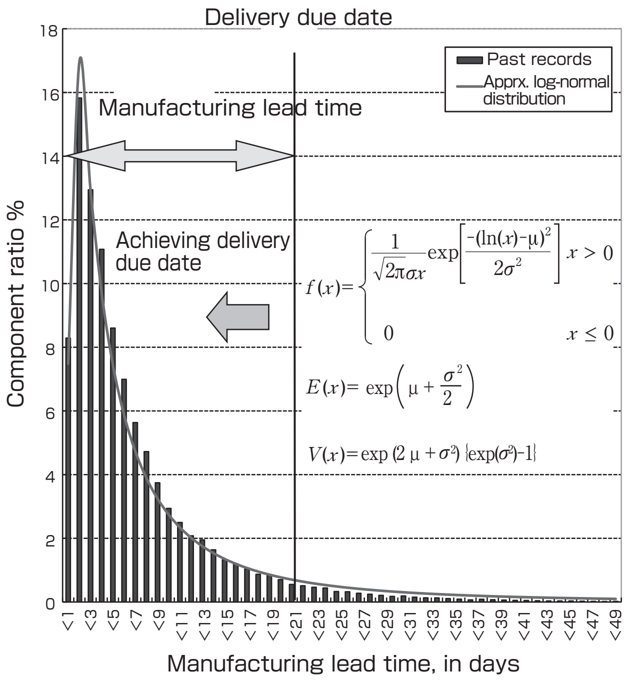

Fig. 4 Distribution of manufacturing lead time

that determines the efficiency of rolling processes as a whole particular to each product group, by properly extracting the factors of each process that affect efficiency, classifying them into product groups where these affecting factors have significant differences, calculating statistically the efficiency by each product group and comparing the efficiency of each process by each product group, and thus identifying the bottleneck processes contained in the sub-processes installed in tandem and connected directly. Once the sizes of product groups are properly adjusted, the difference between the actual records of integrated efficiency and the integrated efficiency specific to each product group is balanced out for the rolling processes as a whole, and irrespective of the changes caused by production permutation, it becomes possible to estimate the rolling efficiency with high accuracy (see NOTE 1). With this rolling efficiency model, it is also possible to estimate the rate of occurrence of processes that occur in the downstream processes for each product type.

The efficiency model's objective is to determine the efficiency and the load of each process, but by applying this model as indicated above, it achieved a substantial enhancement of rolling efficiency in the rolling processes.

5.4 Development of manufacturing lead time model

We achieved a substantial improvement in the efficiency of rolling processes, which, however, resulted in more pronounced characteristics of the push-type structure and in the increase of requirement fluctuation (fluctuation in the amount to be processed) of the finishing processes caused by the larger size of lots. In other words, this raised the issue pertaining to the necessity of optimization in pursuing simultaneously the enlargement of the lot size for the upstream processes of steelmaking to rolling processes and the leveling of the loads of the downstream processes of finishing.

The total amount of intermediate in-process product stock nearly equals the product of the production volume per day and the manufacturing lead time (number of days), and the correct amount of product stock is determined by the variation of manufacturing lead time and the targeted rate of deliveries made within the due date. However, in the past, it was difficult to say that the factors affecting these two items and their relationship were quantitatively grasped and the production scheduling for accurate and optimal control was implemented. Therefore, to shorten the manufacturing lead time and realize a lower stock level, it is necessary to determine the relationship between the lead time variation and the targeted rate of deliveries made within the due date, but at the same time, to develop a model that is capable of describing comprehensively and quantitatively the consequences that are generated by the order mix of product types and manufacturing lot sizes in each process and in the integrated manufacturing lead time and stock volume.

The manufacturing lead time is a variable that is the shorter the better, and is never in the negative, but the average of the number of days and the standard deviation show a linear relationship to some extent. The simplest model expressing this event is that the size of variation is proportional to the instantaneous value, but in this case, because the distribution of variation is a lognormal distribution, we assumed the distribution of manufacturing lead time borders on the lognormal distribution (Fig. 4). If we assume that the manufacturing lead time follows the lognormal distribution, it becomes possible to calculate in a simplified way the number of days considered necessary for achieving the targeted delivery time, which makes it very useful in developing or evaluating the manufacturing lead time model. The lognormal distribution is expressed by the following formula, where μ is the logarithmic mean of x, and σ is the logarithmic standard deviation of x.

$$f(x)=\begin{cases}\dfrac{1}{\sqrt{2\pi}\sigma x}\exp\left[\dfrac{-(\ln(x)-\mu)^2}{2\sigma^2}\right] & x>0\\ 0 & x\le 0\end{cases}$$

The past records of the spare days of the manufacturing completion against the delivery due date are distributed almost normally and if their average value and standard deviation are determined, the probability that the delivery achievement ratio, i.e., the number of spare days against the delivery due date (manufacturing completion until delivery), is recorded as more than zero can be calculated easily by using the cumulative probability distribution function given below:

Ratio achieving delivery due date:

$$p\ (x>0;\ \mu,\sigma\ )=1-\int_{-\infty}^{0}\frac{1}{\sqrt{2\pi}\sigma}\exp\left[-\left(\frac{(t-\mu)^2}{2\sigma^2}\right)\right]\mathrm{d}t$$

where x = spare days until delivery, μ = average of spare days, σ = standard deviation of spare days

Next, we studied the factors contributing to the variation of the number of spare delivery days. The order specifies the delivery due date and based on the transportation facilities and the specification of each product type, the timing to start rolling is decided, at which time, because the ordered diversified products are grouped in a lot for delivering, the spare delivery days and the individual manufacturing lead time become independent. Furthermore, the rolling start timing is affected by the fluctuation of production in the upper stream process of steelmaking. The variation of spare delivery days is affected by the variation of rolling start timing (spare days for starting rolling against delivery day: rolling start until delivery day) and the variation of manufacturing lead time (rolling start until manufacturing completion). If component events occur independently, the sum of variance of each independent event equals the sum of variance for the total, which means, if respective variations are determined independently, the standard deviation of the number of spare delivery days is estimated by the following formula:

$$\sigma_{\text{spare days until delivery}} = (\sigma_{\text{spare days for starting rolling against delivery}}{}^2 + \sigma_{\text{manufacturing lead time}}{}^2)^{1/2}$$

where, $\sigma_{\text{spare days until delivery}}$: standard deviation of the number of spare days until delivery (manufacturing completion until delivery)

$\sigma_{\text{spare days for starting rolling against delivery}}$: standard deviation of spare days for starting rolling against delivery date (rolling start until delivery)

$\sigma_{\text{manufacturing lead time}}$: standard deviation of manufacturing lead time (rolling start until manufacturing completion)

The estimated number of spare days of delivery is in good agreement with the past records and the validity of the assumption that each one of the events is independent was confirmed. Using the formula above we calculated the contribution of each term to the standard deviation of spare delivery days, and revealed that the contribution of the spare days for starting rolling against delivery date to the standard deviation of the number of spare days until delivery and the variation of manufacturing lead time were 70 % and 30 % respectively, and it was confirmed that the former contributed predominantly. Therefore, to reduce the standard deviation of spare delivery days, it is important to narrow down the standard deviation of rolling start timing against the delivery day, which means that for lowering the stock level, it is essential to control the lot size of rolling/ steelmaking casting (see NOTE 2).

5.5 Analysis for the contribution of manufacturing lead time – lead time of each process

Then, we studied the contribution of each plate manufacturing process to the variation of manufacturing lead time. Assuming that the required completion time of each finishing process is determined independently, the variance of the manufacturing lead time as a whole is expressed in the following formula as the sum of variance of the required

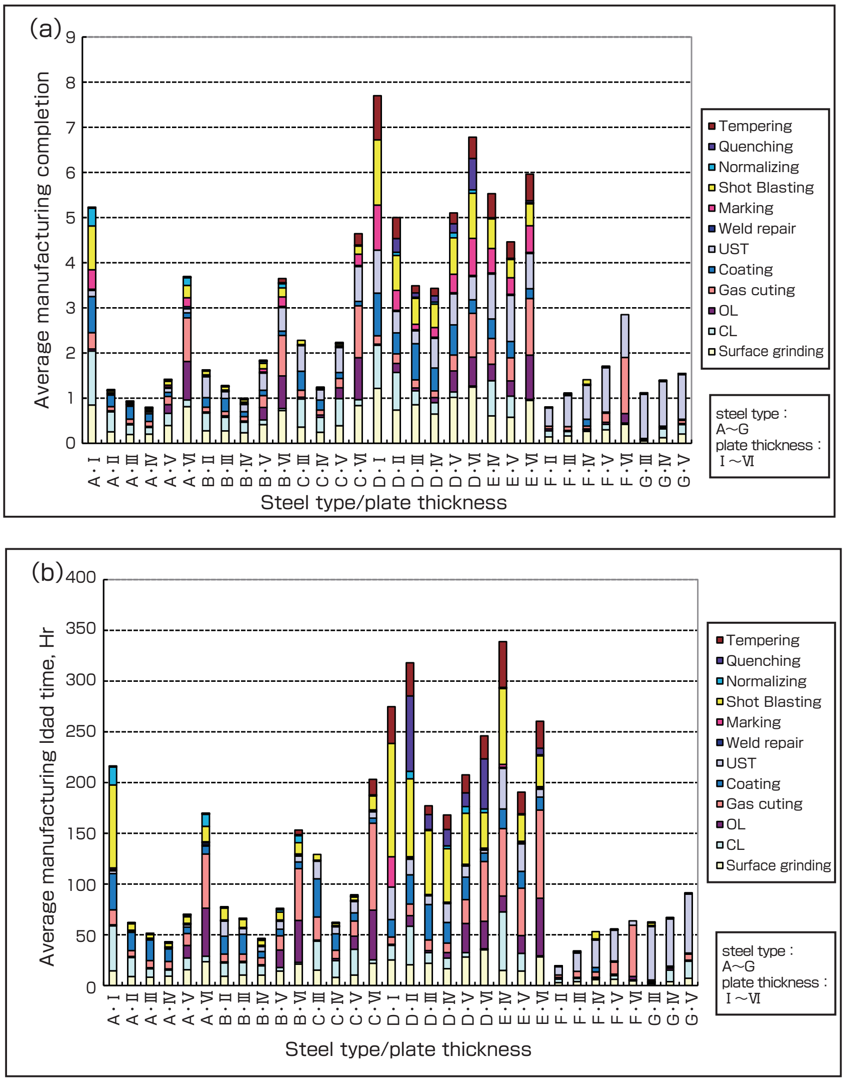

Fig. 5 Average number of processes to be passed and the manufacturing lead time for individual product types

(a) Average number of processes to be passed for individual product types

(b) Average required completion time for individual product types completion time of each process. The standard deviation of all the plate manufacturing processes and that of the rolling + shearing + finishing calculated by the following formula, assuming that the required completion time of each one of the finishing processes is determined independently, are nearly equal and the validity of the assumption that the required completion time of each process is independent was confirmed. Therefore, if the following formula is used, the impact of the fluctuation of the required time and of the capacity of each process on the manufacturing lead time of the entire plate manufacturing can be easily estimated.

$$\sigma_{\text{rolling + shearing + finishing}} = (\sigma_{\text{rolling + shearing}}{}^2 + \sum \sigma_{\text{each finishing process}}{}^2)^{1/2}$$

where, $\sigma_{\text{rolling + shearing + finishing}}$: standard deviation of rolling + shearing + finishing lead time

$\sigma_{\text{rolling + shearing}}$: standard deviation of rolling + shearing lead time

$\sigma_{\text{each finishing process}}$: standard deviation of required completion time of each finishing process (surface grinding, CL, OL, gas cutting, coating, UST, weld repair, marking, shot blasting, normalizing, quenching, tempering)

As a result of the above evaluation, the contribution of rolling + shearing to all the manufacturing lead time of all processes is no bigger than 20 % and the effect of the enhanced rolling efficiency on the shortening of manufacturing lead time is limited. In contrast, where the lead time of finishing processes is concerned, most of the time spent was on waiting, and their contribution to necessary work time was no bigger than 5 %. In other words, if the variation of rolling start against the delivery due date is reduced and appropriate lot sizes are assured, realizing at the same time operation where the required time of each process and the in-process stock level is minimized, it is highly possible that the manufacturing lead time will be substantially shortened.

The number of processes for each product type to pass and the manufacturing lead time are shown in Fig. 5, which indicates that the number of processes to be passed and the manufacturing lead time differ greatly depending on the product type, and that the manufacturing lead time is dependent almost entirely on the number of processes to be passed. Therefore, it is observed that for leveling the load of each process, it is necessary to maintain the input of each product type at an even level, and for preventing the input volume from being in spasm, it is important to control the lot sizes.

We adopted a method to identify the distribution of manufacturing lead time for each manufacturing product type by seeking the distribution of manufacturing lead time for each pass pattern and by dividing it proportionally by the component percentage of pass pattern for each product type to be manufactured (see NOTE 3). We estimated the manufacturing lead time using this manufacturing lead time model, found the estimated time agreed well with the past records, and the validity of this model was thus confirmed. Therefore, if the process to be passed and the required time are known, the manufacturing lead time can be calculated.

5.6 Development of a required time/ in-process stock model

If the processes are arranged independently, and if it is possible to have enough stock between processes, the efficiency of each process is seldom affected by other processes. In contrast, if there is not enough in-process stock, there are “risks” of deteriorating efficiency such as waiting for the processing from other processes, increase in time for changing set ups, etc. Therefore, as long as the stock was within the storage yard capacity, no incentive to reduce stock was instigated, resulting in very sluggish progress in the minimization of in-process stock even after the reinforcement of the finishing processes’ equipment. The lead time of the finishing processes, as explained earlier, contributes no more than 5 % to the necessary work time, and establishment of an operation that minimizes the required time of each process and in-process stock was sought before achieving a shorter manufacturing lead time.

Queuing theory is effective for analyzing waiting time, when there is variation in the occurrence frequency and its intervals and in the processing intervals, as in the case of the plate finishing processes. Therefore, to develop a model capable of describing the required time of each process, we applied the queuing theory to plate manufacturing, and developed a predictive model of the required time and the in-process stock volume of each process (required time/ in-process stock model), and then verified its validity (capable of giving a sufficiently accurate prediction of the in-process stock and required time of product in each process).

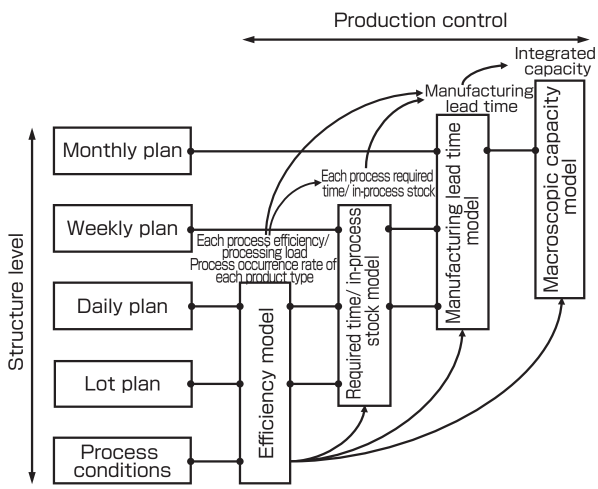

Fig. 6 Production control multi-scale hierarchically structured model

If the occurrence and processing frequency in every hour changes in the general distribution pattern, and if the frequency of stops and time caused by equipment failures, etc. changes, the required time and in-process stock of a certain process is derived as in the following formula using the queuing theory [22]:

$$W=\frac{1}{1-\rho_X(1+\rho_Y)}\left[\frac{1}{2}\rho_X(1+\rho_Y)^2\left(1+C_{SX}^{\ 2}\right)E_X+\frac{1}{2}\frac{\rho_Y}{1+\rho_Y}\left(1+C_{SY}^{\ 2}\right)E_Y\right]$$

$$=\frac{1}{1-\rho_B}\left[\frac{1}{2}\rho_X(1+\rho_Y)^2\left(1+C_{SX}^{\ 2}\right)E_X+\frac{1}{2}\frac{\rho_Y}{1+\rho_Y}\left(1+C_{SY}^{\ 2}\right)E_Y\right]$$

$$N=\lambda W$$

however, the requirements for waiting time W and in-process stock N to stabilize are

$$P_B=\rho_X(1+\rho_Y)<1$$
$$\rho_Y=1-\rho_L\rho_X$$

where, W: average waiting time, N: average number of lots in stock in the process, E_X: average processing time, E_Y: average equipment stop time
C_{SX}: proportion of the standard deviation of processing time and average processing time, C_{SY}: proportion of the standard deviation of stop time and average stop time
P_B: total utilization ratio, ρ_X: utilization ratio, ρ_Y: stop ratio, $1-\rho_Y$: operation rate,
λ: average occurrence rate, ρ_L: operation rate of preceding processes

We applied this required time/ in-process stock model to the plate finishing processes and estimated the required time and stock level. It was revealed that both the required time and the in-process stock level agreed well with the past records even in the cases where there was variation in the frequency of occurrence, processing and stops, and the validity of this model based on the queuing theory was confirmed.

6 Toward the systemization of manufacturing knowledge

6.1 Proposal of a multi-scale hierarchically structured model for production control

In the preceding chapter, we explained, in a time-series schedule, how the support system was developed for solving individual problems of production control, taking examples from the Plate Mill of Kimistu Works. In this chapter, we now consider how and from which viewpoint the realized production control system can be converted into a conceptual model, so that a deeper understanding of the integrated optimization in the process industry can be acquired. We synthesize the knowledge we acquired from our problem solving efforts to solve the individual technical issues we experienced, and propose the following conceptual model.

