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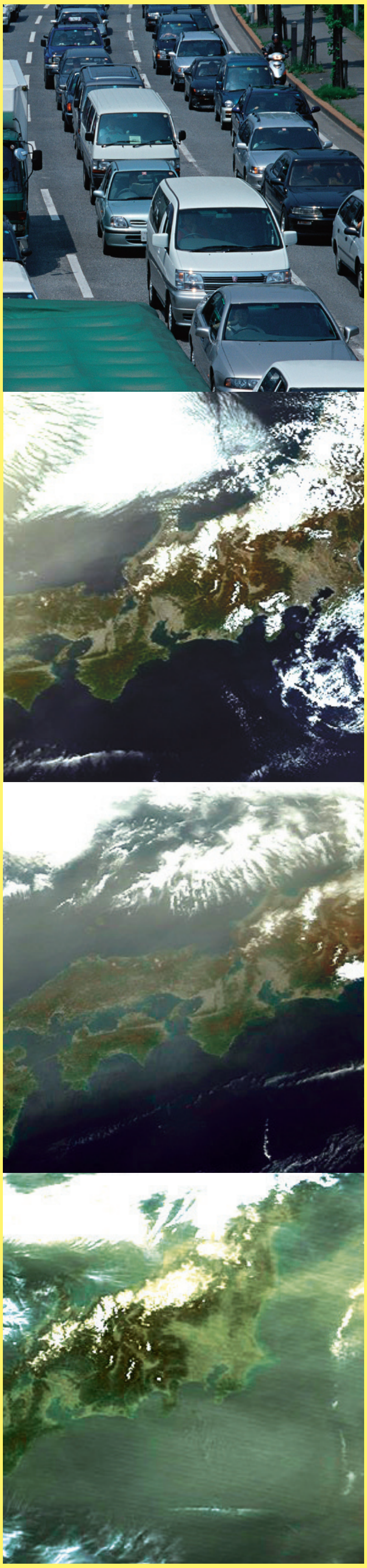

Information and Communication Technologies

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Foreword

This is the latest issue of “Science and Technology Trends — Quarterly Review”.

National Institute of Science and Technology Policy (NISTEP) established Science and Technology Foresight Center (STFC) in January 2001 to deepen analysis with inputting state-of-the-art science and technology trends. The mission of the center is to support national science and technology policy by providing policy makers with timely and comprehensive knowledge of important science and technology in Japan and in the world.

STFC has conducted regular surveys with support of around 2000 experts in the industrial, academic and public sectors who provide us with their information and opinions through STFC’s expert network system. STFC has been publishing “Science and Technology Trends” (Japanese version) every month since April 2001. The first part of this monthly report introduces the latest topics in life science, ICT, environment, nanotechnology, materials science etc. that are collected through the expert network. The second part carries insight analysis by STFC researchers, which covers not only technological trends in specific areas but also other issues including government R&D budget and foreign countries’ S&T policy. STFC also conducts foresight surveys periodically.

This quarterly review is the English version of insight analysis derived from recent three issues of “Science and Technology Trends” written in Japanese, and will be published every three month in principle. You can also see them on the NISTEP website.

We hope this could be useful to you and appreciate your comments and advices.

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Executive Summary

Information and Communication Technologies

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Promotion of Technological Innovation through Medicine-Engineering Collaboration in Japan

—Industry-Academia-Government Collaboration in OCT Technology as a Case Example—

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Funduscopy equipment based on OCT (Optical Coherence Tomography) technology demonstrates its power in the diagnosis of eye diseases such as glaucoma and is typical of the products developed through industry-academia collaboration in medicine and engineering. The underlying principle was first patented in Japan before any other country by Naohiro Tanno, who was then a professor at Yamagata University, in 1990. As the first instance of collaborative innovation between medicine and engineering, OCT had the potential to become a venture launched by a local Japanese university that might succeed as a business proposition. However, in Europe and the U.S., MIT independently applied the invention for U.S. patent in 1991 and, five years later, released a commercial product. In Japan, the first commercial product was released 14 years after the patent application, eight years later than commercialization in Europe and the U.S. As of 2006, the European and U.S. companies hold a 90% share of the global market.

The technology transfer pattern in this case was different from what the western developed countries call “free-riding on basic research”, a pattern observed during the 1970’s and 1980’s in which Europe and the U.S. created research breakthroughs, based on which Japan did the commercialization and formed profitable businesses. This implies that the environment for developing leading-edge research concerning medical equipment was cultivated in Japanese countryside in the early 1990’s, a praiseworthy development that should bolster our national self-confidence as we aim to establish a nation based on creativity through science and technology.

Learning from the circumstances surrounding the first-generation OCT, Japanese industry, academia and government have cooperated in appropriate implementation of the TLO Law to develop second-generation, high-speed OCT. Japan, which once lagged behind Europe and the U.S., has caught up and is ready to overtake these competitors. OCT technology is advancing toward the third generation and, in addition to its current implementation in ophthalmology, is expanding its area of application to dermatology, dentistry, digestive surgery, etc., which is creating fresh global competition.

This report introduces the developmental path followed by OCT technology, from its invention to commercialization, and compares the processes of industry-academia-government collaboration and medicine-engineering collaboration between Japan and the western countries. The Third Science and Technology Basic Plan envisions that “the core strategies are: development of human resources who can produce excellent research findings, creation of a competitive environment, promotion of science, and creation of persistent innovations through strategic investment; and removal of systematic or operational obstacles to return the R&D

benefits to society. Science and technology has a mission to address a broad range of these policy issues for the next five years"; from this standpoint, the report also discusses issues concerning technology transfer from universities and the operational problems of the legal system that are specific to medical equipment development.

In the modern era of technology and business globalization, if the screening process under the Japanese Pharmaceutical Affairs Law continues to consume an unnecessarily long time compared to other countries, Japanese companies will continue to receive approval for clinical trials or product sales abroad before releasing the products domestically. Such a situation would hinder the progress of Japanese medicine and destroy our self-reliance in medical equipment development. Further facilitation of collaborative innovation between medicine and engineering in Japan depends on the further exploitation of the TLO Law and the sophisticated operation of the legal system so that "those that need to be advanced are swiftly advanced and those that need to be withdrawn are withdrawn at early stages". Physical and financial support to achieve these goals is urgently needed.

(Original Japanese version: published in July 2006)

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Outlook on the next steps of Intelligent transport systems (ITS) technologies in Japan: for overcoming Social and Environmental problems brought by Automobiles

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Automobiles using gasoline-fueled internal combustion engines first appeared about 120 years ago. Since then, automobiles have become indispensable. Not only have they contributed to economic development, they have also enriched people's lives through the joy and pleasure of driving. On the other hand, they are the cause of traffic accidents and have significant impacts on the environment. A sustainable mobility cannot be achieved without balancing the maximization of the benefits of the comfort and convenience that automobiles bring and the overcoming of problems they are associated with such as accidents, congestion, and environmental impacts. One method used to address this issue is Intelligent Transport Systems (ITS).

To date, individual systems such as car navigation system, Vehicle Information and Communication System (VICS), and Electronic Toll Collection system (ETC) system have been developed. In order to overcome the problems mentioned above, it is necessary to shift to systems that integrate vehicles and infrastructure by using information and communications among roads, pedestrians, and vehicles. These systems include Advanced cruise-assist Highway Systems (AHS), IC tag systems, and Traffic Demand Management (TDM). In order to move ITS to this second-stage and bring about its implementation, this report proposes that development proceed from the following perspectives.

(1) Research and development of human-machine interfaces that consider elderly people

People aged 65 and above have a strikingly high death rate from traffic accidents, so research and development that focuses on the elderly is vital. Now, integrated interdisciplinary ITS research covering aspects such as ergonomics and cognitive science as well as information engineering and traffic engineering is needed. In particular, the automobile driver's seat requires the most concentrated human-machine interface in daily life. Further research on human-machine interfaces that are easy not only on elderly people but also on world standard users is necessary.

(2) Promotion of social acceptance of ITS implementation

The benefits of second-stage ITS systems involve safety, security, reduced environmental impacts, and other aspects whose costs are difficult to measure. Greater efforts will likely be necessary in order to gain the acceptance of users and society for the new costs that will be incurred. Industry, government, and academia must work together to promote quantitative comparison of costs versus effects, sufficient assessment before implementation, ex-post evaluation, and information disclosure. Furthermore, just as emission regulations in the past promoted improved automobile performance, the examination of possible regulations, for example, requiring new cars to install ITS devices or restricting the access of cars without the equipment to major urban areas is necessary.

(3) Initiatives that contribute to sustainable development in Asia

As motorization proceeds in Asia, associated social problems such as traffic accidents and environmental impacts will become much more serious than ever before. The advancement of second-stage ITS must be expected to contribute to develop a sustainable transportation systems in Asia. Because second-stage ITS systems involve vehicle-infrastructure integration, they must suit the local traffic conditions and needs. The types of traffic accidents that occur in Japan more closely resemble those in other Asian countries than the primarily vehicular ones of Europe and the USA, so Japan and other countries in Asia can probably develop common ITS technology bases. Such an initiative would also boost the international competitiveness of Japan's automobile industry.

(Original Japanese version: published in September 2006)

Environmental Sciences

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Recent Moves to Address the KOSA (Yellow Sand) Phenomenon

— Towards Solutions for a Problem that is an age-old Natural Phenomenon and has concurrently been Influenced by Anthropogenic —

p.45

In the spring of 2006, ferocious KOSA (Yellow Sand) dust storms blew up in China for the first time in four years, causing severe damage and even deaths. To the Japanese, the KOSA (Yellow Sand) is seen as a tranquil sign of spring, as well as the first spring storm. Conventionally, KOSA (Yellow Sand) had been considered a natural phenomenon, but some researchers point out that the rapid expansion of damage in China and elsewhere indicates a major anthropogenic influence. More detailed elucidation of the phenomenon is necessary. At this time, however, the physical and chemical properties of KOSA (Yellow Sand) are not fully understood. In recent years, people have also begun to look at the KOSA (Yellow Sand) phenomenon as a global environmental problem.

Awareness of the KOSA (Yellow Sand) problem differs among countries. In China, the damage is so severe that people have died, and it is widely recognized that the phenomenon is connected with soil degradation and desertification. In Japan, the public is aware of poor visibility and dust sticking to cars and washed clothes, but researchers clearly recognize the phenomenon as a form of air pollution. Like Japan, Korea has no domestic source of KOSA (Yellow Sand), but it has gained attention due to the weather hazard. In Mongolia, moving sand directly threatens local people's livelihoods.