In the lean production system outlined in this paper as an already existing system, the time-wise process structure of a manufacturing line operating on the second time scale/ production plan of monthly scale/ very long manufacturing lead time/ stock, which is common knowledge in the conventional production control, synchronizes the flow of stock with the flow of the manufacturing line (just-in-time), which then synchronizes the time scale in the production control with that of the mainline. In contrast, an examination of the time process structure of the production control for manufacturing plates reveals that it is established as a time-wise multi-scale hierarchical structure of the processing (second time scale), lot planning (hour time scale), daily plan (day time scale), weekly plan (week time scale) and monthly plan (month time scale), and that the shop floor operation and the production control by the staff in charge have been implemented on the basis of such given hierarchical structure. In the past, a macroscopic capacity model calculated the capacity of each process using a spreadsheet based on the product mix forecast in the monthly plan. However, in the course of realizing the integrated optimization of plate manufacturing we developed the following three models: efficiency model, required time/ in-process stock model and manufacturing lead time model. These models meet the time-wise multi-scale hierarchical structure in plate manufacturing; namely, the efficiency model is for the second (processing) → hour (lot) plan → day plan; the required time/ in-process stock model is for the hour (lot) plan → day plan → weekly plan; and the manufacturing lead time model is for the day plan → weekly plan → monthly plan; and these three models are mutually inclusive. The efficiency model shows the efficiency and the load to be processed, but it also gives the occurrence rate of processes that products complete in the downstream processes for each product type (process occurrence rate for each product type). By inputting this processing load and process occurrence rate for each product type together with the day/ weekly plan into the required time/ in-process stock model, the required time of the process and the in-process stock volume can be obtained. For the product type determined by the daily/ weekly plan and monthly plan, if the process occurrence rate of the product type obtained from the efficiency model and the required time obtained from the required time/ in-process stock model are input to the manufacturing lead time model, the manufacturing lead time can be calculated (see Fig. 6).

As described in the preceding chapter, trial and error on the shop floor resulted in the establishment of a production control system of plate manufacturing that has complex processes and product specifications and that ensures different time scales (hierarchy) are covered without contradiction, of both the required accuracy of plan and the responsiveness to the fluctuation of production/ orders. We propose to identify this system from the viewpoint of multi-scale hierarchical structure, and conceptualize it as a multi-scale hierarchically structured model for production control.

In the field of material researches for steels having a complex structure, Olson proposed a spatial multi-scale hierarchically structured model and demonstrated that the model is capable of specifying comprehensively the property extending from the millimeter level to the meter level of commercial steels, by organically combining physical models developed for each hierarchy.[23] We apply this spatial multi-scale hierarchically structured model to the description of time-wise multi-scale structure, namely, we propose dividing the time scale of production control into three levels, and to each level, the efficiency model, required time/ in-process stock model and manufacturing lead time model are assigned respectively together with a time-wise multi-scale hierarchically structured model for the integrated production control that links them organically (see Fig. 6). This is an integrated model that determines the multi-scale nature for time in plate manufacturing and enables the quantitative evaluation of decision-making from the micro (processing in individual processes) to the macro (control of manufacturing lead time) level and the search for the optimal point. This model made it possible to search for the optimal schedule for achieving well balanced coordination of two types of needs difficult to satisfy at the same time, i.e., the optimization of process conditions in the upstream processes based on the push-type production control methodology and the shortening of manufacturing lead time in the downstream processes that anticipate the application of the pull-type production control.

The difficulty of the production control model lies with the multi-leveled time scale, but specifying complex physical phenomena having hierarchical structure is one of the most fundamental research themes of R & D in ferrous metallurgy. One of the authors learned and assimilated the knowledge as his own during his pre-doctoral researches in the USA that it is effective to simplify matters by dividing structures into every level when developing the model of a mechanism that elicits physical phenomena. This engineer, in addition to studying theories, was moved to the manufacturing shop floor, and it can be said that the knowledge of the existing lean production system and his already acquired know-how for advancing his researches were amalgamated through such on-site activities, enabling him to analyze complex phenomena as hierarchical structure.

6.2 Significance of the multi-scale hierarchically structured model

The routine practices of the production control of iron and steel manufacturing is broken down into each task level from the viewpoint of pursuing work efficiency. Therefore, even if the skill for each process is acquired, it is extremely difficult to picture the total view of the production control system in manufacturing. The main significance of the multi-scale hierarchically structured model lies in its ability to provide a framework that enables detailed technical examination of the management issues of integrated optimization via the production control at the level of individual plants by providing an overview of the overall picture of the system. From the very beginning, the basic premise for engineers, when performing work whose mission is to realize continual improvement by designing and redesigning manufacturing systems, is to have an overview of the overall picture of the production control system, and the role played by the proposed model is important.

However, the model proposed at this time does not possess the optimization evaluation function that realizes overall optimization, and does not guarantee the overall optimization theoretically and quantitatively. To realize the optimization, the existence of various models is essential, but compared with the assembly industries represented by the automobile industry, in the steel industry, the fluctuation of daily production and operation in the upstream of iron making and steel making processes is extremely marked and moreover, plans are frequently changed. In such an environment, because the model is developed based on past records that contain also external disturbances, it is difficult to make a highly accurate estimate and its reliability is naturally limited. It is evident that the deterministic approach that seeks optimal answers assuming full-information is available does not fit, and it is not realistic time-wise and from the viewpoint of effectiveness to conduct a complex and large volume of calculation by integrating a model obtained through a top-down analysis.

In contrast, reviewing the history of the development of the proposed models, in the production control system covered by this research, we understand that (i) the individual elements constituting the system are locally organized and the structure that realizes the functions required by the system is sequentially decided through trial and error (hypothesis formation and verification), and (ii) the derived adaptive solution (even if it is not the optimum solution) provides an answer beyond expectation, to complex problems and supports effectively the decision-makings on the shop floor working in a dynamic environment. Our observation strongly suggests that the processes constituting the proposed model were emergent processes.[24]

So, how were the emergent phenomena witnessed in this case example induced? Business scholars who interpret the strategic development of an organization as an emergent process claim that by setting an appropriate "place" (environment) for business activities, it is possible to promote the induction of emergent phenomena among individual persons constituting the organization.[25]-[27] We believe, as mentioned in chapter 4, in this case example, thanks to the management innovation at the level of the head office and under the leadership of middle management at the level of plants, that the basic environmental setting for inducing the emergent phenomena on the shop floor was implemented.[26]-[27] Furthermore, from the viewpoint of how the production control system was made possible, it is important that core persons capable of taking charge of the bottom-up type synthesis were fostered systematically, and such persons played the role of promoting emergent activities on the shop floor.

To introduce the roles of the "technical group" to which the engineers that contributed to the development of the proposed models belong, the group is positioned at the relay point that links the manufacturing site and the staff departments. It has a broad coordination function not limited simply to manufacturing technology for the operation of the plant, and plays the core role in the operation and innovation of the production system (see NOTE 4). It is general practice to assign technical staff to the "technical group" at the time of new recruitment to the company, and as new recruits, they experience on-site work in three shifts. After this period, technical staff gain experience in various job positions but exceptional engineers and leaders of steelworks including the superintendent tend to remain in the "technical group." Such career path suggests that the company has had the intention of fostering the staff in the "technical group" as principal enablers[29] (persons who help others to realize objectives in emergent activities) in the emergent processes by having them physically embed in the staff the knowledge on coordination and means of problem solution acquired through OJT in many fields (corresponding to the habitus of P. Bourdieu[Term 5 [28]]).

Engineers working as system integrators are responsible for achieving both technical superiority by the sophistication of equipment/ operational technologies and economic rationality. The costs and risks that arise when introducing the lean production system to the steel industry at the meticulous level of the automobile industry are imagined to far surpass the authorized scope of decision-making by the on-site plant management. The integrated optimization of the production processes needs to be evaluated from the viewpoint of overall optimization in plant management and the proposed models provide a quantitative guideline for examining in concrete terms how the shop floor management balances the conflicting needs of technologies and management. For example, for the promotion of the lean production system, it becomes necessary to eliminate bottleneck processes, and when studying the optimal equipment investment, it was not possible in the past to evaluate quantitatively the increment of integrated efficiency that the reinforcement of equipment in the finishing processes will incur, making it difficult to make a proper decision in investment in the finishing process equipment. The proposed model opened the possibility of effectively presenting to the management of Kimitsu Works and sales departments of the Headquarters, not to mention within the Plate Mill, the advantages and the necessity of integrated optimization. We also developed in succession the production control systems for the improvement of on-site operation, the optimization of material design aiming to improve production control activities conducted by the staff in charge, the optimization of the tapping schedule and the development of the infrastructure for supply chain management and others. And during such development work, the efficacy of the quantitative analyses made using the multi-scale models was verified.

As explained above, the history of the formation of the multi-scale models proposed in this research has the following bilateral characteristics. Firstly, if the models are considered in terms of their formation process, it is recognized that the structure of the models was determined by the know-how gained in the research method used by the engineers who were in charge of the development, more specifically, by the hierarchical structure approach to complex phenomena. Contrastively, when we saw a series of models that we introduced be developed and emerged in the form of a production control system, we recognized that it is worthwhile to widely propagate the system in the industrial society, and we recognized anew, while working on the formalization of the system, the merits obtainable by systematizing the model as a multi-scale model.

7 Summary and future considerations

If the essence of the manufacturing industry is "transcribing information into materials," the lean production system that creates material flows synchronized with the flow of information is one of the "aspects to be targeted" in the pursuit of the essence of the manufacturing industry.[30] The quest for economies of scale by the mass production system initiated by Ford created the time-wise multi-scale hierarchical structure of production control, represented by the second time scale manufacturing lines, production plan on the monthly time scale and very prolonged lead time / large stock. Ohno who took the lead in the lean production system, under the slogan of "Overcome economy of scale," however, succeeded in this by controlling manufacturing lot sizes and pursuing the synchronization of manufacturing with the production line.[4] When the lean production system is considered within the framework of time-wise multi-scales, it can be understood as the result of the convergence of the manufacturing time scales on that of the mainline. In contrast, because the steel industry is a process industry, and due to the fact that the influence of manufacturing lot size on productivity and quality is larger compared with the automobile industry, an assembly industry, it is fundamentally difficult to realize the similarly high level of manufacturing synchronization and compression of time scales as that of the automobile industry. However, the case example analyzed in this paper shows that the integrated optimization may even be realized in industries other than steel by understanding the production system as a time-wise multi-scale hierarchical structure, and by linking properly each stratum via support systems.

In many industries, the shortening of the time required for manufacturing is an essential element for the development of diversified value-added products and manufacturing them as competitive products. For example, even in the pharmaceutical field that appears to be at the extreme opposite end of the spectrum, we are now in an age where the competitive edge of products is determined by price and speed. In the past, in the field of pharmaceutical products, having differential products protected by patents gave a company its competitive edge. However, due to the diffusion of generic products, having the capability to produce drugs of various kinds as price competitive products is becoming an important management issue. For example, tablets are manufactured into a wide variety of products using a series of equipment and manufacturing processes for mixing, granulation, sieving, mixing, tableting and coating.[31] and these processes are controlled elaborately by computers as it is with the iron and steel manufacturing processes. In other words, the industry has many issues similar to the steel industry also in the fact that efforts to meet various products are required also in terms of its process structure and the approach proposed in this paper of developing a model is considered to enable horizontal deployment in many process industries including pharmaceuticals.

In Japanese manufacturing companies, a succession of technical staff has steadily taken charge of innovation in manufacturing technologies and production control on the shop floor. The manufacturing knowledge acquired during the course of such innovative efforts is expected to be documented and published as educational materials and also engineering as a practical science is expected to be systematized as part of academic fields.[32] It goes without saying that to realize the integrated optimization on the manufacturing shop floor, it is necessary to understand the phenomena at each stratum extending from the micro to macro level, to develop models, and compare them within a developed framework against best practices in other business sectors and companies. The multi-scale hierarchically structured model for production control proposed in this paper was developed based on the knowledge of field engineers obtained from their wide and in-depth OJT throughout their career, and this paper strongly suggests the necessity of systematizing manufacturing knowledge from industries.

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Notes

Note 1) In the actual production, because manufacturing is conducted in combination with more than one product group, the bottleneck processes change sequentially and situations very often occur where the bottleneck process is different from the one particular to the product group concerned. Therefore, the past records of rolling process efficiency observed in actual production vary, unlike the particular integrated efficiency recorded in the case of continued manufacturing of the same product group, in every term for which records were aggregated as influenced by the combination of production permutation that varies in every term. In this efficiency model, this problem was avoided by defining product groups after extracting the factors affecting the processing efficiency of each process so that the efficiency of actual rolling processes as a whole distributes the specific integrated efficiency as the median. In terms of the rolling processes as a whole, irrespective of the production permutation, the product group sizes were adjusted so that the difference between the past record of integrated efficiency and the integrated efficiency specific to the product group was balanced out, thus succeeding in producing highly accurate estimates of the overall efficiency of rolling processes compared with conventional models.

Note 2) The production of steel plates is characterized by receiving orders for various products (products of the same specification in one order are about 3 t), manufacturing them in lots (condition of the same steelmaking: min. 300 t, but considering productivity, desirably over 2,000 t) and delivering products in the unit of a lot (for the same customer, delivery date, transportation means). The delivery date is specified for the same shipment lot, but as requested by the customer, orders of various products are contained in one shipment lot, and the manufacturing lot does not generally agree with the shipment lot. Therefore, even though the timing to start rolling is determined by counting backward the manufacturing lead time set from the delivery date, variation is inevitable when grouping products in a manufacturing lot.

Note 3) With the help of the existing correlation between the number of processes to be passed in the finishing processes and the manufacturing lead time, the following method was adopted: (1) after having estimated the completion pattern of finishing processes (rows of 01 indicating yes or no of completion (a pass)) based on the manufacturing specification, (2) a system to estimate a lead time distribution by each product type is introduced by defining as one group a character string that has added to this completion pattern a category code representing product types grouped in a major category. The category code was added because even though it concerns the same completion pattern, the completion frequency (occurrence rate) of the occurrence process differs and there are cases where the lead time distribution differs. Even though the completion pattern and the completion frequency are the same, depending of the product type, there are cases where the set value of the delivery success rate differs.

For plate manufacturing, for which it is unknown at the time of deciding the order specification which processes for the intermediate goods to pass, such as surface grinding or gas cutting and flattening, and where there are occurrence processes determined regarding their completion after rolling, it is therefore not possible to calculate the completion pattern of finishing processes with a simple logic based on the manufacturing specification of the order. Therefore, using the decision tree that is a methodology used generally for data mining, we developed a completion pattern estimation model.

When seeking the lead time distribution of each product type to be manufactured, the simple method is to collect plates of the same manufacturing product type from the existing data, and use the histogram of their actual lead time data to draw the lead time distribution. However, there are also product types that are manufactured rarely, and the lead time distribution of such product types with a small number of data tends to be low in reliability. Therefore, we adopted a method to obtain the lead time distribution for every production type to be manufactured by obtaining the lead time distribution for each completion pattern and by dividing it proportionally by the component percentage of the completion pattern for each type of product to be manufactured.

Note 4) The technical group in addition assumes the roles of transmitting information to the works' top management (accountability on behalf of the line division, or representing the technical division), coordination with the relevant staff department involved with short-term issues relating to line management (production technology, production scheduling, general affairs, personal affairs, labor, equipment), planning of middle and long-term plans, development of R & D strategies with the R & D department, and the role of overall coordination for various problems that occur mainly with the line division, including areas for which the job description is not necessarily clear such as the coordination with staff department based in the head office.

Terminology

Term 1. Manufacturing lead time: A term used in the steel industry, signifying the duration of time required for manufacturing. Its definition is varied including the duration of time from receiving an order to the delivery of a product and from the start of manufacturing to its completion, but in this paper, it is defined as the time required from the start of rolling a plate to the completion of its manufacturing.

Term 2. Manufacturing processes in a steelworks: A steelworks manufacturing steel products in an integrated manner from iron ore is called an integrated iron and steelmaking works and its processes are generally classified into three processes of ironmaking, steelmaking and rolling, the first consisting of ironmaking by reducing iron ore in a blast furnace; the second in steelmaking by removing carbon from pig iron and adding necessary alloy elements in a converter; and the third in manufacturing various products by rolling semi-products manufactured in the steelmaking process. A steel plate mill is one of the rolling processes and it rolls and produces steel plates.

Term 3. Rolling efficiency: Efficiency indicates the ratio of work accomplished in a given amount of time. Because the rolling process has a series of equipment for heating, rolling, cooling, etc. that are arranged continuously in tandem and are directly connected, the efficiency of continuously making such series of equipment function is called rolling efficiency.

Term 4. Correction (flattening) process: The process where a defect in flatness detected after the rolling process of plates is corrected by a roller leveler or a press.

Term 5. Habitus: As a concept similar to habitus, there is tacit knowledge [Polanyi, M.: The Tacit Dimension, Doubleday Anchor, N.Y. (1967)]. Habitus can be considered as tacit knowledge in scientific activities and is the expertise in the broad sense of the term related to the method of conducting research.

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In 1977, graduated from the Graduate School of Engineering, Osaka University, majoring in Precision Engineering. In 1977, entered Nippon Steel Corporation. Worked there on the manufacturing of steel plates, research, head office technical administration, and planning and development of company-wide technical development as a member of the board. In 1997, assumed the role of superintendent of Kimitsu Plate Mill (General Manager); in 2001, General Manager of Plate Sales Division in Head Office; in 2005, board member; in 2006, Director; in 2009, Executive Advisor; Visiting Research Fellow of the Research Center for Advanced Science and Technology, Tokyo University. In 2005, received the Technical Contribution Award from the Iron and Steel Institute of Japan; in 2007, received the KOMO Thermal Technology Award for Technical Promotion from the Tanikawa Fund Promotion of Thermal Technology. In relation to the present paper, he started innovative undertakings in plate production control as the Plate Mill superintendent and worked as leader for the realization of integrated optimization.

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In 1991, graduated from the Graduate School of Engineering, Tokyo University, majoring in Precision Engineering. In 2006, graduated from the doctorate course of Northwestern University, Ph.D. (Materials Science and Engineering). In 1991, entered Nippon Steel Corporation. Worked as chief researcher in Kimitsu Technical Research Division of the Technical Development Bureau, leader of the technical group of steel plates in

Kimitsu Plate Mill, manager of the plate department and others. Presently working as the Plate Mill manager. Until today, worked for the enhancement of productivity of plate manufacturing, development of TMCP technology, and integrated optimization. For the present paper, he worked as a member of the technical staff and assumed leadership in the planning and implementation of integrated optimization, and at the same time, in the development of the multi-scale hierarchically structured model of production control.

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In 1996, graduated from the Graduate School of Faculty of Science and Engineering, Waseda University. In 1996, entered Nippon Steel Corporation. At the plate mill of Kimitsu Works, worked mainly on higher efficiency, TMCP technical development, etc., improvement of operation techniques, as well as equipment planning and drastic improvement of plate manufacturing processes. In 2005, dispatched to the World Steel Association, and at present, the steel plate technical group manager of the Plate Mill, Nagoya Works. To this paper, he contributed as a member of the technical staff to shop floor reform and operation improvement.

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In 1980, graduated from the Graduate School of Mechanical Engineering of Osaka University. In 1980, entered Nippon Steel Corporation. Engaged in the improvement of plant operation techniques as a member of the technical staff belonging to the Plate Mill of Kimitsu Works. After posts as assistant manager in the Plate Technical Department in Head Office, superintendent (general manager) of the Plate Mill, Kimitsu Works, presently executive counselor in the Plate Division of Head Office. In 2008, received the Watanabe Kensuke Memorial Award of the Iron and Steel Institute of Japan. In relation to this paper, he was assigned the post of superintendent of the Plate Mill in 2001, and succeeded in the shortening of lead time and production increase.

Yasunori BABA

In 1977, graduated from the Faculty of Economics, Tokyo University. In 1986, completed a doctorate course at the University of Sussex, Ph. D., SPRU fellow. After working as chief researcher in the National Institute of Science and Technology, and others, and from April 1993, the assistant professor at the Research into the Artifacts Center for Engineering, and in 1997 became the professor of the same Center. After July 2001, professor at the Research Center for Advanced Science and Technology. Also, from April 2007, professor at the Department of Advanced Interdisciplinary Studies, Graduate School of Engineering, Tokyo University. In this paper, he took charge of the synthesization and systematization of knowledge.

Discussions with Reviewers

1 Productivity of steel plate manufacturing processes

Comment (Kanji Ueda: AIST)

This paper investigates the most difficult problems of optimal integrated production in process industries. It identified the items to be solved through practical undertakings, and developed models and summarized the actual data collected in specific steel plate manufacturing processes and is considered as appropriate in terms of synthesiology. The scenario in this paper is based fundamentally on the recognition of the difficulty of ensuring simultaneously the minimization of lead time and improvement of productivity. However, please describe clearly what is meant by the enhancement of productivity in this paper.

Answer (Kiyoshi Nishioka)

Productivity is the volume of production per hour, namely it is "efficiency." The process reform/ process improvement in the steel industry used to focus on the enhancement of the efficiency of mainlines. However, the enhancement of efficiency of individual pieces of equipment or a group of equipment does not lead to the minimization of manufacturing lead time, and sometimes, it works counter to it. The main subject of our research concerns how to make these two coexist.

2 Middle management

Question (Kanji Ueda)

As one of the arguments in this paper, it describes the importance of the role of middle management in management innovation. Please be more specific in your definition of middle management.

Answer (Kiyoshi Nishioka)

When referring to middle management in this paper, we mean managers at the level of plant superintendent. Top management has the authority to change the corporate-level organizations and systems. Middle management, on the other hand, has the authority to change operation and evaluation within a given range of system and structure. This paper suggests that by synchronizing the reform of corporate-level organizations and work structures implemented under the strong leadership of top management and the innovative efforts of middle management in charge of on-site management, organizational activities that by nature tend to resist changes are rejuvenated completely and become capable of responding actively to the changing market environment.

3 History of modeling multi-scale hierarchical structure and its future development

Question (Kanji Ueda)

Chapter 6 claims that a new model is proposed toward the systematization of manufacturing knowledge. The content is very interesting, but it is not clearly stated how this model was obtained. Please also describe how this proposed model should be deployed horizontally and to which industries and processes in the future.

Answer (Kiyoshi Nishioka)

The proposed model has not been deductively derived, and if a model that was developed through trial and error is understood inductively, the paper claims that it has a model structure that straddles time strata. In contrast to the conventional result-based production control that is based on manufacturing results, it is suggested that the multi-scale hierarchically structured model makes it possible to implement appropriate time control and production control by adding the viewpoint linking the causes and the result of phenomena that occur time-wise. The lean production control gave birth to an epoch-making production control that enables the pursuit of the limit of integrated optimization in the interrelation of lines called processing. In contrast, in the equipment-heavy industries, or process industries where the renewal of existing equipment or changes of its installation layout are difficult, integrated optimization is feasible only within the time span of processing, and it is difficult to realize the integrated optimization for all. In other words, in order to ensure integrated optimization in many industries where the time structure of *monozukuri* extends from the micro to macro level, the understanding of phenomena that are beyond time strata is considered necessary, which means the development of a cause – result-based model is also necessary. There are three categories of these strata in the present case, but this naturally could be two or four depending on the process. What is important is to determine which strata are to be straddled and in what form the model should be developed, so that it contributes to the proper understanding of the phenomena of the process and to the integrated production control, and the present example presents one of such examples.

In many industries, the shortening of time necessary for manufacturing is an essential element for developing a wide variety of value-added products and for manufacturing them as competitive products, and if the time structure in the production control is understood systematically by using the currently proposed model, we consider it will be of some help to it. For the future outlook, please see chapter 7.

4 Application scope of the multi-scale hierarchically structured model

Question (Kanji Ueda)

In the paper, the intent of overall optimization instead of partial optimization is stated. However, the methodology of this paper does not theoretically seek the overall optimization, and therefore, I think it is not guaranteed that an answer for overall optimization will be obtained. Therefore, I think you should refer to the effectiveness or limitation of the application of the present methodology.

Question (Motoyuki Akamatsu, Human Technology Research Institute, AIST)

The contention of this paper is the composition using three different time scale models, which enables quantitative evaluation extending from the micro to macro level and finds the optimal point. However, how do you integrate or interrelate multi-scale models and use them?

Answer (Kiyoshi Nishioka)

The model proposed at this time does not have the optimization evaluation function that realizes overall optimization, and does not guarantee the overall optimization theoretically and quantitatively, nor can it be used as it is by installing it in the production control system.

The steel industry, the representative case of process industries, especially with integrated iron and steel manufacturers having blast furnaces, has physical constraints specific to its processes: its symbolic blast furnaces use natural resources as raw materials; its processes contain those of intense heat and high temperatures; and raw material yards, etc. are in the open air and are easily influenced by the weather/ climate. To overcome these problems, the steel industry has always pursued integrated continuous facilities, higher productivity and higher energy efficiency of high temperature processes by building larger-scaled works.

For conducting smooth production activities in such integrated and continuous large-scale production facilities, an enormous amount of information on equipment control and production control has to be handled, and therefore, it introduced a production control system supported by large-scale computers earlier than other industries. The production control system of an integrated steelworks has constraints as described above, in the upstream processes of the raw materials, ironmaking and steelmaking, which inevitably result in somewhat large fluctuation or variation in production. In the processes of intense heat and high temperatures, time constraints are substantial and no in-process stock is allowed, therefore, fundamentally its production structure is of the push-type. The “product” of the upstream processes of raw materials – ironmaking is mono-grade. During the early days of integrated steelworks, the final product types were limited and there were no such complicated requirements as today. Because of the above reasons, focus had been directed on the optimal control of high temperature processes, measures to deal with the production fluctuation/ variation of the upstream processes and the maximization of manufacturing lot sizes in the upstream processes by summarizing product order information. In contrast, very limited actions were taken for planning overall optimization of integrated manufacturing that examines, from the viewpoint of linking the quality control and delivery of ordered products, the manufacturing lead time and the in-process stock level in the processes of intermediate products such as hot rolling and plate mills, and for supporting scheduling.

To search for optimization, the existence of various models is essential, but compared with the assembly industries represented by the automobile industry, in the steel industry, the fluctuation of daily production and operation is large and moreover plans are frequently changed. In addition, because the model is developed based on the past records that also contain external disturbances, it is difficult at present to make a highly accurate estimation using models, and therefore, it is understood that the optimal answer that depends on the models that contain many errors is naturally limited in its reliability.

In such a situation, it is not realistic from the viewpoint of effectiveness, calculation load, and other work load, to conduct elaborate scheduling in daily routine work that rigorously searches for the answer to the overall optimization, and therefore, the approach to an optimal answer has to be continuous and asymptotic as shown by the example in this paper.

The proposed model grasps actual data for every term and in addition to the result-based production control that performs control based on such data, it identifies the cause-based phenomena from which such data are born. It can be considered as a tool for conducting better control. As a practical problem, huge difficulties may arise if a comprehensive model is to be created that covers all the time strata extending from the micro events that occur in a short time called processing in individual processes to the macro events that occur over a long time called manufacturing lead time that extends from the rolling start to the completion of manufacturing. If models developed through trial and error are overviewed as a whole, the structure is such that respective models link the overall picture going over the time strata, and therefore, this model is called the multi-scale hierarchically structured model. In other words, the proposed model is cause/ result-based straddling of a certain level of time strata, and even though it contributes to the understanding of phenomena extending structurally from the micro to macro level, it is not a model that guarantees an optimal answer. However, it can be understood that it provides a means of approach to the optimal answer continually and asymptotically. The above viewpoint is added in 6.2 “Significance of the multi-scale hierarchically structured model.”

5 Efficiency model

Question (Motoyuki Akamatsu)

What is the difference between the efficiency model and the conventional methodology of conventional production control?

Answer (Yasushi Mizutani)

Processing efficiency is defined, in the rolling processes, as the weight of slabs processed per hour, and in the finishing processes, as the number of plates processed per hour.

The rolling processes are comprised of the processes that are arranged continuously, in tandem and in direct connection and the processes are the slab yard process, heating process, roughing process, finish rolling process, accelerated cooling process and shearing process. In the slab yard process, slabs received from steelmaking are cut; in the heating process, the slabs are reheated; in the roughing process, the reheated slabs are rolled to the specified width; in the finish rolling process, the slabs rolled to the desired width are rolled to the specified thickness and length and the material property is integrated by controlled rolling; in the accelerated cooling process, the slabs after finish rolling are quenched using a large amount of cooling water, to integrate a quenched structure; and in the shearing process, the slabs after rolling/ cooling are divided. Steel plate products come in a wide variety of thicknesses, widths and lengths and of specifications in standards, and because the process conditions of each process are inevitably varied, the processing efficiency of each process varies significantly in response to the product specification. In other words, because the rolling processes are in a large scale and are also of mixed-flow production of many product types, and because the buffer between processes is small, friction between the preceding and subsequent material processing frequently occurs. Therefore, as the bottleneck processes found during processing change sequentially by every material, the efficiency of the overall rolling processes changes substantially, and therefore, it has been technically difficult to predict the efficiency accurately and easily. Most of the existing planning of production, manufacturing and processing used to be implemented by making various assumptions of conditions and calculating sequentially individual events that respond to their respective conditions, evaluating and comparing the results using the evaluation function and selecting the best fitting conditions. However, for large-scale and mixed-flow production of many product types, if the production permutation, i.e., the combination of simulation calculation conditions, becomes enormous, the load on the computer becomes excessive, and such a planning method is impractical.

Each rolling process has different factors that work against good processing efficiency. For example, in the slab yard process, they are slab cutting speed, slab weight, etc.; in the heating process, charging temperatures of the furnace, heating conditions (temperature to extract slabs from the furnace, time to keep slabs), etc.; in the roughing mill process, the extracting temperature from the furnace, slab sizes, etc.; in the finish rolling process, rolling speed, waiting time between completions for controlling rolled structure, length of rolling, etc.; and in the shearing process, cutting speed, cutting accuracy, etc.

In this efficiency model, these parameters that affect the processing efficiency of each process were extracted, and products were classified into groups for which these parameters have significant difference, and the processing efficiency was statistically calculated for every product group. In addition, a method was adopted to obtain the integrated efficiency specific to each product group by comparing the processing efficiency of each process for every product group classified in accordance with their product type, size, furnace charging temperature, etc., bottleneck processes in more than one sub-process arranged in tandem, in direct connection, and in multi-steps that are identified for each product group.

6 Integrated lead time model

Question(Motoyuki Akamatsu)

It is stated that the enhancement of the rolling process efficiency increased the requirement fluctuation of the finishing processes, but is it correct in understanding that the enhancement of efficiency led to larger lot sizes and with the increase in the lot sizes, because the finishing processes are varied, such lot has to wait for processing in the finishing processes, thereby increasing in-stock volume?

Regarding the variance of the spare delivery days, you state that the spare days for starting rolling against delivery date and the manufacturing lead time are independent, and the variance can be obtained by the sum of the respective variances. However, rolling start → manufacturing completion is contained in the rolling start → delivery date and it seems both are mutually dependent. Please additionally state why the spare days for starting rolling against the delivery date and the manufacturing lead time can be considered independent.

Answer (Yasushi Mizutani)

If the daily rolling volume increases thanks to the enhancement of the efficiency of the rolling process, inevitably the flow into the finishing processes, i.e., the required processing volume of the finishing processes, increases resulting in the increase of the fluctuation requirement. Your statement that “the enhancement of efficiency led to larger lot sizes” is correct. Larger variation of processing requirement in the finishing processes leads to longer waiting time and higher stock level.

The production of steel plates is characterized, as already stated in the paper, by receiving orders for various products (products of the same specification in one order are about 3 t), manufacturing them in lots (condition of the same steelmaking: min. 300 t, but considering productivity, desirably over 2,000 t) and delivering products in the unit of a lot (for the same customer, delivery date, transportation means). The delivery date is specified for the same shipment lot, but as requested by the customer, orders of various products are contained in one shipment lot, and the manufacturing lot does not generally agree with the shipment lot. Therefore, even though the timing to start rolling is determined by counting backward the manufacturing lead time set from the delivery date, variation is inevitable as a result of grouping products in a manufacturing lot, and at the same time, variation associated with the fluctuation of operation in the upstream process of steelmaking that is independent from plates exists.

In contrast, the manufacturing lead time is dependent on any processing requirement and on the operation fluctuation, and therefore, it is also with variation. Therefore, the spare delivery days are obtained as the difference in the spare days for starting rolling against delivery date (rolling start until delivery day) and the manufacturing lead time.

Spare delivery days = spare days for starting rolling against delivery date (rolling start until delivery day) − manufacturing lead time

If the two terms on the right are independent, the formula given in this paper of

$$\sigma_{\text{spare days until delivery}} = (\sigma_{\text{spare days for starting rolling against delivery}}{}^2 + \sigma_{\text{manufacturing lead time}}{}^2)^{1/2}$$

is valid. We verified this against past records to confirm that the relation expressed by the above formula is valid, and we concluded that the assumption of “the two terms on the right are independent” is quasi valid.

Information sharing platform to assist rescue activities in huge disasters

— System linkage via data mediation —

Itsuki NODA

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Various "unexpected" situations caused by the Great East Japan Earthquake severely hampered disaster-control systems of Japanese national and local governments. A flexible framework for disaster information systems that is reorganizable depending on circumstances is required to mitigate such serious situations. In this article, I propose the concept of "loose linkages" of information systems based on data mediation and a platform for disaster mitigation information sharing. The platform enables us to link various systems quickly, so that we can reconstruct disaster information systems according to various situations in major disasters. I found that the concept was effective for the Great East Japan Earthquake along with various ad-hoc activities of information volunteers. We should spread this concept and platform to Japanese national and local governments, and support organizations to prepare for future disasters.