The short-term, direct effects of KOSA (Yellow Sand) on the environment and industry are relatively well understood, but much remains unclear regarding long-terms effects such as its relationship to climate change and its role in matter cycling. In Japan's future initiatives on the KOSA (Yellow Sand) problem, therefore, elucidation of the phenomenon, monitoring, and countermeasures are important basic strategies.

In order to directly affected by KOSA (Yellow Sand) may divide measures against KOSA (Yellow Sand) in originating source areas countermeasures that attempt to control the formation of KOSA (Yellow Sand) by changing the formation and development processes themselves, and countermeasures such as forecasts and warnings that attempt to mitigate damage in affected areas.

In order to promote measures against KOSA (Yellow Sand), Japan must promote interagency cooperation within its government. Multilateral international cooperation is also necessary for source countermeasures and effective monitoring for KOSA (Yellow Sand) forecasts. Sharing of KOSA (Yellow Sand) data held by various organizations, establishment of a KOSA (Yellow Sand) monitoring network, and contributions to each country's effective KOSA (Yellow Sand) countermeasures is likely to promote international cooperation. In particular, working to acquirement and dissemination basic knowledge of the KOSA (Yellow Sand) problem to citizens and technicians from local governments in originating source areas is the most important step in effectively promoting KOSA (Yellow Sand) countermeasures. Control measures in KOSA (Yellow Sand) originating source areas are an urgent issue.

As industrial activity in Northeast Asia intensifies, the KOSA (Yellow Sand) phenomenon will become even more closely linked to society and the economy than it is now. Responses that address solutions to the issues that face each of the countries involved are necessary.

(Original Japanese version: published in July 2006)

Nanotechnology and Materials

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Trends in Research and Development on Plastics of Plant Origin

— From the Perspective of Nanocomposite Polylactic Acid for Automobile Use —

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Motorization on a global scale is expected to proceed, and it is necessary to reduce environmental impact at all stages from automobiles development to production, use, disposal, and recycling. To promote the reduction of environmental impact, a sustainable society must be established making use of earth-friendly technologies with particular emphasis on the reduction of global carbon dioxide emissions. This report describes the trends in the research and development of polylactic acid, which is one of the plastics of plant origin presently attracting widespread attention, from the perspective of nanocomposite material for automobile use. Polylactic acid is made by polymerizing lactic acid, which has a structure consisting of three carbon atoms, and is produced from grain sugar. These carbons are originally derived from the carbon dioxide in the atmosphere, so polylactic acid is a carbon neutral material that does not affect the absolute amount of carbon in the atmosphere whether it is biodegraded or incinerated.

In the "Third Science and Technology Basic Plan," the development of innovative materials and components is listed as a theme in the nanobiotechnology field aiming at solving issues on scarce and deficit resources, measures for handling harmful substances, and improvement and conservation of the environment. The "Biomass-Nippon Strategy" lists promotion of the effective utilization of plastics of plant origin as a target of technologies to convert biomass to products such as plastics.

To apply polylactic acid to automobile components, mechanical properties such as heat resistance and impact resistance must be significantly improved, and it is necessary to develop methods to improve mechanical properties of polylactic acid by adjusting the material structures on the nanoscale, microscale, and macroscale from the viewpoints of composite process, crystal control, and molecular control. One of the major causes that disturbs the application and diffusion of polylactic acid is its high cost, which is several times higher than that of plastics of petroleum origin. Therefore, it is necessary to conduct research and development to significantly reduce the production cost of the purified lactic acid used for polymerization, which accounts for about 70% of the cost required for the production of polylactic acid. Furthermore, taking the global trends in the demand and supply of food into consideration, the effect on the demand and supply of food caused by the use of polylactic acid for automobiles in a large amount must be investigated. According to estimates, it is unlikely that the amount of sugar used for automobile plastics immediately causes a food problem, but it is desirable to make use of surplus biomass resources.

For the broad application of plastics of plant origin in the future, it is essential to control the material structures on the nanoscale, microscale, and macroscale so that sufficient strength and reliability of the material are secured under the service environment of automobiles. The application of polylactic acid to automobile components, which is rather small from the quantitative standpoint, may only be a small step, but it will become a major phase toward the realization of a recycling-oriented society if steady efforts are made to expand the application.

(Original Japanese version: published in August 2006)

Energy

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China's Environmental and Energy Problems and the Possibility of Japan-China Technical Cooperation

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As China's economic development makes rapid progress, its massive energy consumption is also causing serious environmental and energy problems. Consequently, in its 11th Five-Year Plan adopted in March 2006, China made a shift away from its previous energy policies - which gave top priority to economic progress underpinned by the expansion of energy production - to a policy that focuses on building a resource conservation-oriented society thereby leading to sustained, stable economic growth.

Japan-China energy cooperation has focused on a cooperative relationship prioritizing supply, through such means as the development of infrastructures and resources backed by official development assistance (ODA). However, there is rapidly increasing momentum toward developing a technical cooperative relationship in the areas of energy and environmental conservation. With this backdrop, Japan and China jointly held the Japan-China Energy Conservation Forum in Tokyo from May 29 to May 31, 2006. Concerned parties from industry, academia and government met and discussed Japan-China technical cooperation from differing viewpoints.

This report describes the current status of environmental and energy problems in China and related issues, and discusses the possibility of future technical cooperation between Japan and China, taking into account discussions held at the forum.

Both countries share the general opinion that the experience and technology of Japan, which survived two global oil shocks and built the world’s most energy efficient society, should be utilized to help solve China’s environmental and energy problems, and they expect their long-term technical cooperative relationship to develop further. However, problems such as the non-disclosure of core technologies of Japanese corporations and the unsatisfactory protection of consumers and intellectual property rights in China still remain. This is unavoidable in a technical cooperation framework focusing on industrial technologies in the private sector.

However the innovation platform in China has developed in its own way, and offers remarkable examples that Japanese policy maker should refer. Discussions at the Japan-China Energy Conservation Forum focused primarily on industrial technology and participants from China proposed establishing a model research laboratory. Therefore, strategic concurrent discussions on basic research and innovation will give a more concrete form to the desired complementary relationship between the two countries and will help build a smoothly functioning cooperative relationship.

(Original Japanese version: published in July 2006)

Monodzukuri (Manufacturing) technology

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R&D of CAD Systems Suitable for Japanese Design Organization Structure

p.86

The manufacturing sector is more internationally competitive than any other industry in Japan. To further reinforce this strength, the Council for Science and Technology Policy has formulated measures to promote what it calls “MONODZUKURI technology (Value-creating manufacturing, Technologies that increase the value of manufactured products) technology” under the area-specific promotional strategy in the Third Science and Technology Basic Plan, established in 2006. One of the key strategic science and technology areas emphasized in this MONODZUKURI technology field is “technology for science-based KASHIKA (dissemination and accessibility) of MONODZUKURI technology that further advances Japanese-style MONODZUKURI technology,” and computer-aided design (CAD) systems are cited as an essential element of this technology. If the government wishes to maintain and enhance the manufacturing sector’s international competitiveness by promoting the development of CAD systems suitable for Japanese manufacturers’ unique design process, the following issues should be addressed.

(1) The design process consists of, in descending order, workflow of planning, concept design, detailed design, and testing & trial production phases. CAD systems applicable to the planning and concept design phases need to be strategically developed.

Japanese manufacturers began utilizing CAD technologies in their design process around 1980, with the aim of increasing the competitiveness of their products. Since then many measures have been implemented to improve the designers' performance through the utilization of the information processing power of CAD systems. However, for technical reasons, current CAD systems are only applicable to later phases of the design process—namely, the final stage of concept design, and detailed design and testing & trial production—, and not applicable to early phases such as planning and concept design. Given that features of a product are often defined in the planning or concept design phase, R&D to produce CAD systems useful in either of these phases is essential.

(2) CAD systems that enable frequent communication across organizational boundaries need to be strategically developed.

In Japanese-style manufacturing, an upstream process designer looks at the entire design process, including its downstream phases. Similarly, downstream process designers send important feedback on quality improvement or other issues to upstream process designers. Such design activities are regarded as the driving force of value creation, such as improving product quality, and are believed to have made the Japanese manufacturing sector highly competitive. However, current CAD technologies are not designed to support frequent communication across organizational boundaries. R&D is needed on an integrated CAD system that (i) enables the designer to consider issues concerning production, maintenance and other downstream processes and (ii) can handle data that allows engineers working on downstream processes to embrace the concepts behind the product structure as envisaged by the designer.

(3) Research is needed to establish theories applicable to planning and concept design.

In Japan there are currently very few researchers specializing in the applied mathematics needed to establish product modeling theory, or engineers with expertise in such applied mathematics. Furthermore, there are only a small number of universities in Japan that offer courses in applied mathematics as fundamental theory for product modeling. Strategic support must be provided to these areas in the future.

(Original Japanese version: published in August 2006)

Social Infrastructure

7 Trends in Research on Turbulence Control Aiming at Reducing Friction Drag

p.98

A turbulent flow is a stream of fluid accompanied by minute eddy motion. While it has adverse effects on the progress of aircraft and ships by generating friction drag due to air or water and increasing fluid noise, it also brings about beneficial effects by accelerating mixing, heat transfer, and combustion. Turbulence control that adequately manages turbulent flows, so that the adverse effects are suppressed and the beneficial effects promoted, leads to energy saving, high-quality products, and prevention of environmental deterioration as well as breakthroughs in the transportation and other fields.

Although research on turbulence has long been conducted, progress is relatively slow and it remains difficult to control turbulent flows. However, research on turbulence control is now being carried out extensively and turbulence control is one of the promising emerging technologies. The background to such circumstances includes the accumulation of basic data on turbulent structures, owing to the increased capability of supercomputers and the development of direct numerical simulation (DNS), and the rapid development of microelectric almechanical systems (MEMS) technology to enable turbulence control. It also represents a driving force, whereby much is expected of turbulence control in terms of energy saving and measures to resolve environmental problems.