Keywords : Information sharing, disaster mitigation, database, system integration

1 Introduction

The off the Pacific Coast of Tohoku Earthquake (The Great East Japan Earthquake) on March 11, 2011 showed us the mercilessness of a natural disaster, the diversity of damages, and the difficulty to make predictions. For the past 15 years, most of the earthquake disaster prevention in Japan was built on the model of the 1995 Hanshin Awaji Earthquake. The Hanshin Awaji Earthquake was an epicentral earthquake where there were many victims of collapsed houses and fire, and the major issues were wide-area firefighting and medical aid, as well as information sharing to support such activities. In order to solve the issues, prior agreements were made among the rescue organizations for the first response to the disaster, and mutual support setup were gradually organized among the local governments. On the other hand, in the 2011 earthquake, most of the victims were of the tsunami, and we were faced with many issues including the information transmission for the tsunamis that occurred with different time lags after the earthquake. Of course, the experience of the Hanshin Awaji Earthquake was utilized, and therefore the initial response and wide-area linkages among the various organizations have improved, and the efforts over the years have steadily fortified the disaster response. However, disaster measure is a kind of endless process, and we were forced to accept the fact that there will always be the *soteigai* (unexpected situations) even if we think we are prepared to the fullest.

In Japan, which is also called the Natural Disaster Archipelago,[1] we must continuously prepare for disasters. All local governments cannot escape from the various natural disasters including earthquakes, volcanic eruptions, tsunamis, typhoons, floods, wind damages, and heavy snow. Also, large cities such as the Tokyo metropolitan area, Keihanshin area, and Chukyo area have high density of buildings and transportations, which may magnify the effects of terrorism or disasters. In fact, major Japanese cities are ranked high as dangerous places susceptible to disasters.[2] Measures to reduce the disaster damage as much as possible are important to protect the lives and properties of the residents, and to help industrial promotion by ensuring a region where people can invest safely.

In disaster measures, establishing frameworks and systems to collect and utilize information is essential along with the preparations of hardware such as earthquake-proof structures. Case-by-case decisions are necessary to deal with disasters including the unexpected, and to do so, it is necessary to gather and share as much accurate information as possible.[3][4] In that sense, there is plenty of room for the development of a disaster prevention information system using the state-of-the-art information technology. However, in practice, during the Great East Japan Earthquake, handwritten memos were posted all over the walls and various pieces of information were scribbled on whiteboards. Communications between the organizations were mainly done by phone and fax, and these were the causes of delay and loss of communication. Of course, the importance of information collection and sharing is widely recognized,

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and various disaster information systems have been constructed by the central government, prefectures, and local municipalities. However, we rarely hear that such systems functioned as expected during the 2011 earthquake. The reasons why such disaster information systems could not be utilized may be because they were designed as closed and unalterable systems dedicated to disaster prevention. As with other disaster measures, the information system must have case-by-case flexibility.

The viewpoints important in designing the disaster information system that can overcome such difficulties are case-by-case flexibility and lifecycle. Since there are many phenomena that occur during a disaster, it is virtually impossible to predict all events and to incorporate the information processing functions into a system. In fact, in the hearings of the local governments after the Great East Japan Earthquake,[5] it became clear that the prior disaster prevention plan had to be altered in various ways. On the other hand, the activities of information volunteers functioned effectively, as will be explained in chapter 5. The characteristic of the activities by these volunteers was the case-by-case flexibility where the system was built according to the situation and real requirements. Of course, it is not practical to build a disaster information system entirely after an event occurs, but it is necessary to leave room to incorporate such case-by-case flexibility when designing the system. The viewpoint of lifecycle is the way of looking at the timescale difference of the day-to-day advancement of information technology versus the once-in-a-hundred or once-in-a-thousand year disaster. This means that rather than packing as much state-of-the-art technologies into the system as possible, the disaster information system must be designed by paying attention to the fact that technologies will become obsolete with passage of time and will be succeeded by newer technologies.

To establish a method for designing a disaster information system that incorporates the above two viewpoints, a concept of "data-centered ad hoc system building" is adopted in this paper. With this approach, the following three points form the design policy for building the information system.

- **Open system**: the design policy where each information system is built assuming usage of individual functions of the system separately and the system being able to be linked with other systems. This responds to the case-by-case flexibility and the lifecycle viewpoints.

- **Universal data format and protocol standard**: the design policy for simplifying the linkages of the functions and for creating common linkage parts to enable easy replacement and succession of the system. This responds to the case-by-case flexibility and the lifecycle viewpoints.

- **Downward scalability**[Note 1)]: the design policy that allows the system to operate on any type of information device or at any sized infrastructure. This responds to the case-by-case flexibility viewpoint.

As the core technologies to realize such a design policy, we introduce the disaster mitigation information platform that is the basic design of the system, the mitigation information sharing protocol (MISP) that is its core, and the database (DaRuMa). The relationships of the viewpoints, design policy, and core technologies are shown in Fig. 1.

The paper will be organized as follows. In chapter 2, the mitigation information sharing platform and its protocol database will be explained. In chapter 3, the design policy of the proposed platform will be discussed from the viewpoints of disaster prevention and mitigation. In chapter 4, the verification system of the proposed platform and examples of actual operating systems will be introduced. In chapter 5, case studies during the Great East Japan Earthquake will be taken up to discuss the effectiveness and the problems of the above design policy.

2 Design philosophy of the mitigation information sharing platform and its implementation

In this chapter, I will explain the design philosophy of the mitigation information sharing platform[6][7] that is the framework for sharing the disaster information proposed in this paper, the mitigation information sharing protocol (MISP) that is the center of its implementation, and the database for rescue utility management (DaRuMa).

2.1 Mitigation information sharing platform by data-centered module linkage

The framework of disaster information sharing is, as shown in Fig. 2, the linkages of the various disaster information systems (these will be called modules) operated by different organizations through the mediation by database. Here, this framework is called the mitigation information sharing platform.

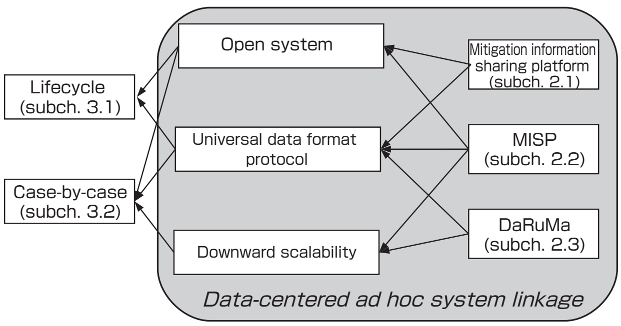


Fig. 1 Relationships of the viewpoints, design policy, and core technology of the disaster information system

As mentioned in the previous chapter, the important concept of this platform is the ad hoc module linkage mediated by data. That is, for each module, information sharing and function linkages are accomplished by retrieving data that were output by other modules to the database, rather than directly calling up the functions of other modules. By limiting to data mediation only, types of linkages are regulated, so that, this will ensure provision of a highly universal framework. The design policy where the modules are linked by a mediating module that acts as a central hub is not new. However, by limiting the linkage format to hub function and data mediation only, continuous and flexible system revision will be possible. Recently, there are many mechanisms where the advanced function linkages are done by the mash-up of web service, but in the framework proposed in this paper, considering the viewpoints of case-by-case flexibility and lifecycles, a simple mechanism is employed. The justification for this choice will be discussed in chapter 3.

2.2 Mitigation information sharing protocol (MISP)

MISP, the mitigation information sharing protocol, is the key of the mitigation information sharing platform.[8] MISP is a database access protocol based on XML, and it determines the basic functions necessary for the database, namely the ways of calling the data search (Query), registration (Insert) and correction (Update·Delete) (upper part of Fig. 3). Instead of preparing high-level functions like the data reconstruction function such as the table join in the structured query language (SQL), we intensively limited the small number of basic functions in order to simplify data expression and to make module linkages easy by data mediation. As a function to help the ad hoc linkages, the meta-function of the database including the data structure definition function (RegisterFeatureType) is provided online (lower part of Fig. 3). This data structure definition function allows additional online registration of the handled data format to the database using the XML Schema. Therefore, it is possible to add a new data format without stopping the system during the operation of the platform, and testing and updating of the new data format can be done in real time as a new module is added. This is an important function in the integration of the disaster prevention information system where it is necessary to link the modules across several organizations. If there is detriment such as stopping the entire system each time a new data format is registered, the module linkage which needs many trials-and-errors will be slowed down. This specification aims to avoid such barriers and to make the system linkage smooth by opening the calling of data feature type online at the module side.

In designing this protocol, emphasis was placed on maintaining the simplicity of the function and ease of description. With a usual Internet protocol design, one tends to consider advanced functions and expandability. For example, XPath and XQuery are being proposed as the retrieval protocol of XML database, but they have become complex to realize highly advanced retrieval and data reconstruction. In the field of information technology that continues to evolve every day, such short-term expandability is important, but as it will be discussed later, considering the fact that the lifecycle of disaster measures is a decade to a hundred years, we need a viewpoint different from the pursuit of advanced functions and expandability. Therefore, simplicity and ease are emphasized in the platform proposed herein. This will be discussed in chapter 3.

The basic function of MISP is based on the web feature service (WFS).[9] Using the various standards including the

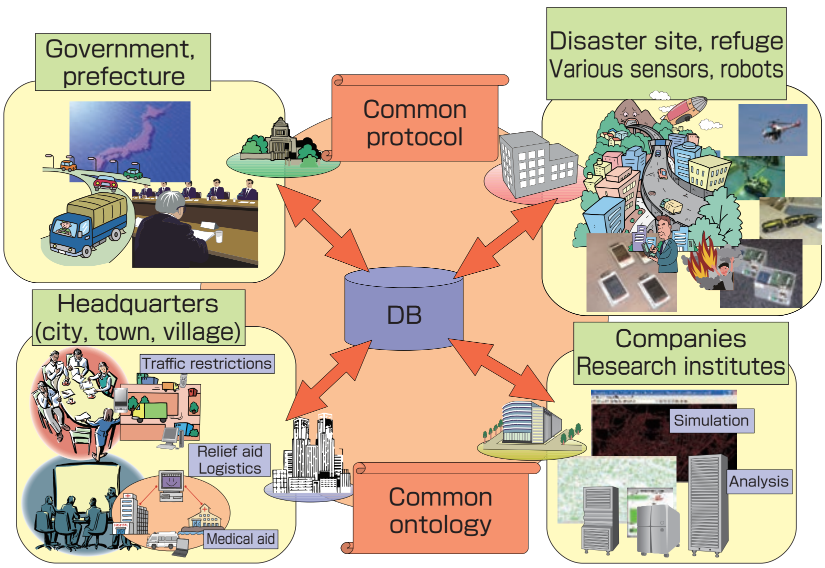


Fig. 2 Mitigation information sharing platform

geography markup language (GML),[10] XML Schema,[11] simple object access protocol (SOAP)[12] that are related to WFS, the areas that may be lacking in sharing the disaster information are defined as additional formats.

These are widely used and standardized by ISO and others, and aim to enhance the compatibility with the existing and future systems. The employment of the standard has the advantage that the existing tools can be used as is, and linkages and application with the systems other than for disaster measures can be done. Downward scalability is achieved by maintaining simplicity that allows handling by systems without large computational ability such as the sensor system.

The reasons for the employment of XML as the expression format are the same as the reasons for being employed in many systems recently, i.e., universality, flexibility and expandability of the data expression. There are four basic data types including numerals (integer, real number) and text, spatial/geographic expression (point, line, and plane defined by GML), and temporal expression necessary in disaster information.[Note 2)] It is possible to handle diverse data structure by defining the arbitrary combination using the XML Schema. That is, any fixed-structured data not limited to disaster information can be handled, and therefore the system can be utilized for normal time routines.

The protocols of MISP are shown in Fig. 4. This example defines a type of feature called ‘RoadLink’. It shows that the feature data are composed of the elements of ‘representativePoint’ described in GML, the list of crossroads (‘nodeList’) and road width (‘roadWidth’), in addition to a structure declared as ‘misp:GeometryFeature’ (defines the information element ‘gml:GeometryProperty’ for position).

2.3 Mitigation information sharing database DaRuMa

DaRuMa is a database developed as the prototype implementation that operates in accordance with MISP explained in subchapter 2.2. It operates as a hub to link the modules in the mitigation information sharing platform. The design and implementation of DaRuMa were conducted under the following policy.

- **Downward scalability and multi-platform**
  The required specification for the operating environment was kept simple as possible, to support a wide range of OS and hardware. Since the information and communication infrastructure may be damaged in a major disaster, high-performance servers and large-scale data centers may not be available. Therefore, one of the requirements was that it would operate in various and restricted computational environments.

- **Utilization of existing software and open sourcing**
  The purpose of the proposed platform was to establish the framework for information sharing during a disaster, and it was not R&D for a new database technology. Therefore, the consideration was to maximize the use of existing software and not to spend much on the development itself. Also, to establish this information sharing framework and to make the diffusion smooth, it was assumed that the results would be provided as open source.

The developed DaRuMa uses MySQL, an existing relational database, or PostGIS[Note 3)] as its backend, as shown in Fig. 5, and has a structure where mediation and conversion of SQL and MISP is done by a middleware written in Java (MISP Processor). Therefore, DaRuMa can be operated on a wide range of OS and hardware that supports Java and MySQL or PostGIS, and it was shown to run on versions of Linux, FreeBSD, Windows, and Mac OS. Moreover, there is a middleware implemented by Ruby, though this is limited in function, and this enables run on portable terminals such as Linux Zaurus, and downward scalability is achieved. The system is light, and in the demonstration experiment that will

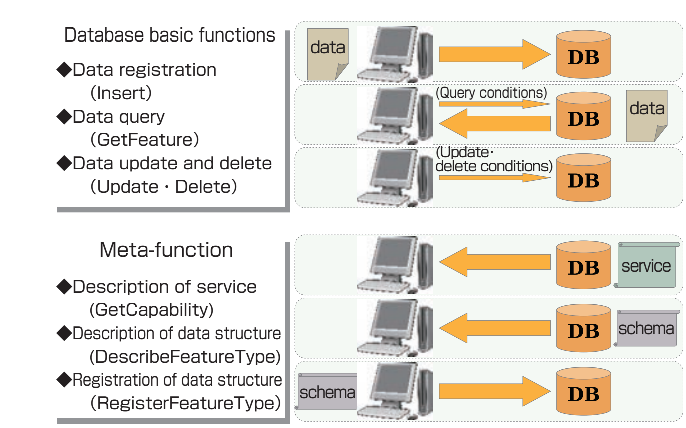


Fig. 3 Basic functions of MISP

```
<misp:RegisterFeatureType uri="urn:gfs:ddt:test:Node">
 <xsd:schema misp:id= "urn:gfs:ddt:test:Node" targetNameSpace= "http:..."
               xmlns= "http:...">
  <xsd:element name="RoadLink" type="RoadLinkType" />
  <xsd:complexType name="RoadLinkType">
   <xsd:complexContent>
    <xsd:extension base="misp:GeometryFeature">
     <xsd:sequence>
      <xsd:element name="representativePoint" type="gml:GeometryPropertyType" />
      <xsd:element name="nodeList" type="nodeListType" />
      <xsd:element name="roadWidth" type="xsd:float" />
      <xsd:element name="nLanes" type="xsd:integer" />
      <xsd:element name="direction" type="xsd:string" />
     </xsd:sequence>
    </xsd:extension>
   </xsd:complexContent>
  </xsd:complexType>
 </xsd:schema>
</misp:RegisterFeatureType>
```

Fig. 4 Example of data structure definition of MISP (RegisterFeatureType)

be explained in subchapter 4.2, we succeeded in receiving over 8,000 reports from residents in 30 minutes and linking them with other information systems and simulations, using an old model laptop PC (Mobile Pentium III 933 MHz, memory 512 MB). This performance is sufficient for disaster information system linkages of a medium sized city, and information systems can be operated on PCs no longer in use in times of emergency. To enable this, we also created the Linux live images where the DaRuMa will run automatically when booted from a USB.

Concurrently with the development of DaRuMa, the development and organization of the tools to connect the DaRuMa and various systems are done. In the mitigation information sharing platform, all modules communicate with DaRuMa by MISP. However it is not realistic to make all the currently existing disaster information system MISP compatible. Rather, it is more practical to achieve partial linkages using the functions of the existing systems and to gradually deepen the linkages when the system is updated, as shown in the right half of Fig. 6. As listed below, the DaRuMa tools are being developed to support such partial linkages.

- **CSV connection tool**
  This is a tool to convert the data output in a comma separated value (CSV) format into XML and to register them to DaRuMa through MISP. It is also a tool to convert the data obtained by MISP into CSV format. Many disaster information systems support the input/output of CSV files that is the universal data format of the spreadsheet software. Partial linkages may become automated by organizing this connection tool. For linkage automation, the functions of regular input/output of the temporal difference data and of setting the condition for data acquisition from DaRuMa are included.

- **GIS viewer linkage tool**
  This is a tool to convert the information (features) stored in DaRuMa linked with the position on the map to KML, and to display them on GIS viewer such as GoogleEarth and GoogleMap. In disaster information where the features will be relevant, it is important to check the information stored in the database on a map as needed to maintain linkages among the modules. The free or low-cost, high-performance GIS viewer such as GoogleEarth is effective as a means to provide information to related organizations, as well as providing linkage support, and the presence of connection tools is important in utilizing the existing software.

- **Log replay tool**
  This is a tool to utilize the log recorded with timestamp of database maneuver and MISP communication to DaRuMa, and to reproduce the flow of situations of shared information according to time steps. When adjusting the linkages of multiple modules, it may be difficult to keep all modules in usable status. Particularly, when conducting linkages across multiple organizations and institutions, they have limited opportunities to connect modules for linkage adjustment. Since the log replay tool will allow pseudo-reconstruction of the recorded receiver module activities, it is possible to simplify the linkage adjustment. This tool can also be used when conducting simulated joint training exercise.

3 Disaster information system linkage based on data mediation

3.1 Lifecycle of a system and continuity of data

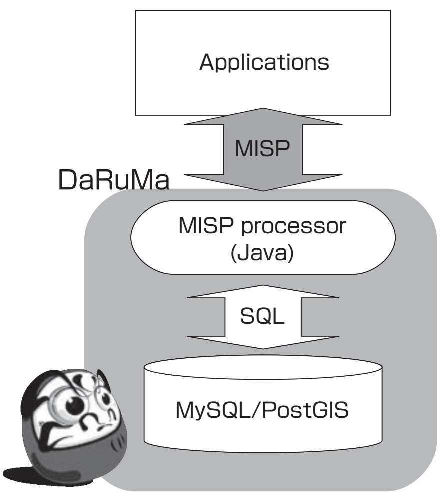


Fig. 5 Structure of DaRuMa

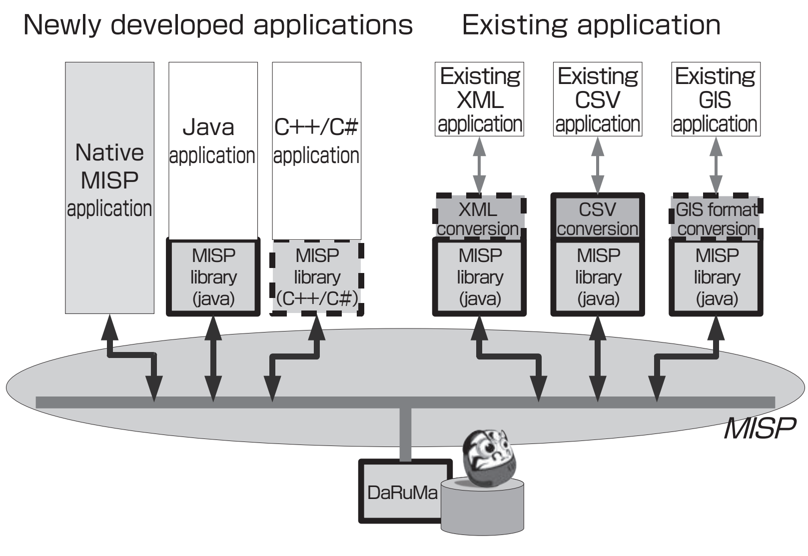


Fig. 6 System linkage by mitigation information sharing protocol (MISP) and DaRuMa

When designing the mechanism for sharing and utilizing the disaster information, particularly in designing the information system, the difference in the lifecycles of disaster and information technology must be carefully considered.

Most disasters occur irregularly and at long time intervals. For example, earthquakes of a scale that incurs societal damages occur at several decades to several hundred years time span, or in some cases in a thousand years for certain regions. The wind and flood damages occur relatively frequently but not regularly every year. Generally speaking, disasters cause unexpectedly large damages because they occur infrequently. In other words, the disaster information system will not operate most of the time, except during disaster drills or during those "infrequent moments." The disaster information system of the local government is updated at five to ten year intervals, and the latest technologies and functions are introduced during the updates. At the same time, old technologies and functions are gradually removed. Therefore, most systems and technologies may be used only a few times or finish their jobs without ever being deployed in actual disasters.

The difference in the time scale of lifecycles is overcome by the continuity of the data. Compared to frequent updates of systems, data is accumulated over a long time, and its lifespan is long. Particularly, value of data recorded in usable format may not become obsolete so quickly. As mentioned earlier, while the information systems of local governments may be updated by five to ten year intervals, it is important how the data is carried over during such updates. Therefore, in designing the disaster information sharing system, it is important to focus on the reusability and accumulation of the data over decades or a hundred years.

3.2 Data-centered case-by-case system linkage

The data-centered concept is important in the viewpoint of case-by-case system linkages. Responses to disasters are done by many organizations, and the disaster information system must be operated across such organizations. Designing and implementing a monolithic information system where multiple organizations are involved is very difficult in reality. The realistic solution will be for each organization to design and construct an information system individually as a subsystem, and to link them. In that case, there are two design policies of linkages: function-centered or data-centered.

One example of the function-centered system linkages is the web service linkage mechanism using the web services description language (WSDL) or universal description, discovery and integration (UDDI). In the web service linkages, individual servers realize and provide various functions, and a high-level service is achieved by combining them. This is excellent in that flexible response to diverse requirements can be realized easily, and is an effective concept for rescue activities where diverse responses are demanded. However, each server must be designed and implemented with consideration of "linkages," and the local governments must prepare the necessary functions.

The data-centered system linkages are represented by the blackboard model. In the blackboard model, each subsystem provides data to the common area (blackboard) or retrieves data from the common area to achieve linkages among the subsystems. In this concept, the subsystem can be operated as long as data are provided to the blackboard, and the "linkages" among the subsystems do not have to be the prime consideration. On the other hand, it is difficult to combine the functions closely or flexibility, and it is not suitable for achieving multiple, high functions.

Considering the fact that the disaster information system is utilized by the local governments throughout Japan, the mechanism of system linkages should be data-centered rather than function-centered. Japan spreads out from south to north, and there are various types of disasters. There are regions that suffer from heavy snow and other regions that must watch out constantly for floods. The functions required vary greatly and the combinations are complex. Also, the disaster prevention system of the local governments and the relevant organizations are not uniform, and the ways of building the subsystem differ. Therefore, the important points are which subsystems have the necessary functions and data and how to supplement the items that are short. While the supplementation of lacking functions is difficult to solve instantly, the lacking data is not too hard to supplement if the deterioration of dynamic property and accuracy can be tolerated.

Moreover, according to the hearings[5] of the local governments of the regions affected by the Great East Japan Earthquake, it has become apparent that many local governments had to alter existing disaster prevention plans because various unexpected conditions occurred. While the disaster prevention plans will certainly be reviewed thoroughly by the local governments after the Great East Japan Earthquake, it is necessary to maintain flexibility in the response, anticipating that the unexpected will happen. The information system must be designed as a system where the functions can be rearranged after an event. The key to allow quick rearrangement after an event is the simple linkage mechanism by data mediation. A case study will be presented with a demonstration system in the next chapter.

The data-centered system linkage concept is similar to the concept of the open source program development. In *The Cathedral and the Bazaar* (http://www.catb.org/%7Eesr/writings/cathedral-bazaar/; Japanese translation available in http://cruel.org/freeware/

cathedral.html), Eric S. Raymond introduces the words of a famous hacker:

> "Smart data structures and dumb code works a lot better than the other way around." (Fred Brooks: *The Mythical Man-Month*, Chapter 11)

> "Show me your flowchart and conceal your tables, and I shall continue to be mystified. Show me your tables, and I won't usually need your flowchart; it'll be obvious."(Fred Brooks: *The Mythical Man-Month*, Chapter 9)

In the open source system development done by numerous people under a relatively loose policy, it is important to reuse the modules created by other people. The above words show that the hand-over of reusable knowledge goes smoothly for data structures that handle modules rather than the functions of the modules. Similarly, many people and organizations will be involved in the design and development of partial modules in the disaster information system. The development span is long, and the transfer of the design philosophy and knowledge of the architecture are important. In that sense, the concept of data-centered module linkages is appropriate as the development method of the disaster information system.

4 Demonstration systems

The mitigation information sharing platform proposed in this paper was developed in the following projects: Special Project for Earthquake Disaster Mitigation in Urban Areas, Special Coordination Funds for Promoting Science and Technology, Science and Technology Project for a Safe and Secure Society, and Special Project for Earthquake Disaster Mitigation in Tokyo Metropolitan Area of the Ministry of Education, Culture, Sports, Science and Technology (MEXT); and Strategic Advanced Robotic Elements Engineering Development Project of the Ministry of Economy, Trade and Industry (METI). Several linkage systems were built through these projects, and demonstration experiments were done. In this chapter, the outline of the demonstration experiments in Mitsuke City and Toyohashi City will be described.

4.1 Demonstration experiment in Mitsuke City

When a disaster hits, the sharing of information reported among various sites and different sections is important. As an attempt in multiple linkages of various disaster information systems based on the proposed architecture, we conducted a demonstration experiment of using the DaRuMa mediation to integrate the various information systems of various institutions that were involved in the disaster prevention and mitigation during flooding, at Mitsuke City Hall, Niigata Prefecture, on October 27, 2006 (Fig. 7). In this experiment, the information from several divisions of the city hall, police and fire departments, and companies of lifelines such as for electricity and gas were integrated by DaRuMa mediation, and attempts were made to share the information among the divisions. At the same time, reports from disaster volunteers using portable terminals and automatic transmissions from water level sensors were integrated. We built an integrated system where the disaster response personnel would not be drowned in the organization of information and therefore could concentrate on disaster response activities.[13]

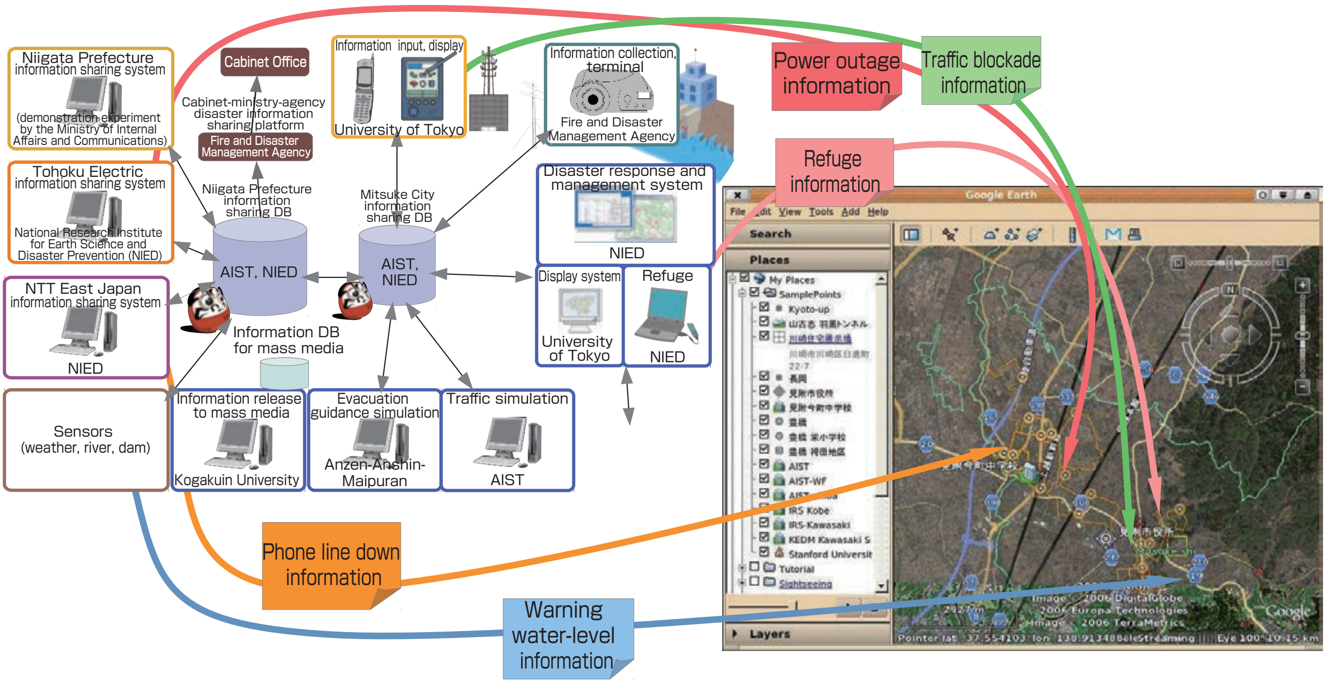


Fig. 7 Overall diagram of the Mitsuke City demonstration experiment

The characteristic of this experiment is that the linkages of over 10 information systems was accomplished in three days, as shown in Fig. 7. In general, time is required for system linkages for matching the functions and adjusting the protocols, and particularly, many steps are required when separately linking designed and implemented systems. On the other hand, in the proposed platform, the linkages were limited to only through the data on DaRuMa, and the protocol was a simple database protocol MISP. The changes to the systems were minimized to the modification to adapt for MISP. As a result, the system integration done in a short time became possible since the connection test between the individual systems and DaRuMa was simple.

This experiment was done as part of the disaster prevention drill of the city hall, and was carried out by the disaster prevention staff of the city using a realistic disaster scenario. Although the evaluation of such systems is difficult, we obtained the evaluation from the personnel who participated in the drill that the disaster response could be done accurately by unifying the information through system linkage.[13] Note 4) From this point and the little time required for system linkage, we can say that the effectiveness of the platform design philosophy was demonstrated.

4.2 Demonstration experiment in Toyohashi City

Several information systems for earthquakes were integrated with DaRuMa mediation at Toyohashi City, Aichi Prefecture on November 12, 2006 (Fig. 8). In this experiment, the voluminous information gathered from the citizens who gathered at the evacuation shelters were organized and integrated using DaRuMa. Based on this information, predictions of fire spread and traffic jams and the search of evacuation routes were done, and attempts were made to provide useful information to ensure smooth disaster response actions.[14][15] The citizens who arrived at the refuges reported the damages they saw when they were evacuating, and the accuracy of damage projections and disaster measures was increased by reflecting such information in the simulations. At the same time, another objective was to raise the citizens' consciousness for disaster prevention and their sense of involvement by visually showing that such citizens' information collection activities help the disaster measures.

The main focus of the proposed platform in this experiment was the simulation linkages (Fig. 9). In multiple simulation linkages, careful adjustment of dependent relations of the boundary conditions was necessary to connect the

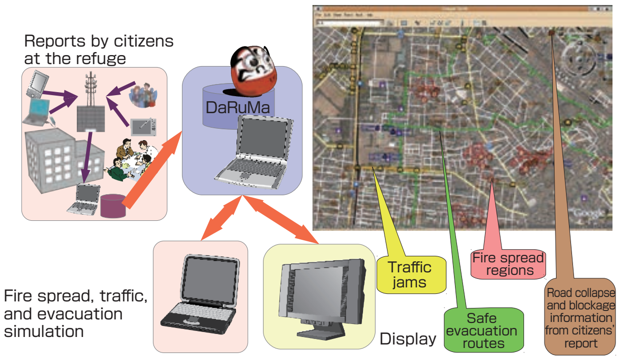


Fig. 8 System configuration for Toyohashi City demonstration experiment

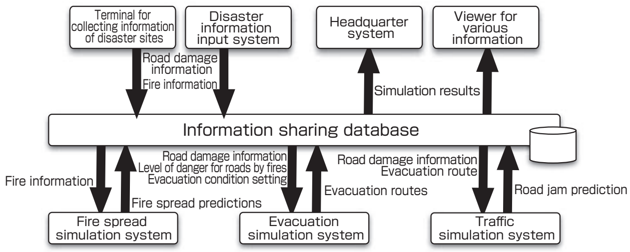
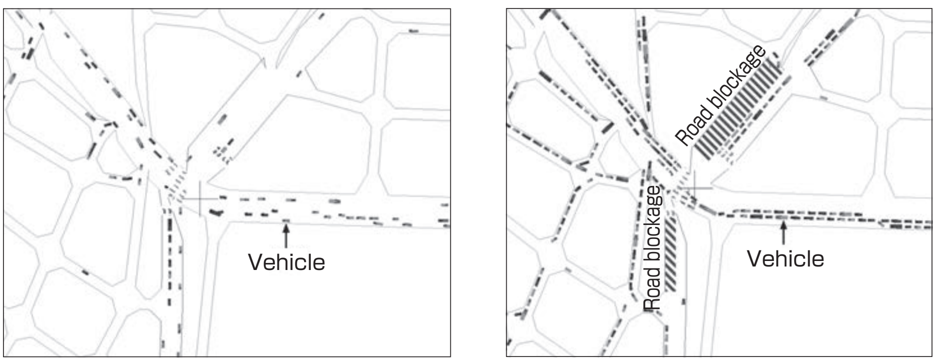


Fig. 9 System configuration for Toyohashi City demonstration experiment



(a) No road damage information (b) With road damage information

Fig. 10 Change in traffic simulation results with absence/presence of road damage information (around Takashiguchi, Toyohashi)

simulations. In this example, we did cut-offs to simplify the dependency relation to one-way, to make the linkages easy. While this cut-off policy is inferior in terms of close simulation linkages, there were many occasions where this worked sufficiently in the context of rescue. Also, since it was by database mediation, the computer environments for running multiple simulations did not have to match exactly, and this is important in realizing the case-by-case simulation linkages with various combinations. The operation of the simulation systems was as follows.

- **Fire spread simulation system**
  The initial setting was fire information reported from the sites, and the spread projections were done from that information.

- **Evacuation simulation system**
  Settings such as road damage information, projection of danger to roads by fire using the fire spread simulator, starting point and destination of evacuation, and others were obtained from the information sharing database, to determine the appropriate evacuation routes.

- **Traffic simulation system**
  The road damage information and evacuation routes were acquired, and simulation was done under a setting that the traffic was restricted on such roads, to predict the roads where traffic jams and congestions would occur.

Figure 10 shows the example of changes in traffic simulation results by the absence/presence of the road damage information. In this example, the difference in the projection of traffic jams is shown when the blocked road information of the main road from upper right to center was reflected in the simulation and when it was not. Each simulation module not only sorts and shifts the conditional information from the information sharing database, but outputs the simulation results to the information sharing database. The results can be checked against the damage information using the system of the disaster management headquarters, and enables use in other simulation modules. The system of this experiment shows that by handling the reports and various simulations as simple data links, the simulations at varying levels could be done easily, including the projections that incorporated the low accuracy information such as the reporting by the general public and simulation projections, as well as the analysis of highly accurate data only.