Turbulence control is related to diversified fields of technologies and it is difficult for a single organization to solve all the problems and advance research. Japan is one of the global leaders in individual elemental technologies, including monitoring technologies such as optical sensing, MEMS technologies such as sensors and actuators, and DNS technology. This means that Japan has sufficient seeds for organizing a systematic interdisciplinary research project aiming to achieve turbulence control. For example, a research project called "Smart Control of Turbulence: A Millennium Challenge for Innovative Thermal and Fluid Systems" was implemented for five years from 2000 based on the Organized Research Combination System sponsored by the Ministry of Education, Culture, Sports, Science and Technology. This project saw the participation of multiple independent administrative agencies and universities.

For Japan to remain ahead of the United States and European countries in practically implementing the results of these studies, it is necessary to aid in the research and development of technologies that bring about miniaturization, high accuracy, energy saving, low cost, and long-term stability of sensors and actuators composing the control systems for wall turbulence as well as control algorithms that produce significant effects. Since the development of turbulence control is closely related to the progress of MEMS technology, micro fabrication technology, and control algorithms, it is necessary to transmit research information in a positive manner in order to promote combined research and development with industrial fields that possess mass production technologies.

(Original Japanese version: published in September 2006)

1

Promotion of Technological Innovation through Medicine-Engineering Collaboration in Japan

— Industry-Academia-Government Collaboration in OCT Technology as a Case Example —

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1 Introduction

The Third Science and Technology Basic Plan[1], initiated in fiscal year 2006, primarily emphasizes the importance of technological innovation. It also emphasizes the importance of interdisciplinary and consolidated research, also emphasized in the previous term, and holds the collaboration between medicine and engineering to be a high-priority issue.

In Japan, the rapid aging of the population and the declining birthrate will eventually create a serious social issue: the lack of a young labor force. To address this issue, the “Revised Law concerning Stabilization of Employment of Older Persons” was enacted in fiscal year 2006, extending the mandatory retirement age to slow the reduction of the labor force and reduce national pension expenses. The success of this policy relies on the health and longevity of older people so that they can continue on the job. Moreover, the maintenance of people’s good health, regardless of their age and sex, should reduce the nation’s continuously increasing medical expenditure. Most of all, if we consider the basics of life, to stay healthy, i.e. to be free of diseases, is a fundamental need for anyone who seeks to live a happy life.

Over the past few decades, Japan has maintained its strong international competitiveness as a nation excelling at “manufacturing things” such as automobiles, machinery, electric and electronic appliances and materials[1, 2]. The country is already equipped with a high technology development capacity, which is one of the requirements for satisfying the social need for developing medical equipment. Today, the global and Japanese markets for medical equipment are estimated as approximately twenty trillion yen and two trillion yen, respectively. The values of Japanese imports and exports in this area were about the same in fiscal year 1992, but the value of imports has increased rapidly since then, reaching 955 billion yen in 2004 and far exceeding the value of exports (430 billion yen) for the same year[3].

In domestic and international road maps, the development of molecular imaging technology is regarded as the next step after the completion of the Human Genome Project, a step that should contribute to the establishment of molecular libraries and ultimately to the promotion of molecular therapy and preventive medicine[4, 5]. The promotion of collaborative innovation between medicine and engineering is crucial to the implementation of this road map and should be regarded as a top-priority issue in Japan.

The present report focuses on OCT (Optical Coherence Tomography)[6], a growing technology whose development illustrates the perils and promises of this trend. The first patent for such an invention was applied for in Japan by a local university at the peak of the bubble economy in the late 1980s[7]. Even back then, the technology gave a glimpse of its potential to create business opportunities through its application to medical equipment, but Europe and the U.S., although latecomers in OCT invention, have unfortunately gone far ahead of us in commercialization of the technology.

In Japan, the Law for Promoting University-Industry Technology Transfer (TLO law) went into force in 1998. The Third Science and Technology Basic Plan[1], approved at a Cabinet meeting in March 2006, notes that "S&T system reforms enabled steady progress in industry-academia-government collaboration such as: increase in the numbers of industry-academia joint research, technology transfers by technology licensing organizations (TLOs), and university-derived ventures (the total number of such ventures has reached 1,000)," and that "in order for the activities of industry-academia-government collaboration to achieve sufficient results, it is necessary to further revitalize the activities of university intellectual property centers and TLOs and make them more effective," suggesting that measures for promoting university startups have already been taken. However, if such measures had been taken a decade earlier, i.e. before the bubble economy in late 1980s, and the significance of public investment in technological innovation had been recognized earlier, Japan would have had an advantage over Europe and the U.S. in the development and commercial exploitation of medical equipment.

Given these situations, we have reaffirmed the significance of the TLO Law and recognized the necessity of examining the current and future state of technology development in Japan, i.e. whether the development of technology (including OCT) synchronizes with the trend of technology transfer promotion and whether there is any obstacle to its future progress. Moreover, as is pointed out by the Ministry of Health, Labour and Welfare[8], we need to expose any operational problems in the clinical trial system or other systems related to the Pharmaceutical Affairs Law that are part of the approval process for new medical equipment products, as such problems may demotivate entrepreneurs and ultimately impair Japan's global competitiveness in medical equipment development.

The Third Science and Technology Basic Plan[1] envisions that "the core strategies are: development of human resources who can produce excellent research findings, creation of a competitive environment, promotion of science, and creation of persistent innovations through strategic investment; and removal of systematic or operational obstacles to return the R&D benefits to society. Science and technology has a mission to address a broad range of these policy issues for the next five years," emphasizing the importance of evaluating success in terms of concrete results.

From these standpoints, this report focuses on the application of OCT to ophthalmic diagnostic imaging systems and chronologically compares its developmental process in Japan and in western countries, from its invention to its commercialization. Moreover, this report introduces the attempt of industry-academia-government cooperation in Japan to recover the initiative, not only in first-generation but also in second- and third-generation OCT technology, and proposes some measures to promote collaborative innovation between medicine and engineering in Japan.

2 Principles underlying OCT and the course of its development

2-1 Principles underlying OCT

OCT is a technology derived from the Michelson interferometer, and its mechanism is roughly described in Figure 1[6]. The light source is a current-injection type semiconductor light source called an SLD (Super Luminescent Diode), which is an infrared light with a wavelength of around 780 nm, 830 nm, 1.3 μm or 1.5 μm that

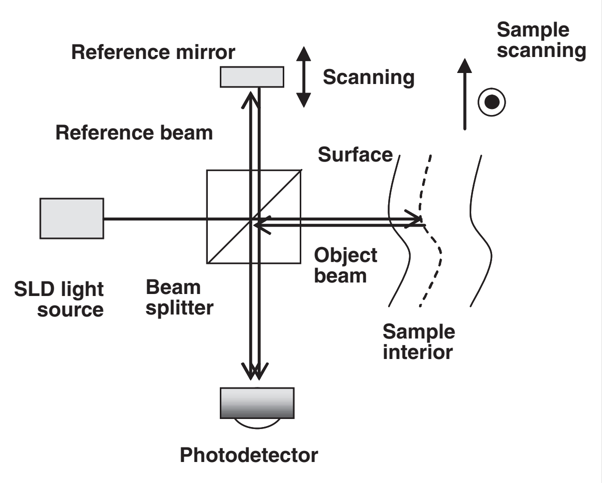

Figure 1 : Mechanism of OCT

Prepared by the STFC based on Reference[6]

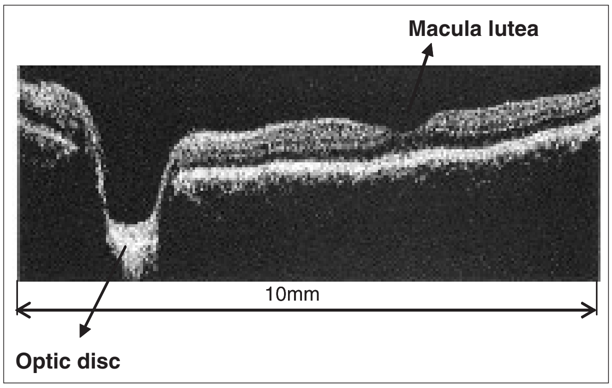

Figure 2 : Example of a retinal tomogram taken by OCT

Photograph provided by Microtomography Co., Ltd.

can penetrate 1-2 mm deep into a living body and that has a sufficiently high spatial coherence but a low temporal coherence. The beam is divided in two by a beam splitter; the transmitted beam reaches the surface of the test sample, enters the test sample and is reflected or scattered by any scattering object or by any boundary between materials with different refractive indices. This reflected or scattered beam returns to the beam splitter, where it is reflected to the photodetector as the object beam. Meanwhile, the beam initially reflected by the beam splitter is reflected by the reference mirror surface, passes through the splitter this time and reaches the photodetector interfering with the object beam based on the superposition principle.

When the path lengths (the distance traveled by the individual beams after being divided by the beam splitter until being combined again) of the object and reference beams are equal to each other (i.e. at zero path-length difference), the two waves intensify each other, and the intensity of the light received by the photodetector is greater than when the path-length difference is not zero. By performing such measurements with multiple reference-mirror positions and scanning the sample two-dimensionally and perpendicularly to the axis of the incident light, the laminar structure (boundaries of refractive indices) inside the sample can be displayed in a three-dimensional manner.

If light with a high temporal coherence, e.g. a laser beam, is used as the light source, intensification of interference occurs irrespective of the path-length difference, making it difficult to see the laminar structure of the sample. Thus, the use of a light source with lower temporal coherence gives a higher depth resolution. This is the key to this invention, and the depth resolution can be 10-20 μm, depending on the spectral bandwidth (about 50 nm) of the light source.

2-2 Process of development in Japan

The first patent on the principle of OCT was applied for in 1990 by Naohiro Tanno, who was then a Professor at Yamagata University[7]. An application was filed only for a Japanese patent and not for a U.S. or any other foreign patent. Meanwhile, the first research paper on OCT, titled “Backscattering Optical Heterodyne Tomography”[9] was prepared for the 14th Laser Sensing Symposium in 1991, and was written in Japanese and not in English. This reminds us of the famous story of Koichi Tanaka, the winner of the Nobel Prize for chemistry in 2002. Since Mr. Tanaka had never published any paper in English except for one that he wrote for a symposium held in China, his research had not received much international attention until he won the Prize. In earlier times, researchers did not have enough funds to publicize their discoveries to the world or to claim their intellectual property rights, and the importance of publishing research papers in English is here reacknowledged.