Interviews were conducted to the Toyohashi City Hall personnel after the experiment, as in the demonstration experiment at Mitsuke City. As a result, we obtained the evaluation that “it is important to handle the damage projection, emergency response demand load, and emergency response items at the onset of the event with shared recognition by all participants of the disaster management headquarters or the disaster management meeting,” and “the mechanism proposed in the experiment may be an effective means along with information gathering done by the government organizations.”

4.3 Toreta Doro (Passable Road) Map

To make the rescue and support activities in massive disasters as smooth as possible, the road information, particularly of passable roads is important for the rescue teams and relief supply carriers. However, most of the road information provided by the local government and police is information of blocked roads or restricted traffic. Moreover, it is not comprehensive information, and it is difficult for the relief

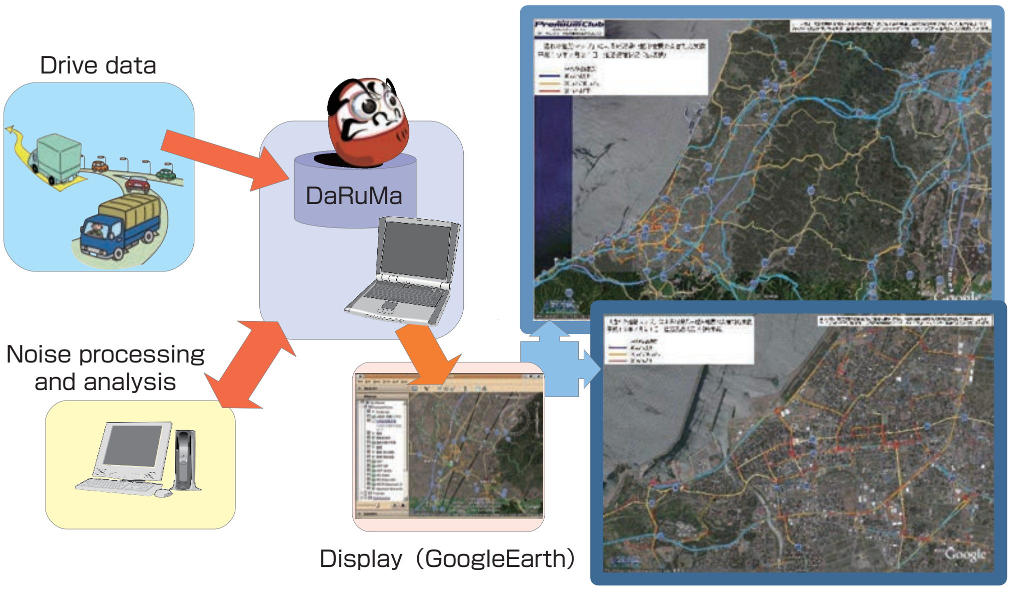


Fig. 11 Toreta Doro Map provided for the Chuetsu-oki Earthquake

teams, particularly those from outside the region, to find the routes to their destinations.

As a method to solve this problem, the passable road information was devised. Based on the driving data of automobiles, the roads that were actually used on a certain day or at a certain time after a disaster were identified and integrated with map data. Since a certain number of cars actually traveled on the roads, it could be expected that the roads were passable to some degree. Because many cars are equipped with car navigations with communication functions recently, it is possible to comprehensively capture the passage data of a specific region. It is also possible to categorize the roads according to the number of passing cars, and to estimate the usability as major roads.

With the cooperation from Honda Motor Co., Ltd. and jointly with Dr. Yasunori Hada of the University of Tokyo (currently at Yamanashi University), AIST organized the passability record information during the Niigata Chuetsu-oki Earthquake that occurred in July 2007. This was organized as the "Toreta Doro (Passable Road) Map" (Fig. 11) and this information was released on the web. For this "Toreta Doro Map," the passability record of each road was processed as follows. First, the drive route data of the vehicles that received Honda's communication car navigation system service were accumulated at the center. Of these data, the areas affected by the earthquake were organized per day, and after securing anonymity of personal information,[Note 5)] removing miss value and errors, and matching with the road data, the average speed for each road was calculated and the passability status was categorized into three levels. The results were overlaid and displayed on the GoogleEarth map, and this was released on the web as image data. The information was updated every day, and the passability of the prior day could be checked.

The production process of the "Toreta Doro Map" was done on the mitigation information sharing platform, and the progress of each process was stored on DaRuMa. Although this process was done by trials-and-errors after the earthquake, due to the data mediation format on DaRuMa, the trials-and-errors could be done quickly and simply, and information provision was commenced three days after the earthquake.

As it will be mentioned later, since this passability record information was established as a processing method, it was directly provided to the public from Honda in the Great East Japan Earthquake. Later, it spread by being provided by Toyota Motor Corporation and ITS Japan. Similar information was provided by ITS Japan during the flooding of the Kii Peninsula due to the typhoon in September 2011, and it has become standard disaster information.

5 Experience from the Great East Japan Earthquake

In the Great East Japan Earthquake of March 11, 2011, many people involved in disaster prevention were overwhelmed with the feeling of helplessness. At the time of writing this paper, there were 19,503 people dead or missing, and the economic damage continued to grow, including the accident at the Fukushima Daiichi Nuclear Power Plant.

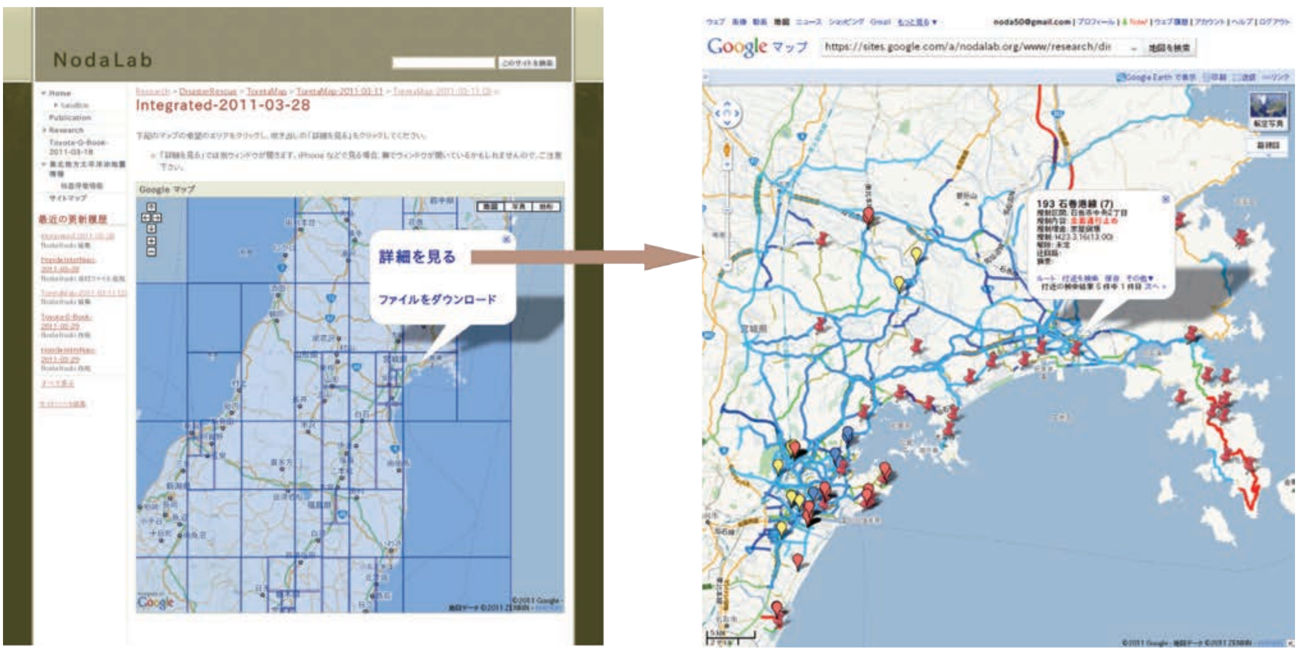


Fig. 12 Toreta Doro Map provided for the Great East Japan Earthquake

Even in such a situation, various forms of trials-and-errors were done to mitigate the damages as much as possible. There are many factors that enabled such mitigations, but it is thought that the design policy of the platform proposed in this paper, including the concept of open system, standard, and downward scalability functioned effectively.

In this earthquake, there was much relief and support by information volunteers on the Internet. For example, in the Person Finder led by Google, photos of the handwritten evacuee lists were shot with a digital camera, and the volunteers at the sites entered this information as text data to create a database. This simple but effective method was certainly supported by advanced technologies such as cloud computing and high-speed Internet, but it was a typical instance where simple functions (photo shooting by digital camera, text reading by people, and database search) were mediated by image and text data. Although there were time delays due to human processing, the linkages were made without problems, most likely due to the fact that it was mediated by data rather than by function.

As mentioned in subchapter 4.3, the "Toreta Doro Map" (road passability report information) was provided by Honda, Toyota, and ITS Japan. This time, detailed data was released using the KML, an international standard format. [Note 6)] Therefore, various attempts were made for information integration using the available data. For example, the author *et al*. lightened the weight of the passability information to create and provide a map that combined the information for gas stations and road blockages (Fig. 12).[17] There were also volunteers that worked to create image files of the passability information that was viewable only on PC so it could be viewed on cell phones. That several attempts can be made concurrently is one solution for responding to diverse needs in times of emergency. There should be more focus on the point that one of the foundations that makes this possible is the build-up of processing by data mediation through a universal format. Such grass-root system development and ad hoc system configuration centered on revisions and linkages are often neglected in disaster measures that are involved in the heavy mission of saving lives. However, considering the case-by-case response to the course of events including the unexpected ones, such loose but supple methods must also be considered. As a preparation, it is necessary to diffuse the system configuration based on the concepts of an open system, a universal format and a protocol standard, and downward scalability.

6 Conclusion

In this paper, the design policy for disaster information system based on the concept of module linkage centered on data mediation and the mitigation information sharing platform that is the implementation of this concept were discussed.

The concept of data mediation aims at rough and simple module linkages. It realizes the case-by-case linkages of simple functions rather than advanced linkages of high functions.

As discussed in chapter 3, whether major or minor, disasters include unexpected events, and the local governments must respond flexibly. Many of the cases in the Great East Japan Earthquake presented the necessity for case-by-case responses and the efficiency of the ad hoc system construction through data mediation to support such flexibility.

Of course, mere data linkages will not take care of all disaster prevention work, and security technology to handle privacy information and the framework for accurate and high-speed processing of massive data will become necessary and possible with the advancement of technology. The concept and the platform proposed in this paper must be developed further by responding to the changes.

Acknowledgements

This project was supported by the following: Special Project for Earthquake Disaster Mitigation in Urban Areas, Special Coordination Funds for Promoting Science and Technology, Science and Technology Project for a Safe and Secure Society, and Special Project for Earthquake Disaster Mitigation in Tokyo Metropolitan Area of MEXT; and Strategic Advanced Robotic Elements Engineering Development Project of METI. The system was developed with the cooperation from many people who participated in these projects. I am grateful for their cooperation.

Notes

Note 1) This is a concept where the system is designed so the function is maintained according to the capacity of the device, even if the system is run on a small and poor information processing device. The counter-concept is "upward scalability" where the function is maintained even if the size is increased.

Note 2) For multimedia data, there are several standard formats such as MIME, but some are difficult to handle with XML such as certain streaming formats, and there is the problem of data size. It is necessary to employ a format with emphasis on operation over long periods, and the choice should not be limited to XML.

Note 3) The connection with the backend database is implemented with abstracted API. So, switching to other database is easy.

Note 4) Mitsuke City experienced extensive damage in the 7.13 flood that occurred in July 2004, and many of the city staff experienced difficulties due to the confused information. In this experiment, the drill plan was created and evaluated based on that experience.

Note 5) Since an individual could be identified if there was only one passability report, only the data with multiple passability reports were extracted.

Note 6) In the Chuetsu-oki Earthquake, detailed information could not be released from the perspective of privacy protection, and we provided only the road map images. In the Great East Japan Earthquake, the privacy protection problem was under control, and we were able to provide detailed information.

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Discussions with Reviewers

1 Organization of the main points as a *Synthesiology* paper

Comment (Hideyuki Nakashima, Future University Hakodate)

This is a paper on the disaster information system realized by system linkages through data mediation. Its objective is to link the various and the future information systems, or to synthesize open systems where not everything can be predicted beforehand, and I think it is very appropriate as a *Synthesiology* paper.

As the editorial policy of *Synthesiology*, we expect a clear statement of the basic policy for the construction of such an open system. In fact, such a basic policy is actually written in the text of this paper. However, although I can understand the individual descriptions well, I think you should clarify the overall concept to help readers understand. Particularly, I think you should emphasize the "synthesis method," and provide descriptions with emphasis on the service engineering methods.

In chapter 1, you give the three basic policies of design: "open system, standard, and downward scalability." On the other hand, you also state the concept of data-centered (or data mediated linkages) in subchapter 2.1 and chapter 3. In subchapter 2.3, you give the two points of design and implementation policy: 1) downward scalability and multi-platform, and 2) utilization of existing software and open sourcing. The relationships among these points are not clear. I think you should organize the overall concept and provide descriptions using diagrams or tables.

As a proposal, I think you can give the characteristics that a disaster information system should possess, position the requirements in a top-down manner, and then position the corresponding implemented functions. Is my following understanding correct?

Characteristics of disaster information

- Various organizations (as well as individuals?) operate the disaster information system at varying scales.
- Difference in timescale of the disaster and the information technology
- Disaster measures must be updated frequently, and in some cases, complete makeover is necessary.

The system linkages by data mediation are optimal as the linkage platform that fulfills the above objectives. The requirements to realize such a platform are as follows:

- Simplify the new linkage connections
- Maintain universality: universal input format, universal output format, common structure, etc.
- Simplify the task for new linkages
- No need to consider computational capacity

The functions that came up as issues in implementation were as follows:

- Module linkages mediated by data: to link the various disaster information systems
- Data structure definition function: to test and update the new data format in real time when a new module is added
- Employ standards for the basic function of MISP: to increase compatibility with the existing and future systems. It should be simple, and should be capable of being handled by sensor systems without computational capacity.
- Employ XML: universality, flexibility, expandability
- Low requirement of operating environment: assuming that large servers may be down, it must run on small terminals
- Open sourcing: establish the framework of information sharing and allow smooth diffusion
- Tools to allow linkages, even partially, without limiting to MISP
  - ⋆ CSV connection tool: system widely supports the universal data format of spreadsheet software
  - ⋆ GIS viewer linkage tool: tool for displaying data on GIS viewers such as GoogleEarth
  - ⋆ Log replay tool: tool for reconstructing the changes in shared information of the various modules, including the time axis. Simplifies adjustment of linkages.

I think if you add tables or figures that show the relationships of these functions and the requirements in matrices, it will clarify the synthetic concept (research scenario) toward the research goal, and provide useful information as a *Synthesiology* paper to the readers.

Answer (Itsuki Noda)

Thank you very much for your useful advice. As you indicated, the flow of the entire paper and the relationships of the keywords were difficult to understand. I added some texts to chapter 1 to supplement the explanations. I also added figures to show the relationships of the keywords.

2 Title

Comment (Motoyuki Akamatsu, Human Technology Research Institute, AIST)

Please add a title and subtitle that clarify the above points. For example, "Construction of a platform for disaster information system linkage – Linkage of various information systems that change over a long period via data mediation." Please consider this along with the main points.

Also, please reconsider the subchapter titles of chapter 3 to clarify the main points of the paper.

Answer (Itsuki Noda)

For the title, I added "platform" which is the proposed technology. For the subchapter titles of chapter 3, I used the keywords discussed in subchapter 3.1 to clarify the corresponding relationships. I also added the subchapter numbers to the keyword relationship diagram in Fig. 1.

3 DaRuMa

Question (Motoyuki Akamatsu)

When I look at Fig. 7, it seems that there were two DaRuMas made, one for Niigata and the other for Mitsuke. Did you need two systems for smooth operation? Please explain why you had two DaRuMas.

Answer (Itsuki Noda)

During the experiment at Mitsuke City, there was no access control on DaRuMa, and all systems that could access DaRuMa could see all the information there. Therefore, the information that had to be kept closed within the city hall and offices could not be loaded to DaRuMa, and information sharing in the offices was stopped. To prevent this, we set up the internal DaRuMa and external DaRuMa, installed a mirroring tool with filtering functions, and only the information that can be released publicly was reflected in the external DaRuMa. Later, access control was added to the DaRuMa (and MISP) so such a dual setup is no longer necessary. In this paper, I describe the system configuration used during the experiment. Since access control is not the main subject of this paper, I will not include the explanation.

4 Map

Question (Motoyuki Akamatsu)

In this paper, you present the demonstration at Mitsuke City, demonstration at Toyohashi City, and Honda's Toreta Doro Map. I think it is extremely important to do the demonstrations on site, but what were the backgrounds in which you obtained permission to do the demonstration experiments? What were the motivations of the people on site to participate? Can you describe this to the extent of your knowledge? Were these people members of the MEXT or METI projects, and if so, what were the motivations for the organizations to participate in this project? What are the differences between organizations with and without motivations? I think this should be clarified in terms of synthesiology. Similarly, who initiated the passable road map by ITS Japan during the Great East Japan Earthquake?