At that time, Professor Tanno was one of the key members of Biophotonics Information Laboratories, Ltd. (capitalized by the former Ministry of International Trade and Industry) led by Humio Inaba, who was then a professor at Tohoku University. The project was launched by researchers who were inspired by the idea of X-ray CT (Computer Tomography (theory by Allan Cormack, apparatus by Godfrey Hounsfield)), which was awarded the Nobel Prize in Physiology or Medicine in 1979. They were seeking techniques to view the interior of human bodies or other organisms by detecting transmitted light using laser beams instead of X-rays.

In this project, professor Tanno proposed the idea of using in an interferometer a light source that retains one advantage of a laser light source, i.e. low spatial coherence, but has an intentionally reduced temporal coherence compared with a laser. Traditional interferometers used light sources with low coherence in both temporal and spatial domains, such as incandescent lamps. However, an incandescent lamp is not a point source; it has width, i.e. has a low spatial coherence, and is thus incapable of providing a high resolution at the object plane. In practice, the resolution can be improved by placing a pinhole behind the incandescent lamp; however, this lowers the intensity, preventing the photodetector from catching enough light. OCT employs an interferometric measurement that takes advantage of the high spatial coherence and low temporal coherence of an SLD light source, which is the key feature of this invention.

Unlike X-ray CT that detects photons transmitted through an object, OCT detects the reflected light and enables non-invasive, in-vivo imaging of the tissues in layers close to the surface of a living body. Since this concept appeared to be too different from the original idea of utilizing the coherence of laser beams, which was the dominant focus in the Biophotonics Information Laboratories, Ltd., it was not accepted by some project members. As a result, the concept of OCT was never regarded as fundamental to the project, and a high priority was not placed on investigating potential applications of OCT such as medical equipment development. Nevertheless, immediately after inventing OCT, Professor Tanno and his colleagues approached the Faculty of Medicine of Yamagata University and gave seminars several times a year to regularly introduce their technology seed from the engineering side.

The development process of OCT technology in Japan, from its invention to its application in medical equipment, is chronologically shown in Table 1 along with that in Europe and the U.S. Professor Tanno continued to spread his technology seed by introducing OCT technology at the Yamagata Technopolis Foundation and suggesting to local companies the potential application of semiconductors to testing apparatus. However, in terms of actual research activity, since Yamagata University had no doctoral program then, he taught his master's students the methods of simulation and other calculation techniques. Although he published his first English paper[10] in 1994, he could not perform a full-scale demonstration experiment.

While Japan was in the middle of this "blank period", in 1996, Zeiss-Humphrey Systems, Inc. (Humphrey), a U.S. subsidiary of the well-established German optical firm Carl Zeiss Meditec AG (Carl Zeiss), released a test model of the industry's first OCT equipment. Professor Shoji Kishi and his colleagues in the Faculty of Medicine of Gunma University showed an interest in this product and purchased the first model. They became the first group to collect clinical data in Japan and demonstrated its utility in the diagnosis of diseases of the ocular fundus[11].

Hearing this news, Professor Tanno noticed that the principle used in the OCT equipment was just what he had invented, and notified Carl Zeiss of this fact. With governmental support based on the Law for Promoting University-Industry Technology Transfer (TLO law) enacted in May 1998, he received financial aid from JST (Japan Science and Technology Agency) and started to make a prototype in 2000. In 2001, he received a visit from the CEO of Carl Zeiss for patent negotiation and persuaded the CEO to accept that his Japanese patent had preceded Carl Zeiss's use of the technique. Carl Zeiss agreed to pay him a royalty on the use of the patent in Japan and to mark their domestically sold products with the Japanese patent number. Fueled by the success of the patent negotiation, Professor Tanno further promoted the development of the product; in 2001, the project was approved under the Temporary Law concerning Measures for the Promotion of the Creative Business Activities of Small and Medium Enterprises and received grants from the Tohoku Bureau of Economy, Trade and Industry and a Yamagata Prefecture New Industry Creative Type Technology R&D Grant. In 2002, then Professor Tanno, who had become the Chairman of the Cooperative Research Center of Yamagata University, founded Microtomography Co., Ltd., a venture capital firm jointly established by a semiconductor-manufacturing equipment manufacturer, MTEX Matsumura Corporation. He was appointed the director of the venture capital firm, and Sumio Matsumura and Michiro Hasegawa were appointed the CEO and the director, respectively. In 2003, the product was

Table 1 : Comparison of OCT development processes in Japan, Europe and the U.S.

Year	Japan		Europe-U.S.
	Engineering	Medicine	Medicine-engineering collaboration
1990	Professor Tanno applied for Japanese patent		
1991	Professor Tanno introduced his idea at the Yamagata Technopolis Foundation, and taught the associated calculation methods in a master's-level course, because the university offered no doctoral program		Professor Fujimoto applied for a patent, published an angiotomogram in Science.
1992	Biophotonics Information Laboratories, Ltd. was founded		Professor Fujimoto received $6 million from Zeiss-Humphrey Systems Inc. (a subsidiary of CZ in U.S.) for promoting collaboration with an image processing group and the Eye Center of the Lincoln Laboratory. He published a fundus photograph in ’93 Opt. Lett.
1993			
1994	Professor Tanno et al. published their first English paper		
1995			
1996			Professor Fujimoto et al. published a collection of clinical data. CZ made the first shipment of a test model of funduscopy equipment
1997		Professor Kishi purchased the first model manufactured by CZ	
1998	The TLO Law was enacted	Professor Kishi et al. reported clinical cases.	G. Hausler et al. of the University of Erlangen published the principle of high-speed OCT
1999			
2000	Professor Yasuno et al. of University of Tsukuba published the FD-OCT method. Professor Tanno et al. took part in a regional collaborative research project and received grants from JST (MTEX Matsumura Corporation (MTEX), the parent company of the current MT)		Speed-up and multifunctionality of OCT were pursued. Development of next-generation OCT was promoted, e.g. blood flow measurement utilizing the Doppler effect
2001	Professor Tanno received a visit from the CEO of CZ for patent negotiation. MTEX was approved under the Temporary Law concerning Measures for the Promotion of the Creative Business Activities of Small and Medium Enterprises and received a Yamagata Prefecture New Industry Creative-type Technology R&D Grant		
2002	MTEX received grants from the Tohoku Bureau of Economy, Trade and Industry. Microtomography Co., Ltd. was founded		
2003	MT received approval under the Pharmaceutical Affairs Law		
2004	MT shipped the first domestic funduscopy equipment. Professor Yatagai et al. launched the “ultrahigh-speed Fourier optical radar microscope for biometrics” project funded by JST		
2005	NEDO project “eye fundus blood flow, internal disease examination project” (Kyoto University, Yamagata Technopolis Foundation, Topcon, Nidek, Hamamatsu Photonics) was launched. Professor Yatagai et al. launched “the study concerning application of OCT to ophthalmology” through technological cooperation with Topcon Corporation.		CZ's market share of first-generation OCT equipment reached 90%
2006	MT proposed the application of spectroscopic OCT to 3D tomography to in vivo oxygen saturation in cooperation with Professor Hidetoshi Yamashita of the Yamagata University Faculty of Medicine and Professor Tetsuya Yuasa of the Faculty of Engineering		

MT: Microtomography Co., Ltd. CZ: Carl Zeiss Meditec AG approved under the Japanese Pharmaceutical Affairs Law, and in 2004, 14 years after the technology was invented and eight years later than its commercialization in Europe and the U.S., Japan's first OCT equipment was finally put on the market.

2-3 Process of development in Europe and the U.S.

For comparison with the process described in Japan, this section explains the process of OCT development in Europe and the U.S., using Table 1. Professor J. Fujimoto and his colleagues at MIT[12], an institute famous as a base of industry-academia collaboration in the U.S., independently invented a principle similar to Professor Tanno's invention. In 1991, they applied for a U.S. patent and published the world's first English paper on OCT titled "Optical Coherence Tomography" in Science[13]. The term OCT currently used among experts around the world is derived from this paper. Professor Fujimoto launched a medicine-engineering collaboration project with an image processing group within MIT and medical scientists at the Eye Center of the Lincoln Laboratory. In 1993, they made the world's first in vivo tomographic observation of the retina[14]. The professor received $6 million as a grant from Humphrey and vigorously worked on the commercialization of OCT equipment. In 1996, he took the initiative in publishing a 5-cm-thick book of clinical data collected in trials of optical coherence tomographic imaging[15], which astonished ophthalmologists around the world. At about the same time, Humphrey released the world's first test model of the equipment. Today, a decade after the product was first released, three companies are engaged in the production and distribution of the equipment, including the above-mentioned two companies and a latecomer, OPI (Opthalmic Technologies Inc.) of Canada. Carl Zeiss and its subsidiary Humphrey command 90% of global market share.

The speedy process of OCT development in Europe and the U.S. can be compared to a football game; the players cooperated in passing the ball (OCT) efficiently, from the defender, to the mid-fielder to the forward player, to take the shortest distance from the invention to the ultimate goal of market domination. The players comprehensively maintained a good balance between work-sharing and cooperation and worked swiftly to bring the university-launched innovation to practical use. The U.S. is already equipped with dynamic systems to facilitate collaborative innovation between medicine and engineering, i.e. the creation of technology seeds and swift technology transfer, and for collecting clinical data, systems that actually operate night and day. Researchers in Japanese universities and public institutions should learn from the smooth cooperation among industry, academia and government in the U.S. and should strongly support Japan's original dynamic systems for facilitating collaborative innovation between medicine and engineering.

3 Institutional and operational problems of the system

This chapter focuses on the legal process in Japan that affects the speed of the collaborative innovation between medicine and engineering. Regarding the developmental process of medical equipment, i.e. R&D (invention) → prototype → clinical data collection → application → screening under the Pharmaceutical Affairs Law → commercialization → shipment, the TLO Law is applied to the first half of the process; in the second half of the process, i.e. clinical data collection and subsequent steps, the Pharmaceutical Affairs Law is applied to screen the products to be put on the market[16]. Although OCT is medical equipment, it is regarded as a pharmaceutical product and must be approved under the Pharmaceutical Affairs Law.