Answer (Itsuki Noda)

Speaking of the relationship with the local governments that offered us the sites, it is most important that the relationship is built before and after the experiment, not just during the project. The local governments where the demonstration experiments discussed in this paper were done cooperated via individual relationships with the researchers who participated in the projects. Many of the relationships grew from coincidences, and often a leader of the local government or a person in charge of disaster prevention was very interested. Such coincidental relationships were nurtured carefully by the researchers, and a common consciousness for the disaster issues were identified by visiting the regions and the sites, to obtain understanding of the new technologies, and that led to the execution of the demonstration experiment. The project may last only a few years, but the relationships with the local areas exist from before and extend well after the termination of the projects. I simply received the benefits of the relationships nurtured by the joint researchers of the projects introduced herein, but I am spending effort to maintain as many relationships with various people after the completion of the projects.

For the case of ITS Japan, it started when I was thinking about the idea of Dr. Hada of the Yamanashi University during the Chuetsu-oki Earthquake. I happened to receive cooperation from Honda in the Chuetsu-oki Earthquake, and I was able to provide information, though in a small scale, using an improvised system. Thanks to this success, Honda and Google went into action in the Great East Japan Earthquake, and ultimately, the information was transmitted through the all-Japan system under ITS Japan. In this case, I think the continuity of the relationships from the time of Chuetsu and Chuetsu-oki Earthquakes (and way before that when I started to create various tools) is important, through activities such as the NPO study sessions.

Science and technology policy and synthesiology – Bridging science and values

[Translation from *Synthesiology*, Vol.5, No.2, p.135-140 (2012)]

One of the aims of the Fourth Science and Technology Basic Plan, which was decided by the Government of Japan last August, is to create "solution-seeking" or "issue-driven" innovations such as green innovation and life innovation. The Research Institute of Science and Technology for Society, Japan Science and Technology Agency (JST-RISTEX) is promoting various R&D programs that lead to the implementation of the research results in society. Because this approach is in line with *Synthesiology*, we talked to Dr. Tateo Arimoto, Director of JST-RISTEX, in a roundtable talk session.

***Synthesiology* Editorial Board**

Participants of the round-table talk

Tateo Arimoto	Director, JST-RISTEX and Professor, National Graduate Research Institute of Political Studies
Naoto Kobayashi	Vice editor-in-chief, *Synthesiology*
Motoyuki Akamatsu	Executive editor, *Synthesiology*

Kobayashi

Last year, the Fourth Science and Technology Basic Plan that covers the fiscal years from 2011 to 2015 was established. In face of crises in Japan including the Great East Japan Earthquake as well as the various global issues, the Plan spells out the basic science and technology policy for Japan to realize the ideals. Dr. Arimoto, you speak actively from your position where you have overviewed the national and global science and technology policies. Can you discuss your thoughts and experiences on the future trends, both domestic and overseas, on the science and technology policies, with focus on the Fourth Science and Technology Basic Plan?

The characteristic of Fourth Science and Technology Basic Plan "Significance of emphasis on solution-seeking research"

Arimoto

The Science and Technology Basic Law was established in 1995 with unanimous vote of the ruling and opposing parties in the Diet. In the background was a sense of crisis, though not as strong as it is now, that Japan's competitive capacity might decline as globalization progressed. During the 15 years from Phase 1 to Phase 3 of the Basic Plan, I believe there was a value in the emphasis on certain fields such as biotechnology, information technology, and nanotechnology, to fortify Japan's science and technology activities. However, with the changing global socio-economic system over the course of time, various weaknesses were exposed. Therefore in Phase 4, the direction shifted to problem solving and issue driven policy. It was supposed to be approved by the Cabinet at the end of March 2011, but after experiencing the East Japan Earthquake on March 11, it was reviewed and the weight has shifted even more toward demand-driven or solution-oriented topics. This is also a global trend. The science and technology policies of the world are driven from the policy of heavy emphasis on R&D upstream toward emphasis on innovation of how to create "value" from downstream as well as upstream.

Another point is that the Fourth Basic Plan proposes "deepening the relationship between society and science and technology" and "promotion of science and technology innovation with immediate effect." On the other hand, it is important to keep an eye on whether the support of basic science and basic research upstream is okay, and whether diversity and richness are maintained.

Kobayashi

In Phase 2, priority of resource allocation was given to the four focal areas of life science, information and communication, environment, and nanotechnology/materials. In Phase 3, selection and concentration were on our focal areas. In addition, national core technologies, solution-seeking R&D, and response to emerging and fused disciplines were set as main policies. Looking at the selection of the Funding for World Leading Innovative R&D on Science and Technology (FIRST), I got an impression that the effect of concentrating investments on nanotechnology and life science is clearly observed. What do you think about the promotion of life innovation and green innovations in Phase 4, and the "linkages" to system reformation for promoting science and technology innovation?

Arimoto

In general, I think there were many papers produced during these years. When you say "linkage," if you mean whether it is progressing toward the creation of final values, I'm afraid that is not necessarily going well. That is a total issue, and it is the fault of the scientific community, funding, policies, as well as companies. It also includes the issues of people's capabilities, consciousness, education, and whether there are paths to advance careers in the future.

Akamatsu

Synthesiology is a term where *synthesis* and *-ology* are joined, and perhaps "linkage" is a keyword. The researchers thought it was simply okay just to generate good research results, but now it is important to "link" those research results to social values. It is important to think what kind of approach should be taken to create a system that can utilize the research results in society, and to train "people" who are capable of working in that system.

Arimoto

It is important to share the roles and structures of the university research and education and the funding programs to see whether there is wide and diverse support and whether the support matches the research phases. There are the basic science and curiosity-driven research phases, and then there are the mission-oriented basic research, application, and prototype development phases. The scales of funding, research management and evolution systems are different according to the stages. I don't think such process and eco-system of innovation are shared among the scientists/engineers and bureaucracy/government and companies.

Trends of science and technology policies and promotion activities in other countries

Kobayashi

You have mentioned that the system or the structure for promoting innovation is not well understood in Japan. Is this a characteristic only of Japan? What is the situation overseas?

Arimoto

It is not as bad as in Japan. In other countries, there is a wide coverage from science and technology policies to science and technology innovation policies. As values become diverse and the world becomes connected, countries, particularly the advanced countries, are struggling to redesign an innovation system including funding management and reviews, human resource training, and others. How to maintain their competitiveness; how to sustain the development of science and technology to maintain the quality of life of their citizens; those are the important viewpoints.

What I wish to emphasize is that a funding system plays an extremely important role. The public research funding system was started by developing the system of grants, contracts and fellowships around 1930. The mechanism for convening the researchers and engineers to solve the research and technological issues across the boundaries of research institutes and universities was organized and nurtured. I think we must now return to the history of science policies and build a new model.

Kobayashi

You have mentioned the situation in the 1930s. The United States experienced the Manhattan Project where "amazing things could be accomplished when scientists are convened nationally." After World War II, this became the DARPA model. Are you suggesting that there is a reemergence toward the direction that scientists should cooperate across the boundaries to solve problems?

Arimoto

Exactly. Now, countries are trying to change the funding mechanism. While upstream has quite matured, the

Dr. Motoyuki Akamatsu

Dr. Tateo Arimoto

mechanism for downstream values is very weak. USA is trying to create a DARPA style mechanism under various agencies, and the Advanced Research Projects Agency - Energy (ARPA-E) under the US Department of Energy is one such example.

Giving examples of other countries, France set up a competitive funding organization called l'Agence Nationale de la Recherche (ANR) a few years ago, and it gives out fairly large amounts of funds. Sweden also created the Swedish Governmental Agency for Innovation Systems (VINOVVA). Britain has traditionally the strong Research Councils. In Germany, the Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V. is for basic research, while the work of the Fraunhofer-Gesellschaft, FhG is interesting as an innovation system. Other developing countries are emulating the examples and are creating their own funding systems.

Funding strategy for future science and technology

Kobayashi

You say "funding is important," and that is absolutely true for us who apply for funding. We create a matching proposal and the good ones are accepted. That means how to strategically create good funding is important for the policies.

Akamatsu

What one must not forget along with the importance of funding is who reviews the proposal and how it is reviewed. I often discuss with Dr. Kobayashi, "Is it possible to do reviews of proposals that are not analysis?" If one tries to score high to get funding, the content often ends up being one that can withstand analytic scrutiny.

Arimoto

That must be included in the objectives when designing the funding. If it is selected by peer review only, it tends to become conservative. In the United States, program officers (PO) and program directors (PD) have some level of decision-making authority based on their insights on the direction of the development of their specialties. The reason there is such a sense of crisis in the advanced nations is because they are faced with a situation where, to use the funds effectively, the current system must be changed and human resources must be recruited, as R&D money won't increase or perhaps will decrease as the financial status declines. I'm afraid Japan does not share this sense of crisis.

Dr. Naoto Kobayashi

Kobayashi

In the case of the United States, the PDs and POs are being trained as specialists at the National Science Foundation (NSF) and the National Institutes of Health (NIH). However, I don't think there is a system that trains such people in Japan. When the Japanese economy was moving upward on an incline in the 1970s and 1980s, were such roles filled by the technology officers of the Science and Technology Agency (STA) or the Ministry of International Trade and Industry (MITI)?

Arimoto

I think they were doing that in large-scale projects. This could be done, even if the officers in charge shifted in one to two years, because it was a catch-up model. They simply had to copy others. However, now that Japan's status has changed completely, it has to be done by professionals research administrators (or managers). Japan failed to respect such professional groups, or failed to train young people. That is why we are in deep trouble in this great turning point.

In Japan, there is a polarization of people who do research versus people who hand out money, and even in universities, they are divided into professors and managers. We suddenly realized that we have failed to train people who can "link" the two, or the mediators. There is no mechanism where people, like the science communicators, can carry out their jobs as a stable profession.

Kobayashi

In Japan, the training of researchers and policymakers for "science for the science and technology innovation policy" is important for building a new policy forming process.

Arimoto

In Japan, the Council for Science and Technology Policy has led the science and technology policy making. I think it will be important to establish the process of integrating the various policy analyses, designing the policy, and providing alternatives in an evidence-based manner, even though the politicians will make the final decisions. It is also important in the future to nurture the "people" and solidify the "methodology."

Kobayashi

In the United States, NSF is funding the Science of Science and Innovation Policy (SciSIP). Is US advanced in that aspect?

Arimoto
I think the US is doing alright so far, but it has its own problems. It has been five years since the Science of Science Policy fund was started, but a major part of the budgets has gone to analytical economic methodologies, according to information, and I think there's a feeling that that isn't right. When I introduced the Japanese SciSIP at the 2012 Annual Meeting of the American Association for the Advancement of Science (AAAS), Dr. Lewis Branscomb, former professor of Harvard University and a prominent figure of the science and technology policy, said, "I claimed that one should maintain balance of policy analysis and policy design in these fields, but there are still lots of analyses and no resolutions." This was a statement that made a powerful impression. Looking at the US and European university programs related to SciSIP, they are so diverse, and I believe there is still plenty of room for Japan to create a program that is internationally viable.

Activities of RISTEX and *Synthesiology*

Kobayashi
RISTEX engages in funding and program formation for the science for science innovation policy. Can you tell us what the current situation is?

Arimoto
The philosophical foundation of RISTEX is the Budapest Declaration (Commitment of Science in the 21st Century: "science for knowledge," "science for peace," "science for development," and "science in society, science for society"). Based on this declaration, the "Study Group on the R&D for Social Challenges" (Chairman Hiroyuki Yoshikawa) declared the following three points: "technology to solve the problems of society," "technology by the fusion of natural science, humanities, and social sciences," and "technology not affected by market mechanism." The Science and Technology for Society System was established, and this was reorganized and renamed as the Research Institute of Science and Technology for Society (RISTEX). Actually, the first five years were in the style of ordinary research grants that was immature as a methodology. Therefore, we were criticized severely that papers were produced, but it was not quite in line with the initial objective of solving the social problems. In the past five years, we intensively changed the mechanism of priority setting, the standard for screening, and the ways of funding and doing management and evaluation. I think now these methods are becoming fairly mature.

Kobayashi
The RISTEX research projects are conducted throughout Japan. Can you give us some interesting cases?

Arimoto
We have been supporting about 80 projects across Japan, For example, the representative of the project "Measurement of crime damages against children and the establishment of demonstrative core for crime prevention activity" in FY2007 was a section manager at the National Research Institute of Police Science. He said, "There is no scientific data for preventing crimes against children, and it is not set up so we can accumulate case studies. I want to do a scientific version of the traditional detective's 'a lot of legwork and the use of one's insight to gather information.'" With the help from the region, data was collected, and areas of high risks were marked. Last year, the World Congress of the International Society for Criminology was held in Kobe where the case studies were presented, and the work was highly acclaimed.

Another case that was beyond our expectation is the "Development and training for forensic interviews to protect children against crimes" that was selected in FY2008. The representative of this project was a psychology professor of the Hokkaido University. This is about who would interview a child when the child has become a victim of a crime. For example, when a stern-faced policeman asks questions or depending on how the questions are asked, the child may not tell the truth or become reluctant to talk out of fear. Therefore, with the cooperation of the Children's Guidance Center, methods have been developed and personnel members of the regional centers have been trained. This method is spreading throughout Japan. This is a good example.

In the "Nagahama Rule for the genome epidemiology research open to the region," the representative was an official of Nagahama City. There was a proposal from a university to Nagahama that it wanted to use Nagahama citizens for a genomic epidemiology research. A committee was formed, and discussions were held among the university researchers, citizens, officials, and mediators. This resulted in an ordinance of Nagahama City, and an NPO was created to continue and expand these activities.

As you can see, there is a story behind each project. It is said that the generalization of such stories is important, and I truly think so, being involved in the projects myself. To conceptualize, we need lots of case studies and scientific methods, and it is important to know and understand thoroughly the actual situation behind each case.

Contact point with the utilization of research results in society, the aim of *Synthesiology*

Akamatsu
The problem is searched and extracted, the R&D is conducted, and a prototype is made. Perhaps it is small and much effort is needed until a certain stage, but it will be gotten done. To implement this in society, probably it may not be done in three years, but it may be done in five years. When it is done and can be shown, people will say "Great!"

and then you can step up. I think we have to install some kind of "mechanism" for that.

Arimoto

Exactly. Something that was done in a certain place can be done in another place if the region is about the same size and has a similar social capital culture. As Dr. Hiroyuki Yoshikawa mentioned after the 3.11 earthquake, one of the touchstones for how to spread that to a wider region is perhaps by creating a fellowship system where young researchers and post-docs are sent to the various disaster areas. Maybe that will generate new ideas and insights. I think this is an important advice.

Kobayashi

To actually apply the prototype to society, the effort of how to express this as a study is necessary. *Synthesiology* started from that point of view. When Dr. Yoshikawa came to AIST, he said that *Full Research* where the *Type 1 Basic Research*, *Type 2 Basic Research*, and *Product Realization Research* are done coherently is important. *Type 1 Basic Research* is mostly analytical research evaluated in the traditional peer review. We were thinking about promoting research that widely selects, synthesizes, and integrates the knowledge of different fields based on a scenario centering on *Type 2 Basic Research*. Since we felt that there was no place to publish the results and to evaluate them as a study, we published *Synthesiology*. Therefore, the greatest concept is "for society," but as Mr. Arimoto said, the most important is how to write the scenario and how to link results to implementation in society.

Since this journal is an –ology or "study," it may start from a researcher's curiosity. However, we have the authors clearly state how the research may link to society, write the scenario, describe which elemental technologies are selected, explain the relationships among the elements and their integration, and state the future prospects, in an academic paper form. While listening to you today, I thought that your work done at JST and RISTEX seems to be similar to *Synthesiology*.

Arimoto

I think there are similarities. The "Message" for the launch of *Synthesiology* is very carefully written. It is important to nurture this approach as a type of discipline and to increase awareness. On the other hand, when a discipline creates its domain, it attempts to exclude others. Both *Synthesiology* and RISTEX, however, must create associates and communities that support them in order to help this approach grow.

Akamatsu

RISTEX states that it attempts to link the "observing scientist" who understands the regional demands and social issues and the "engineering scientist" who proposes the methodology and design to solve the problem, as well as linking the "actors" and "scientists" in society. I think the problems of "science for society" and how to set the career path of the people who are capable of such engineering research are closely related.

Arimoto

Yes indeed. I feel many people who engage in "science for policies" are similar to engineering scientists. I am very concerned about their career paths.

Kobayashi

It is indeed "science for society."

Arimoto

AIST conducted a synthesiology workshop at the annual meeting of the Japan Society for Science Policy and Research Management last year. I think it is very important to conduct activities outside of your institution. It is "co-creation" where each part maintains independence. I think this "co-creation" will be the keyword in social technology.

I think this is a movement. This movement has been done individually, as *Synthesiology* by AIST and practice of specific cases by RISTEX. Both have arrived at the phase where the methodology could be organized by meta-phase. It is important to collect case studies. I hope we can summarize the case studies that continuously accumulate along some axis.

In *Synthesiology*, the names of the reviewers and the discussions are disclosed, and this is very important for the development of new methodologies and the axis of evaluation. I think you are doing very well. I hope you continue.

Akamatsu

When the reviewers are selected, one is selected from those who understand the field and another is from outside the field. One of the characteristics is that it is not a peer review.