This also applies to the development of OCT equipment; preliminary clinical trials must be performed to collect clinical data demonstrating that the equipment is clinically effective and has no adverse effects. Clinical trials are accompanied by risks, which gives rise to issues of liability for accidents. Thus, screening must be performed with deliberation, requiring a vast amount of time and money. In the U.S., it only took five years for Professor Fujimoto and his colleagues to succeed in the commercialization of the equipment; in Japan, it took 14 years from the invention to commercialization of the same technology. From now on, innovation based on collaboration between medicine and engineering must be advanced through comprehensive consideration of a variety of issues, e.g. those surrounding the facilitation of technology transfer from universities and the operational differences of the Pharmaceutical Affairs Law as it applies in Japan and the corresponding regulations in the U.S. For example, physicians and professors in the U.S have larger discretionary powers in the clinical trial process. If the physicians or professors consider that trials can be conducted safely, they are authorized to take the initiative in collecting clinical data on their own responsibility. This is why they can accumulate a large amount of clinical data to demonstrate the safety and efficacy of medical equipment within a short time.

In the case of this OCT equipment, Carl Zeiss submitted an application for approval under the Pharmaceutical Affairs Law, first in the U.S. and Europe and then in Japan. Following its successful development of the OCT equipment, the company also succeeded in commercializing OCT-based equipment for measuring the length of the eyeball and received approval under the Japanese Pharmaceutical Affairs Law before any other company. Meanwhile, Microtomography Co., Ltd. of Japan also developed a similar product and applied for the approval under the Pharmaceutical Affairs Law in November 2004 as a generic machine using OCT equipment. However, the light source in Microtomography's product had a wavelength of 830 nm[17], which was different from that in the Carl Zeiss product (780 nm), so the company withdrew the application in March 2005 and re-applied for the machine as a new product in November 2005, and it still has not been approved as of June 2006.

Another typical case of medicine-engineering collaboration is a physician's report of a therapeutic method for an intractable auditory disease[18]. The disease involves impairment of the cochlear duct, which is found between the eardrum and the auditory brain stem and which converts sound vibrations into neural signals. One technique to restore the auditory capability of patients affected by this disease is the transplantation of an artificial cochlea into the patient's cochlear duct, which involves medical technology developed through medicine-engineering collaboration. The artificial cochlea comprises a receiver and an electrode, which are placed inside the body, and a microphone, speech processor and a battery, which are placed outside the body. This procedure has been performed on more than sixty thousand people worldwide and more than four thousand people in Japan. Regarding this therapeutic method, Japan led the world at the development stage; however, it is reported that today the global market for the artificial cochlea is dominated by Australian, U.S., Austrian and French companies. This was reported in the 10th memorial lecture titled "Fusion between different fields and new research trends" given in the ME Forum hosted by the Science Council of Japan in cooperation with the Japanese Society for Medical and Biological Engineering (held on January 23, 2006 in Sanjo Conference Hall at the University of Tokyo).

In this lecture, Mr. Yasuhiro Suzuki of the Health Policy Bureau, Ministry of Health, Labour and Welfare reported that "in cutting-edge basic technology, Japan is a world leader, along with the U.S. and European countries. Meanwhile, with respect to exploratory research on the application of such basic technology to novel medical equipment that satisfies clinical needs, as well as the infrastructure of clinical tests and trials using this equipment and the equipment screening system under the Pharmaceutical Affairs Law, Japan confronts many more problems than Europe and the U.S."[8] These countries have many judges for screening and approving new drugs or medical equipment. For instance, the U.S. FDA (Food and Drug Administration) has 9,000 judges, while its Japanese counterpart has only 300. In his report, Mr. Suzuki also acknowledged that "it is urgent that we improve the environment not only for basic and translational research but also for the clinical studies and trials that lie ahead. For a long while the clinical trials system in our country has been "hollowed-out", and as the environment for conducting clinical trials in other Asian countries is rapidly improving, the number of clinical trials conducted in our country is steadily decreasing. This not only deprives Japanese citizens of opportunities to benefit from leading-edge medical equipment but also directly decreases the global market share of domestic manufacturers." He also acknowledged that "with the aim of drastically reforming the infrastructure for conducting clinical trials and studies in fiscal year 2006, the Ministry of Health, Labour and Welfare launched a 'Research project for promoting establishment of infrastructure for clinical research' with MHLW Grants-in-Aid for Scientific Research and performs a model project of a physician-driven clinical trial for improving the environment for secure accomplishment of clinical trials," reflecting the Ministry's active stance toward the operational improvement of the systems.

New drugs and medical equipment must all be approved under the Pharmaceutical Affairs Law, which reflects the strong public demand for product safety[19-21]. In the White Paper on Labour Economy 2005[22], the Ministry declared its determination to "be deeply aware of our important duty to supply safe and effective drugs to the public and to protect people's life and health from adverse effects of drugs or from defective drugs, and to exert our best efforts so that the disastrous health damage caused by such drugs will never occur again".

Such assurance of safety seems incompatible with the swift action required for innovation. However, dealing with this severe contradiction is a top-priority issue confronted by every country, and Japan is no exception. In this sense, the above-mentioned report[8] from the Ministry of Health, Labour and Welfare suggests that "domestic development of superior medical equipment, collection of clinical data, swift screening of products and their clinical application are essential for the development of medical equipment. However, each of these steps is accompanied by risks and liabilities, and the quickest way to solve the problem of medical equipment development is to obtain a national consensus on how to deal with such risks and liabilities." The primary purpose of medical equipment or drug development is the recovery and maintenance of health for patients and potential patients. The medical institutions and manufacturers are constantly demanded that they recognize their roles as suppliers of health, and without confusing the means with the ends, find transparent solutions acceptable to all.

To promote future collaborative innovation between medicine and engineering, we must explore measures to improve the operation of systems, such as expanding the discretionary powers of judges and ensuring the transparency of the screening process by giving access permission to research centers and research sites and bringing about more extensive disclosure of information concerning the screening process, etc., in addition to increasing the number of judges and building physician-driven, highly transparent systems for clinical trials. This would require an increase in the budget allocation to support the relevant departments in industry, universities and government. Moreover, for the mid- and long-term, we need to establish an interdisciplinary human resource development system between humanities and science to foster the development of people who are qualified both in the law and medicine or engineering and who are capable of making decisions at higher levels. Then we should be able to assign such people to the R&D of medical equipment or the screening process under the Pharmaceutical Affairs Law.

4 Next-generation OCT

4-1 Second-generation high-speed OCT

As discussed above, Japan can be credited as the first country in which OCT technology was patented. However, Japan lagged far behind others in the commercialization of OCT and is in a weak business position, at least for first-generation OCT. This section discusses the potential for Japan to catch up in the second and later generations of OCT.

Figure 3 can be compared to Moore's Law for

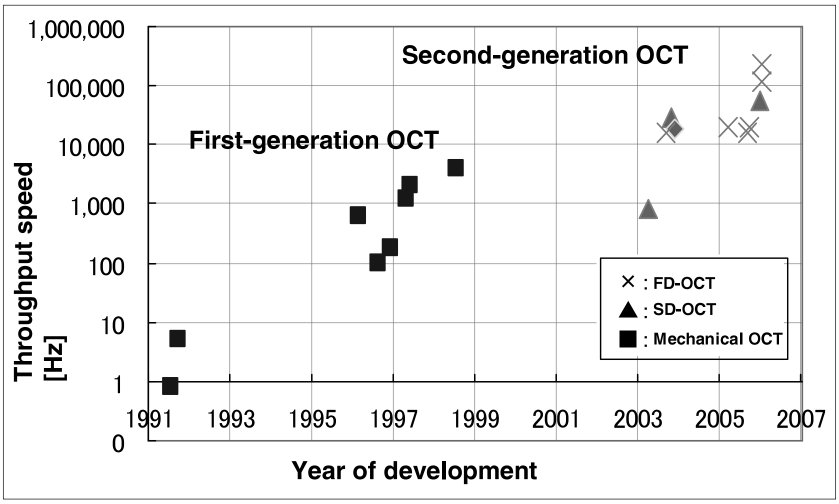

Figure 3 : Annual progress in the performance of OCT equipment

Prepared by the STFC based on reference data by Professor Yatagai

semiconductors; it shows the annual progress in performance of OCT equipment, using the throughput speed of OCT as an index. The throughput speed in first-generation OCT was about 1Hz in 1991 at the laboratory level but increased to 4 kHz by 1999. However, after this 4,000-fold increase, the throughput speed seemed to reach a saturation point. Meanwhile, regarding the medical application of OCT equipment, there is a strong need to collect in vivo real-time tomograms as video data. As a result, the development of second-generation OCT involved a technology race to improve the throughput rate. The throughput rate has reached 200 kHz in recent models, and real-time recording and replay of 3D video data at video rates has been achieved at the product level.

The two most interesting technologies for speeding up the equipment are FD-OCT (Fourier Domain OCT)[23, 24] and SD-OCT (Spectral Domain OCT)[25], in which the number of moving parts in the equipment is reduced. First-generation OCT provided three-dimensional tomograms by mechanically moving the reference mirror and the movable head comprising the optical interferometer, which limited measurement speed. Meanwhile, FD-OCT enables data gathering in the depth direction of the sample with the reference mirror fixed. The interference light obtained from the interferometer shown in Figure 1 is divided into wavelength spectra by a grating spectrometer and detected by a CCD (Charge Coupled Device) array, and the detected signal is subjected to real-time Fourier transformation by a computer to acquire the entire reflection intensity distribution in the depth direction substantially within one measurement[25]. Therefore, mechanical movement of the reference mirror can be omitted. Moreover, by exploiting the features of spatial collective parallel processing, which is an advantage of the optical system, and adopting one-dimensional imaging optics using a cylindrical lens, the uniaxial scanning of the sample plane can also be omitted. Furthermore, using a wavelength-tunable SLD light source means that spectrometers are no longer needed, which enables both speed-up and miniaturization of the equipment.

The use of such high-speed OCT that takes advantage of the more subtle features of light waves makes practical the real-time, three-dimensional observation of blood flow in the ocular fundus. Such R&D, exploiting the key characteristics of optical techniques, is being actively conducted by the Computational Optics Group led by Toyohiko Yatagai of University of Tsukuba. During fiscal years 2004 through 2007, the group is promoting research titled the “ultrahigh-speed Fourier optical radar microscope for biometrics” with support from JST (Japan Science and Technology Agency). The group is also engaged in technology transfer under industry-academia collaboration and started a study of the application of OCT to ophthalmology in fiscal year 2005 to promote commercialization of the next-generation high-speed OCT equipment through technological cooperation with Topcon Corporation. Topcon Corporation has retained the largest share of the global market for conventional funduscopy equipment developed before OCT. The industry-academia collaboration in this case is similar to the relationship between Professor Fujimoto of MIT and Humphrey. With engineering-medicine collaboration, the university takes charge of the basic design of the equipment, the development of know-how for instrumentation and the patent application, while the company takes charge of the marketing and the legal process required for clinical trials and Pharmaceutical Affairs Law approval, utilizing its long-term experience and performance. The collection of clinical data in the university must be approved by the university's ethics committee, as has become obligatory since fiscal year 2005. Under the provisions of the TLO Law, University of Tsukuba sold the patent and the technical know-how concerning high-speed OCT to Topcon Corporation and shared the profit from the sale with the inventor. In the case of high-speed OCT, the TLO Law functioned effectively, and the perils of the "Valley of Death" and the "Darwinian Sea" were successfully navigated through industry-academia collaboration. In June 2006, the first high-speed OCT was commercialized by Topcon Corporation, and it is attracting attention for its potential to capture part of Carl Zeiss's share of the entire OCT market in the future. Unfortunately, however, therapies using this equipment are not covered by insurance.

4-2 Various applications of OCT and the situation abroad — toward the third generation —

It is well known that the progress of diabetes results in visual impairment. Microtomography Co., Ltd. has proposed a method for measuring the oxygen saturation in hemoglobin in the capillaries exposed on the retina by using OCT. Moreover, the Department of Ophthalmology of Kyoto University Hospital is cooperating with Yamagata Technopolis Foundation, Hamamatsu Photonics K.K., Topcon Corporation and Nidek Co., Ltd. to develop equipment for measuring the blood flow in the ocular fundus. The project has received a grant from the New Energy and Industrial Technology Development Organization (NEDO), and its success is expected to have a large impact. With the aim of improving the resolution of the ocular fundus tomogram up to the diffraction limit, the group is planning to adopt a method for collecting data while performing real-time measurement and correction of ocular aberration, utilizing the adaptive optics techniques of Hamamatsu Photonics K.K., i.e. a liquid crystal spatial phase modulator.

So far, OCT technology has mainly been used in funduscopy equipment, but as the technology shifts into the third generation, its potential areas of application seem to be increasing, e.g. dermatology, dentistry, dental surgery, digestive surgery, cardiovascular surgery etc., in addition to its current implementation in ophthalmology. As an example of such new OCT technology, Professor Masamitsu Haruna of Osaka University[26] is developing an OCT that uses a light source with a wavelength of 1.3 or 1.5 μm. These wavelengths are absorbed by moisture and thus cannot be used for funduscopy, but can be applied to corneous or skin tomography or facial tomography applied to cosmetic product development, or can be combined with an endoscope for non-invasive tomography of the stomach wall. Moreover, with the attempt to understand the physiology of the living body, high-speed OCT is used to perform time-lapse photography, permitting dynamic observation of sweat glands and secretory glands[27]. Since this wavelength range is also used in optical fiber communication, companies including the former NTT have made a vast investment in relevant R&D. Achievements in cutting-edge devices such as light sources and photodetectors may be transferable to OCT equipment, including optical amplification by the multi-wavelength method or rare-earth-doped optical fibers.

The U.S. NIH (National Institutes of Health) has drawn a road map in which the development of molecular imaging technology, which should contribute to the establishment of molecular libraries and ultimately to the promotion of molecular therapy and preventive medicine, is regarded as the next step following the completion of the Human Genome Project. Professor Fujimoto currently holds an additional post at NIH to explore the extension of OCT applications to molecular imaging. Meanwhile, Professor deBore and his colleagues, who left Professor Fujimoto's group and moved to MGH (Massachusetts General Hospital), are working on the facilitation of medicine-engineering collaboration by taking advantage of high-speed OCT technology. Moreover, the University of California at Irvine has integrated the Schools of Medicine and Engineering and founded a medicine-engineering collaboration center, a facility similar to MGH. The establishment of such institutions in universities reflects the acceleration of medicine-engineering collaboration in the U.S. Meanwhile, in Europe, Professor Fercher and his colleagues at the Medical University of Vienna, Austria, and Professor Drexler and his colleagues who left this group and moved to Imperial College, U.K., are actively engaged in the R&D of high-speed OCT technology.

As can be seen, the global competition to speed OCT innovation through medicine-engineering collaboration is becoming more and more intense. The competition is not only in the technical realm but also in the area of establishing systems to support industry-academia-government collaboration and the implementation of local equivalents of the Pharmaceutical Affairs Law. In the modern era of technology and business globalization, it is unavoidable that Japanese companies first perform clinical trials and receive product sales approval in the U.S. or Europe and then release the products in Japan. In order to stop this hollowing-out of clinical trials, as mentioned in the report by the Ministry of Health, Labour and Welfare[8], "we are working on the establishment of a registration system for clinical studies and an information disclosure system, following a global trend in which the contents of human studies such as clinical trials, clinical studies, etc., must be notified to a third-party organization beforehand." To further facilitate collaborative innovation between medicine and engineering in Japan, it will be more important than ever to further exploit the TLO Law, and safely, swiftly and transparently implement the Pharmaceutical Affairs Law.

5 Conclusion

This report focused on OCT technology to illustrate the issues involved and the measures required to promote collaborative innovation between medicine and engineering from the standpoint of "strategic investment for the creation of innovations and removal of systematic or operational obstacles to return the benefits to society," as required for the Third Science and Technology Basic Plan.

Funduscopy equipment typifies products developed with medicine-engineering collaboration, and has demonstrated its power in the diagnosis of glaucoma and retinal separation. The underlying principle, OCT (Optical Coherence Tomography) technology, was patented for the first time in Japan by Yamagata University in the late 1980s. As the first case of medicine-engineering collaboration, OCT had the potential to take a startup launched by a Japanese local university to success. In this sense, the technology transfer pattern in this case was different from that observed during 1970s and 1980s, in which Europe and the U.S. created research breakthroughs, based on which Japan did the commercialization and formed profitable business.

However, in the case of OCT technology, from its invention to commercialization, Europe and the U.S. preceded Japan in commercialization by eight years and together hold a 90% share of the global market as of 2006. In order to make up for the loss, Japan not only needs to resolve issues of technology transfer but also needs to revise the screening process under the Pharmaceutical Affairs Law, a procedure specifically involving medicine-engineering collaboration. For instance, we should establish a physician-driven, highly transparent system for clinical trials where safety can be ensured, by expanding the discretionary powers of physicians, professors and ethics committees in the clinical trial process so that they can collect clinical data on their own responsibility in trials they consider safe.

Currently, intense competitions in product development are taking place, both domestically and internationally, involving second-generation, high-speed OCT technology. In this second generation, Japanese industry, academia and government have cooperated in exploiting the TLO Law appropriately, and Japan, which once lagged behind Europe and the U.S., has caught up with these countries and is ready to take the lead. OCT technology is advancing toward the third generation and, in addition to its current ophthalmologic application, is seeing wider use in, e.g. dermatology, dentistry, dental surgery, digestive surgery, and cardiovascular surgery, which is creating fresh global competition. Such global competition, involving collaboration between medicine and engineering in such areas as OCT innovation, is becoming more and more intense, not only in the technical realm but also in the area of transforming systems to support industry-academia-government collaboration and the operation of clinical trial systems.

In the modern era of technology and business globalization, as the Ministry of Health, Labour and Welfare points out, if the Japanese legal system continues to consume an unnecessarily long time compared to other countries, Japanese companies will continue to receive approval for clinical trials or product sales in Europe or the U.S. before releasing the products in Japan. Such a situation would hinder the progress of Japanese medicine and destroy our self-reliance in the development of medical equipment.

In order to improve this situation, and following the global trend in which the contents of clinical trials and clinical studies must be notified to a third-party organization beforehand, Japan must work on the establishment of a registration system for clinical trials and a system for disclosing related information to the public and increase the budget to achieve this. Moreover, we must reinforce and expand medicine-engineering collaboration centers that integrate areas of medicine and engineering and, in the mid- and long -term, must establish an interdisciplinary human resource development system between humanities and science to foster the development of people who are qualified both in the law and medicine or engineering and who are capable of making decisions at higher levels so that we will be able to assign such people to the R&D of medical equipment or the operation of the legal system.

For further facilitation of the collaborative innovation between medicine and engineering in Japan, it will be more important than ever to further exploit the TLO Law and safely, swiftly and transparently implement the Pharmaceutical Affairs Law so that “those that need to be advanced are swiftly advanced, and those that need to be withdrawn are withdrawn at early stages.” It is urgent that we design a highly transparent, comprehensive strategy to promote collaborative innovation between medicine and engineering. Such policies are expected to result in further improvement in Japanese medicine and reinforcement of our global competitiveness in medical equipment development.

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2

Outlook on the next steps of Intelligent transport systems (ITS) technologies in Japan: for overcoming Social and Environmental problems brought by Automobiles

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1 Introduction

Automobiles using gasoline-fueled internal combustion engines first appeared about 120 years ago. Since then, automobiles have become indispensable. Not only have they contributed to economic development, they have also enriched people's lives through the joy and pleasure of driving. Today, the automobile industry has become synonymous with Japan's manufacturing skill, driving the nation's economic growth and leading the world in quality, from parts to finished products. The industry has made a major contribution to Japan's economic and social development.

Already, there are about 800 million automobiles in the world. With global population expected to reach 9 billion in 2050[1], and especially because of the recent remarkable economic growth in the so-called BRIC nations (Brazil, Russia, India, and China), the number of automobiles is expected to grow at a rate of 100 million every five years. This market expansion is good news for automobile-related corporations, but at the same time, this rapid increase in motorization may lead to concomitant increases in traffic accidents, congestion, environmental impacts, and energy consumption, aspects that threaten quality of life. Worldwide deaths from traffic accidents in 2002 reached 1.18 million, meaning over 3,000 people die in traffic accidents every day[2]. This number is the equivalent of six or more jumbo jets crashing each day.

Unless positive aspects such as convenience and comfort can be maximized while negative aspects such as accidents, congestion, environmental impacts, and energy issues are minimized, a sustainable mobility cannot be achieved. Intelligent Transport Systems (ITS) are a promising solution and one which Japan is now engaged in investigating to contribute toward the world.

This report takes an overview of the status of and issues related to ITS in Japan's automobile society. Along with technical trends in ITS, the report looks at measures to establish a sustainable mobility that balances comfort with safety, security, and reduced environmental impacts.