You mentioned the career path of the personnel. This is a very important subject.

Arimoto

Yes, indeed. It is the issue of human resource. At RISTEX, if there is one post-doc or a young researcher for one project, then there are nearly 100 people. One case that made an impression on me is that of a professor at Gunma University who developed a "comprehensive disaster scenario simulator for tsunamis." He was working on activities to raise consciousness for disaster among the residents and to provide disaster prevention education to elementary and junior high students. One of his activity sites was Kamaishi which was hit badly by the 3.11 tsunami last year. He told people of the town, "Do not trust the tsunami simulation. Nature very often outdoes simulation." This was imprinted so deeply in their minds that the children could make decisions on their own and wisely fled from the tsunami. That is why 3,000 children in Kamaishi successfully survived. It is called the "Kamaishi Miracle."

That is it. It is ultimately "people" who are the key. People who focus on social implementation have different goals than production of papers—not writing papers, but "I want to save as many people as possible at times of emergency." The traditional discipline-based researchers of modern science will not say that because that will be denying their own work. However, many young researchers who engaged in action research suffer from the fact that they cannot write papers. That is probably why *Synthesiology* was created.

Akamatsu

Indeed, it is difficult to write about social implementation in an academic paper. I think *Synthesiology* is a receptacle for such papers.

Education at the engineering department must shift from paper first to value first

Kobayashi

I think engineering was originally for making things that are useful for society. However, engineering turned into science and has moved toward analysis.

One such example is the architecture department in the university. The evaluation is higher for people who can leave excellent architectural work rather than someone who writes a lot of papers, but that makes it difficult for architecture to be considered an academic discipline. Therefore, we decided to create a journal where the making of an architectural work can be published as a result.

Arimoto

What Dr. Kobayashi just said is very important, and Dr. Yoshikawa has stated this recently also. The method of education and training at the engineering department must be changed, and there must be a shift "from paper first to value first." The curriculum of the engineering department must be changed. When the Japan Accreditation Board for Engineering Education (JABEE) joined the Washington Accord in 2005, an international panel came to Japan for screening, and I was surprised that it was written clearly in its report, "Japanese engineering education should be redesigned. It does not teach systems or design. There is no training." The Imperial College of Engineering at the beginning of the Meiji Period, however, did provide world-leading sandwich-style engineering education with thorough basics, practice, and training.

One of the greatest reasons for this change is because people have walked into their own little narrow paths and have become discipline-based. They cannot provide overall, synthesized knowledge and policy options that the citizens desire or the government wants. For example, they cannot discuss what will become of Fukushima in the future based on scientific knowledge. After March 11 last year, the responses of the Japanese scientists and engineers to the public and policies were so divorced from the expectations of society. The citizens saw this. There is a spread of distrust for science. We must do something about this.

Kobayashi

What we, the scientists, can do and how *Synthesiology* can contribute are topics we would like to continue to discuss. Thank you very much for today.

This roundtable talk was held at JST-RISTEX in Chiyoda-ku, Tokyo on February 27, 2012.

Profile

Tateo Arimoto
Completed the master's course at the Graduate School of Science, Kyoto University in 1974. Joined the Agency of Science and Technology in 1974. Worked as the Deputy Director General for Policy on Science and Technology and Director-General, Science and Technology Policy Bureau, Ministry of Education, Culture, Sports, Science and Technology. Works as the Director, JST-RISTEX and Deputy Director, Center for Research and Development Strategy, JST from 2006. Professor of the National Graduate Institute for Policy Studies, Visiting professor of Doshisha University, Waseda University, and Tokyo University of Science. Books and papers include "Science and Technology Policy",(by T.Arimoto, in *Have Japanese Firms Changed*, edit. by Y. Nakata and H. Miyoshi, Palgrave Macmillan, 2011) and "Rebuilding Public Trust in Science for Policy Making"(by Tateo Arimoto and Yasushi Sato, *Science*, Policy Forum, in press).

Editorial Policy

Synthesiology Editorial Board

Objective of the journal

The objective of *Synthesiology* is to publish papers that address the integration of scientific knowledge or how to combine individual elemental technologies and scientific findings to enable the utilization in society of research and development efforts. The authors of the papers are researchers and engineers, and the papers are documents that describe, using "scientific words", the process and the product of research which tries to introduce the results of research to society. In conventional academic journals, papers describe scientific findings and technological results as facts (i.e. factual knowledge), but in *Synthesiology*, papers are the description of "the knowledge of what ought to be done" to make use of the findings and results for society. Our aim is to establish methodology for utilizing scientific research result and to seek general principles for this activity by accumulating this knowledge in a journal form. Also, we hope that the readers of *Synthesiology* will obtain ways and directions to transfer their research results to society.

Content of paper

The content of the research paper should be the description of the result and the process of research and development aimed to be delivered to society. The paper should state the goal of research, and what values the goal will create for society (Items 1 and 2, described in the Table). Then, the process (the scenario) of how to select the elemental technologies, necessary to achieve the goal, how to integrate them, should be described. There should also be a description of what new elemental technologies are required to solve a certain social issue, and how these technologies are selected and integrated (Item 3). We expect that the contents will reveal specific knowledge only available to researchers actually involved in the research. That is, rather than describing the combination of elemental technologies as consequences, the description should include the reasons why the elemental technologies are selected, and the reasons why new methods are introduced (Item 4). For example, the reasons may be: because the manufacturing method in the laboratory was insufficient for industrial application; applicability was not broad enough to stimulate sufficient user demand rather than improved accuracy; or because there are limits due to current regulations. The academic details of the individual elemental technology should be provided by citing published papers, and only the important points can be described. There should be description of how these elemental technologies are related to each other, what are the problems that must be resolved in the integration process, and how they are solved (Item 5). Finally, there should be descriptions of how closely the goals are achieved by the products and the results obtained in research and development, and what subjects are left to be accomplished in the future (Item 6).

Subject of research and development

Since the journal aims to seek methodology for utilizing the products of research and development, there are no limitations on the field of research and development. Rather, the aim is to discover general principles regardless of field, by gathering papers on wide-ranging fields of science and technology. Therefore, it is necessary for authors to offer description that can be understood by researchers who are not specialists, but the content should be of sufficient quality that is acceptable to fellow researchers.

Research and development are not limited to those areas for which the products have already been introduced into society, but research and development conducted for the purpose of future delivery to society should also be included.

For innovations that have been introduced to society, commercial success is not a requirement. Notwithstanding there should be descriptions of the process of how the technologies are integrated taking into account the introduction to society, rather than describing merely the practical realization process.

Peer review

There shall be a peer review process for *Synthesiology*, as in other conventional academic journals. However, peer review process of *Synthesiology* is different from other journals. While conventional academic journals emphasize evidential matters such as correctness of proof or the reproducibility of results, this journal emphasizes the rationality of integration of elemental technologies, the clarity of criteria for selecting elemental technologies, and overall efficacy and adequacy (peer review criteria is described in the Table).

In general, the quality of papers published in academic journals is determined by a peer review process. The peer review of this journal evaluates whether the process and rationale necessary for introducing the product of research and development to society are described sufficiently well.

In other words, the role of the peer reviewers is to see whether the facts necessary to be known to understand the process of introducing the research finding to society are written out; peer reviewers will judge the adequacy of the description of what readers want to know as reader representatives.

In ordinary academic journals, peer reviewers are anonymous for reasons of fairness and the process is kept secret. That is because fairness is considered important in maintaining the quality in established academic journals that describe factual knowledge. On the other hand, the format, content, manner of text, and criteria have not been established for papers that describe the knowledge of "what ought to be done." Therefore, the peer review process for this journal will not be kept secret but will be open. Important discussions pertaining to the content of a paper, may arise in the process of exchanges with the peer reviewers and they will also be published. Moreover, the vision or desires of the author that cannot be included in the main text will be presented in the exchanges. The quality of the journal will be guaranteed by making the peer review process transparent and by disclosing the review process that leads to publication.

Disclosure of the peer review process is expected to indicate what points authors should focus upon when they contribute to this journal. The names of peer reviewers will be published since the papers are completed by the joint effort of the authors and reviewers in the establishment of the new paper format for *Synthesiology*.

References

As mentioned before, the description of individual elemental technology should be presented as citation of papers published in other academic journals. Also, for elemental technologies that are comprehensively combined, papers that describe advantages and disadvantages of each elemental technology can be used as references. After many papers are accumulated through this journal, authors are recommended to cite papers published in this journal that present similar procedure about the selection of elemental technologies and the introduction to society. This will contribute in establishing a general principle of methodology.

Types of articles published

Synthesiology should be composed of general overviews such as opening statements, research papers, and editorials. The Editorial Board, in principle, should commission overviews. Research papers are description of content and the process of research and development conducted by the researchers themselves, and will be published after the peer review process is complete. Editorials are expository articles for science and technology that aim to increase utilization by society, and can be any content that will be useful to readers of *Synthesiology*. Overviews and editorials will be examined by the Editorial Board as to whether their content is suitable for the journal. Entries of research papers and editorials are accepted from Japan and overseas. Manuscripts may be written in Japanese or English.

Required items and peer review criteria (January 2008)

	Item	Requirement	Peer Review Criteria
1	Research goal	Describe research goal ("product" or researcher's vision).	Research goal is described clearly.
2	Relationship of research goal and the society	Describe relationship of research goal and the society, or its value for the society.	Relationship of research goal and the society is rationally described.
3	Scenario	Describe the scenario or hypothesis to achieve research goal with "scientific words".	Scenario or hypothesis is rationally described.
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.	Elemental technology(ies) is/are clearly described. Reason for selecting the elemental technology(ies) is rationally described.
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".	Mutual relationship and integration of elemental technologies are rationally described with "scientific words".
6	Evaluation of result and future development	Provide self-evaluation on the degree of achievement of research goal. Indicate future research development based on the presented research.	Degree of achievement of research goal and future research direction are objectively and rationally described.
7	Originality	Do not describe the same content published previously in other research papers.	There is no description of the same content published in other research papers.

Instructions for Authors

"Synthesiology" Editorial Board
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Revised June 18, 2008
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Revised March 23, 2009
Revised August 5, 2010
Revised February 16, 2012

1 Types of contributions

Research papers or editorials and manuscripts to the "Readers' Forum" should be submitted to the Editorial Board. After receiving the manuscript, if the editorial board judges it necessary, the reviewers may give an interview to the author(s) in person or by phone to clarify points in addition to the exchange of the reviewers'reports.

2 Qualification of contributors

There are no limitations regarding author affiliation or discipline as long as the content of the submitted article meets the editorial policy of Synthesiology, except authorship should be clearly stated. (It should be clearly stated that all authors have made essential contributions to the paper.)

3 Manuscripts

3.1 General

3.1.1 Articles may be submitted in Japanese or English.
Accepted articles will be published in Synthesiology (ISSN 1882-6229) in the language they were submitted. All articles will also be published in Synthesiology - English edition (ISSN 1883-0978). The English edition will be distributed throughout the world approximately four months after the original Synthesiology issue is published. Articles written in English will be published in English in both the original Synthesiology as well as the English edition. Authors who write articles for Synthesiology in Japanese will be asked to provide English translations for the English edition of the journal within 2 months after the original edition is published.
3.1.2 Research papers should comply with the structure and format stated below, and editorials should also comply with the same structure and format except subtitles and abstracts are unnecessary. Manuscripts for "Readers' Forum" shall be comments on or impressions of articles in Synthesiology, or beneficial information for the readers, and should be written in a free style of no more than 1,200 words. Editorials and manuscripts for "Readers' Forum" will be reviewed by the Editorial Board prior to being approved for publication.
3.1.3 Research papers should only be original papers (new literary work).
3.1.4 Research papers should comply with various guidelines of research ethics.

3.2 Structure

3.2.1 The manuscript should include a title (including subtitle), abstract, the name(s) of author(s), institution/contact, main text, and keywords (about 5 words).
3.2.2 Title, abstract, name of author(s), keywords, and institution/contact shall be provided in Japanese and English.
3.2.3 The manuscript shall be prepared using word processors or similar devices, and printed on A4-size portrait (vertical) sheets of paper. The length of the manuscript shall be, about 6 printed pages including figures, tables, and photographs.
3.2.4 Research papers and editorials shall have front covers and the category of the articles (research paper or editorial) shall be stated clearly on the cover sheets.
3.2.5 The title should be about 10-20 Japanese characters (5-10 English words), and readily understandable for a diverse readership background. Research papers shall have subtitles of about 15-25 Japanese characters (7-15 English words) to help recognition by specialists.
3.2.6 The abstract should include the thoughts behind the integration of technological elements and the reason for their selection as well as the scenario for utilizing the research results in society.
3.2.7 The abstract should be 300 Japanese characters or less (125 English words). The Japanese abstract may be omitted in the English edition.
3.2.8 The main text should be about 9,000 Japanese characters (3,400 English words).
3.2.9 The article submitted should be accompanied by profiles of all authors, of about 200 Japanese characters (75 English words) for each author. The essential contribution of each author to the paper should also be included. Confirm that all persons who have made essential contributions to the paper are included.
3.2.10 Discussion with reviewers regarding the research paper content shall be done openly with names of reviewers

disclosed, and the Editorial Board will edit the highlights of the review process to about 3,000 Japanese characters (1,200 English words) or a maximum of 2 pages. The edited discussion will be attached to the main body of the paper as part of the article.

3.2.11 If there are reprinted figures, graphs or citations from other papers, prior permission for citation must be obtained and should be clearly stated in the paper, and the sources should be listed in the reference list. A copy of the permission should be sent to the Publishing Secretariat. All verbatim quotations should be placed in quotation marks or marked clearly within the paper.

3.3 Format

3.3.1 The headings for chapters should be 1, 2, 3…, for subchapters, 1.1, 1.2, 1.3…, for sections, 1.1.1, 1.1.2, 1.1.3.

3.3.2 The text should be in formal style. The chapters, subchapters, and sections should be enumerated. There should be one line space before each paragraph.

3.3.3 Figures, tables, and photographs should be enumerated. They should each have a title and an explanation (about 20-40 Japanese characters or 10-20 English words), and their positions in the text should be clearly indicated.

3.3.4 For figures, image files (resolution 350 dpi or higher) should be submitted. In principle, the final print will be in black and white.

3.3.5 For photographs, image files (resolution 350 dpi or higher) should be submitted. In principle, the final print will be in black and white.

3.3.6 References should be listed in order of citation in the main text.

Journal – [No.] Author(s): Title of article, Title of journal (italic), Volume(Issue), Starting page-Ending page (Year of publication).

Book – [No.] Author(s): Title of book (italic), Starting page-Ending page, Publisher, Place of Publication (Year of publication).

4 Submission

One printed copy or electronic file of manuscript with a checklist attached should be submitted to the following address:

Synthesiology Editorial Board
c/o Website and Publication Office, Public Relations Department, National Institute of Advanced Industrial Science and Technology(AIST)
Tsukuba Central 2 , 1-1-1 Umezono, Tsukuba 305-8568
E-mail: synthesiology@m.aist.go.jp

The submitted article will not be returned.

5 Proofreading

Proofreading by author(s) of articles after typesetting is complete will be done once. In principle, only correction of printing errors are allowed in the proofreading stage.

6 Responsibility

The author(s) will be solely responsible for the content of the contributed article.

7 Copyright

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Letter from the editor

It is now the fifth year from the launch of *Synthesiology*. This journal was created to cause a stir in society, out of concern that a trend in the R&D of academia and industry for pursuing the fine details of individual elemental technologies was getting stronger.

Unlike the analytic pursuits of science and elemental technology development, *Synthesiology* publishes papers on the ways to integrate multiple elemental technologies, or on the descriptions of technological developments that undergo the process of selecting multiple methods and approaches in establishing elemental technologies for solving issues. This can be positioned as the methodology of solution-oriented R&D that society expects, and as a result, the researchers are urged to adopt the thought pattern for providing hardware, software, and services that satisfy the customers and society.

Looking at the hit of iPad by Apple Inc. of USA and the conversion from mainframe and PC to solution provision using ICT by IBM Corporation of USA, I imagine that the readers are becoming aware of the importance of the synthesiology style of thinking. I have experienced R&D at both a private company and AIST, and so I feel that industry is much superior in actively taking in such ways of thinking and developing new products and technologies from an integrated, or synthetic, perspective. Therefore, I hope the people working in companies will submit papers and provide hints to the universities and public research institutes on how to adopt the synthesiological way of thinking.

In this issue, the paper "Toward the integrated optimization of steel plate production process" discusses the difficult issue of an essential deviation that is induced between the "lean" and "push" production models in the steel industry, develops a multiple scale hierarchical model where the technical group steps into the site of production, and verifies the practicality of the model. In the "Paleoclimate reconstruction and future forecast based on coral skeletal climatology," a biological approach is taken to the geochemical approach using corals for the 21st century issue of global warming, to understand the phenomenon actually taking place. Future development is expected in this research. The common research methodology among these papers is the attempt to approach the essence by combining the knowledge and technologies of different disciplines that are based on different awareness. This is indeed synthesiology.

The papers of this issue are case studies that practice the concept of synthesiology. However, they do not employ some fixed methodology, and are characterized by the fact that the authors customize the methodologies that are optimal for individual issues. Over 80 papers have been published as of Volume 5 Issue 2, and I hope a new field will develop based on the synthesiological ideas and data at universities, public research institutes, and private companies.

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