2 Status of and issues in the automobile society

2-1 The status of ITS in Japan

ITS is defined as "using information and communications technology to form systems that address vehicles, roads, and people as a triune entity in order to improve safety, transportation efficiency, and comfort while protecting the environment" (Figure 1). In 1996 in Japan, a national project designed to lead the promotion of ITS was announced. It centers on four government agencies (reorganized from five previous agencies), the National Police Agency, the Ministry of Internal Affairs and Communications, the Ministry of Economy, Trade and Industry, and the Ministry of Land, Infrastructure and Transport, and relevant outside organizations. In addition, the non-profit organization ITS-Japan was formed by relevant organizations centered on industry, experts, and so on. It develops its promotional activities in collaboration with the four government agencies (Figure 2).

Table 1 depicts the history of ITS in Japan. Since the establishment of the overall concept in 1996, ITS has been positioned as a major Japanese policy. It is also listed in the 3rd Science and Technology Basic Plan as an important research theme in the fields of energy, information and communications, and social infrastructure.

As shown in Table 2, the nine areas contained in the August 1995 "Guidelines on the Implementation of Informatization for Roads, Transport, and Vehicle Fields" were designated by the (then) five government agencies for ITS development. To date, dissemination of car navigation systems and VICS*1 (Vehicle Information and Communication System) has been advancing since the second half of the 1990s. Dissemination of ETC*2 (Electronic Toll Collection system) began in 2001 (Figure 3). As of March 2006, car navigation systems were installed in over 22 million vehicles and VICS in over 15 million. As of June 2006, there were 12 million vehicles with ETC installed, and nearly 62 percent of Japanese expressways utilized the service. Japan thus leads the world in ITS device installation.

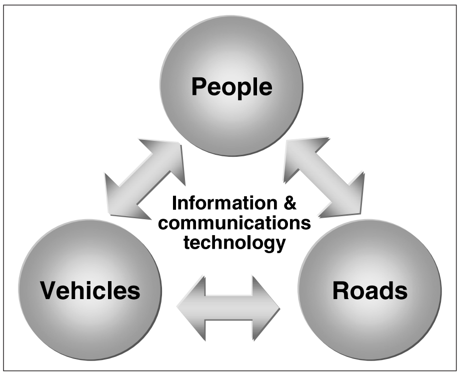


Figure 1 : Conceptual diagram of ITS

Prepared by the STFC based on Reference[3]

Development of elemental technology for "Assistance for safe driving" is progressing in parallel with these developments. The Advanced Safety Vehicle (ASV) has been developed in order to improve the safety and convenience of automobiles themselves through advances in

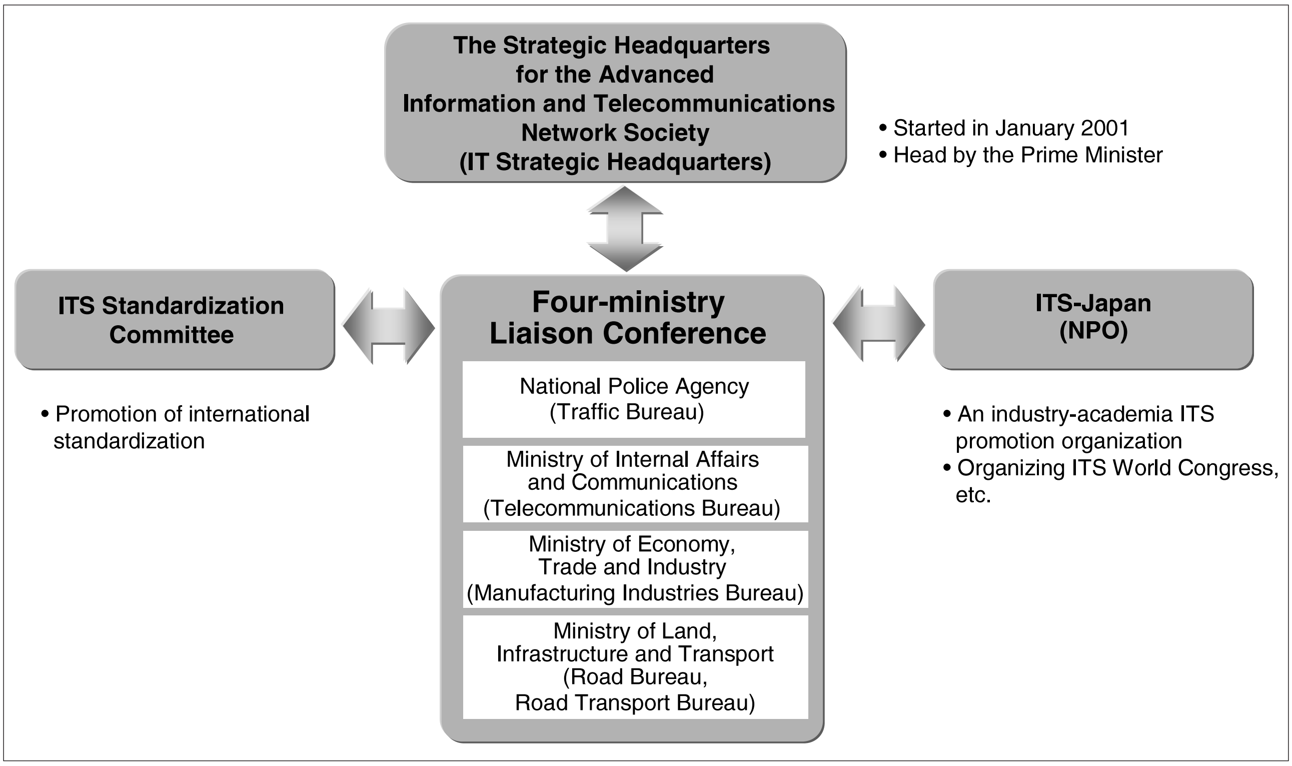


Figure 2 : Japan's ITS promotion Framework

Prepared by the STFC based on Reference[4]

Table 1 : Government policy evolution for ITS promotion in Japan (selected events since establishment of overall concepts)

Date announced	Policy	Summary
July 1996	Overall concepts for ITS promotion	The (then) five government agencies collaborate to establish a master plan for user services and development over the following 20 years.
January 2001	e-Japan Strategy	The vision of mobility and transportation in an ideal society includes the following: "The advanced Intelligent Transport Systems (ITS) will inform people how to get to their destinations using the most appropriate transportation means and via the quickest routes and will help them avoid traffic jams and accidents, thereby ensuring safe and comfortable traveling."
June 2004	e-Japan Priority Policy Program–2004	Promotion of ITS to utilize leading-edge information and communications technologies to address road transportation issues such as congestion, accidents, and environmental degradation.
October 2004	ITS promotion guidelines	ITS basic strategy developed by the ITS Promotion Council, which comprises users, industry, academia, and government, is announced at the ITS World Congress.
February 2005	IT Policy Package – 2005	Initiatives for more advanced ITS include promotion of Dedicated Short Range Communication (DSRC) systems, driving support systems to prevent accidents, and support to realize safe and smooth mobility for the elderly and people with disabilities.
January 2006	New IT Reform Strategy	Moves to the stage of IT utilization following on from the previous strategy of emphasizing the establishment and spread of IT infrastructure. Reduce accident deaths and the number of accidents through practical implementation of safe driving support systems through infrastructure harmonization.

Prepared by the STFC based on References[4,5]

Table 2 : The nine development areas of ITS

	ITS development area	Description of development and achievements in major elemental technologies
1	Advances in navigation systems	Advances navigation systems with VICS, etc. → car navigation, VICS, etc.
2	Electronic toll collection systems	Non-stop payment at toll gate, etc. → ETC
3	Assistance for safe driving	Hazard warning and automated driving → ASV, AHS
4	Optimization of traffic management	Route guidance, traffic signal control, etc.
5	Increasing efficiency in road management	Management of specially permitted commercial vehicles and others, traffic control information, etc.
6	Support for public transport	Management of public transportation operation, etc.
7	Increasing efficiency in commercial vehicle operations	Assisting commercial vehicle operations and management, automated platooning, etc.
8	Support for pedestrians	Route guidance for pedestrians, etc.
9	Support for emergency vehicle operations	Automated emergency notification, disaster and accident announcemrnt, etc.

Prepared by the STFC based on References[4,6]

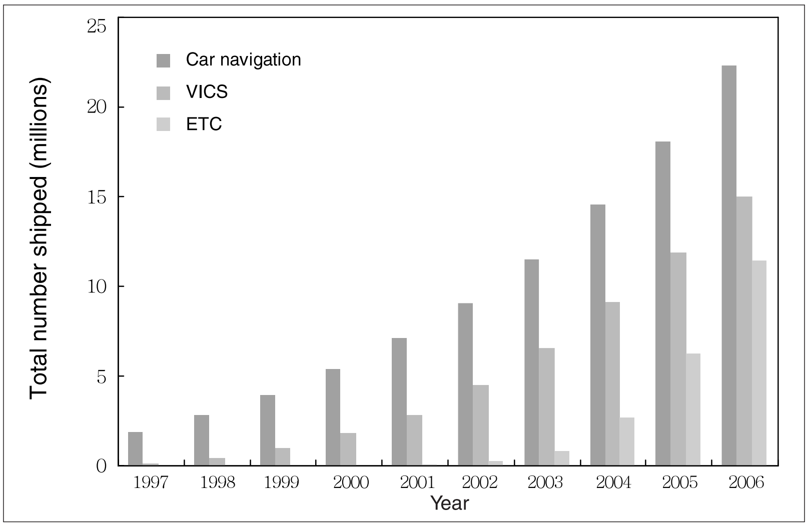


Figure 3 : Spreading of ITS devices

Prepared by the STFC based on Reference[7]

electronics technology. The Ministry of Land, Infrastructure and Transport has spearheaded the progress being made in the ASV through Phases 1 (FY 1991-1995), 2 (FY 1996-2000), and 3 (FY 2001-2005). The basic concept is that drivers are the primary actors in safe driving, and information and communications technology only supports them.

Figure 4 depicts the ASV concept. Collision warnings that alert drivers before they crash, lane-keep assist that helps them stay in their lanes, impact mitigation braking that assists driver braking before impact, night-vision cameras that ensure vision even during darkness, and many other active safety functions to stop accidents before they happen have been put into practical use. In addition to these functions, Japan is a world leader in both research and development and dissemination of car navigation systems, VICS, ETC, and other elemental technologies that comprise ITS.

2-2 *Status of and issues in traffic accidents*

What is the relationship between the dissemination of ITS and the status of traffic accidents?

Figure 5 shows the number of traffic accidents and the numbers of casualties and fatalities these accidents cause in Japan. Fatalities have been on a downward trend since 1990, but accidents and casualties have continued to rise. The number of casualties in 2005 was 1.16 million, roughly double the figure in the second half of the 1970s. The rises in accidents and casualties are associated with increased ambulance and police dispatches, as well as accident-related congestion. Including such indirect losses, the total economic cost of accidents is estimated at more than 4 trillion yen annually[9]. In light of this situation, in January 2003, the Japanese government declared its intention to halve traffic accident fatalities over the following 10 years. Furthermore, in January 2006, the “New IT Reform Strategy” of the Strategic Headquarters for the Promotion of an Advanced Information and Telecommunications Network Society (IT Strategic Headquarters) set the concrete numerical goal of reducing traffic accident fatalities to below 5,000 per year by the end of 2012 by using information and communications technology[10].

Figure 6(a) shows a breakdown of the causes of traffic accidents. The most common cause is late recognition, in other words, errors in recognition. With errors in judgment causing

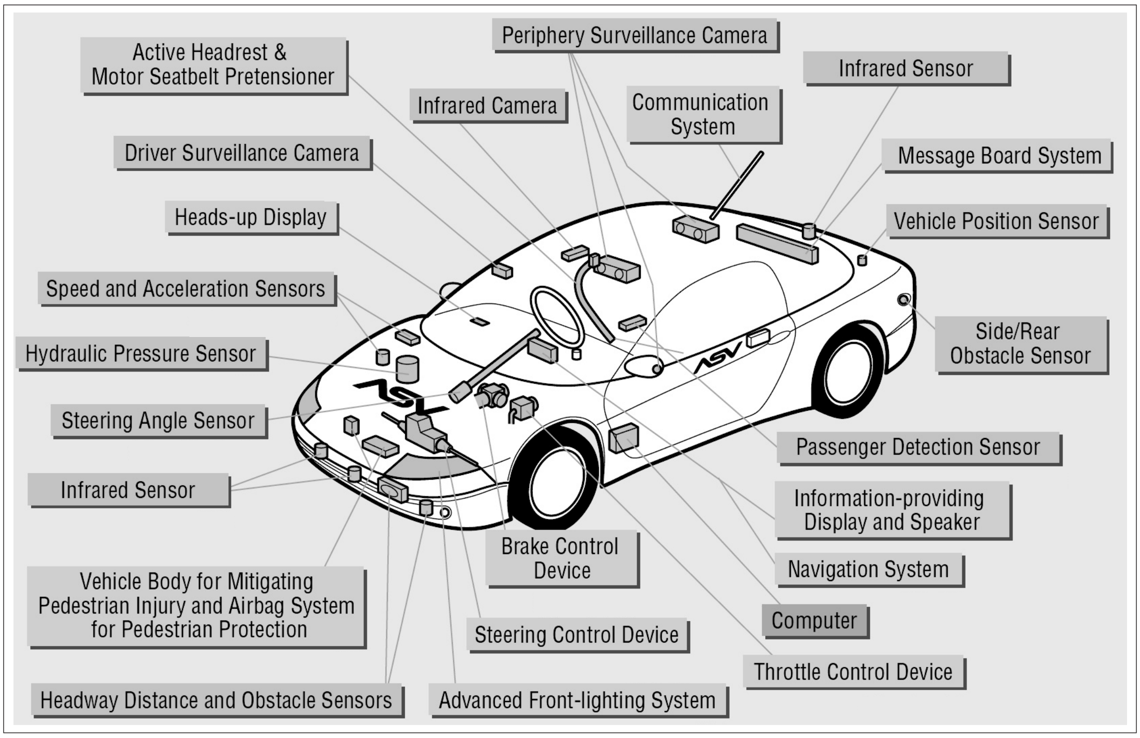


Figure 4 : ASV (Advanced Safety Vehicle) concept

Source: Study Group for Promotion of ASV, Ministry of Land, Infrastructure and Transport[8]

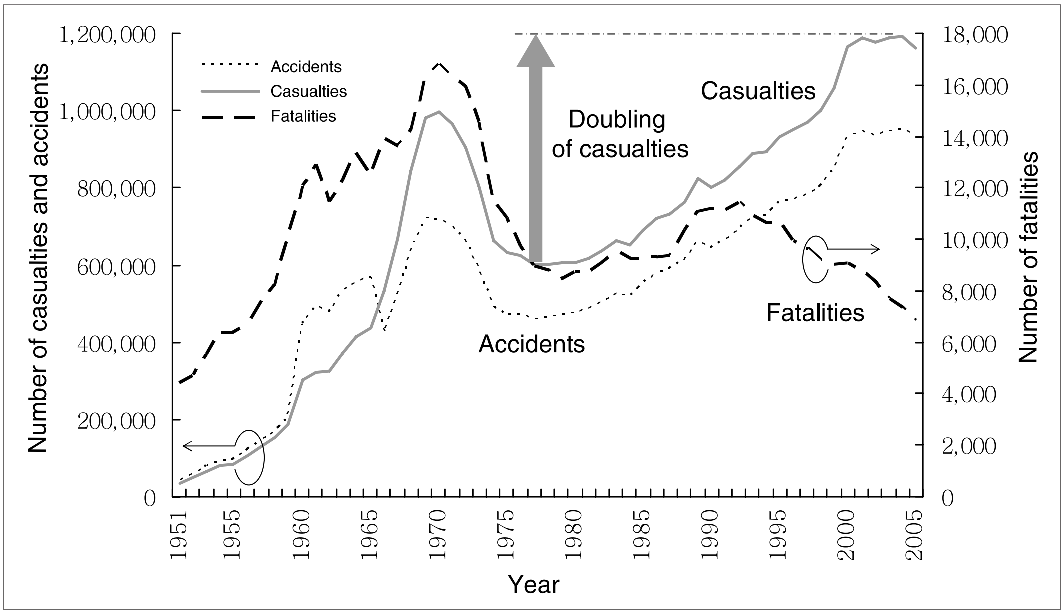


Figure 5 : Number of road traffic fatalities, casualties and accidents

Prepared by the STFC based on Reference[11]

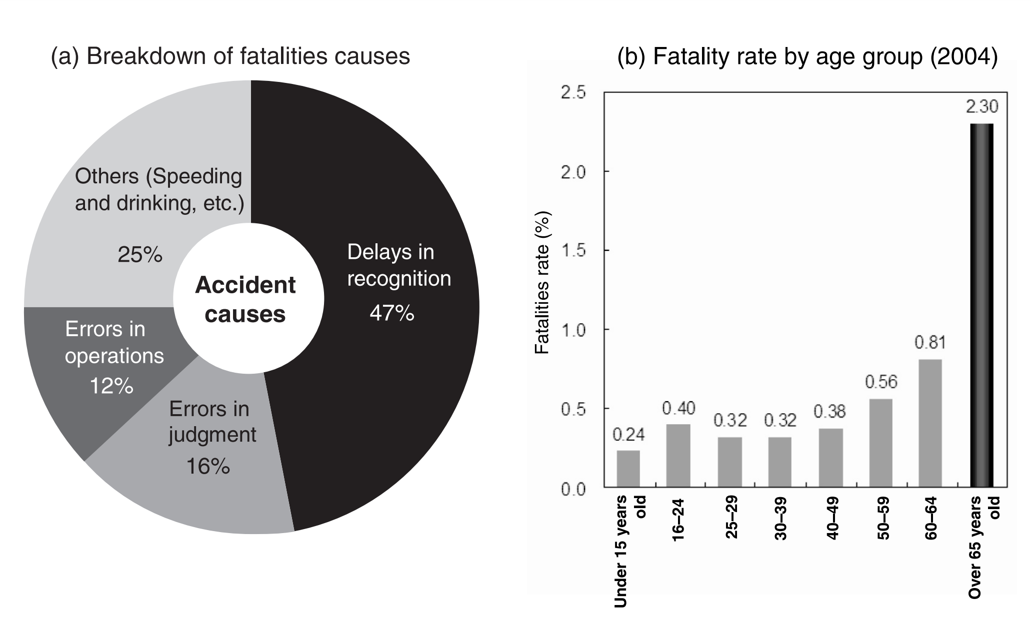


Figure 6 : Breakdown of fatalities causes and fatality rate in traffic accidents by age group

Prepared by the STFC based on References[12,13]

16 percent of accidents and errors in operation another 12 percent, approximately 75 percent of traffic accidents are caused by driver behavior immediately before the accident. In order to reduce traffic accidents, it is therefore necessary to take measures regarding driver action immediately before accidents occur. In addition, looking at traffic accident fatality rates by age group (Figure 6(b)), the rate is markedly higher for drivers 65 and older. This is reportedly not only because of vision declining with age, but also because of slower decision times. With the aging of Japanese society expected to accelerate, it is vitally important to address traffic accidents involving elderly people if tragic accidents are to be reduced.

In light of the above circumstances, the dissemination of ITS in its current approach of concentrating individual functions in onboard devices and ASV is not having a major effect on reducing the number of Japanese traffic accidents.

2-3 Status of and issues related to automobile carbon dioxide emissions

Next, this report will discuss the relationship between dissemination of ITS and carbon dioxide emissions. Carbon dioxide emissions from Japan's transportation sector in 2004 were 2.62 million tonnes, about 20 percent of Japan's total carbon dioxide emissions (Figure 7)[14]. Automobiles emissions amounted to 2.27 million tonnes of CO2, approximately 90 percent of total emissions from the entire transportation sector. While emissions have been declining since peaking in 2001, in fiscal 2004 they were still about 20 percent above 1990 levels. By type of vehicle, carbon dioxide emissions from commercial vehicles such as trucks, buses, and taxis are declining, but emissions from personal and company cars are steadily increasing.

The three factors influencing carbon dioxide emissions from private automobiles are fuel consumption performances of each vehicle, average driving speed, and total amounts of drive distance (vehicle kilometers)[15]. Figure 8 provides a summary of carbon dioxide emissions according to each factor. First, carbon dioxide emissions in relation to fuel consumption performances of each vehicle have been gradually declining in recent years. Since the 1998 revision of the

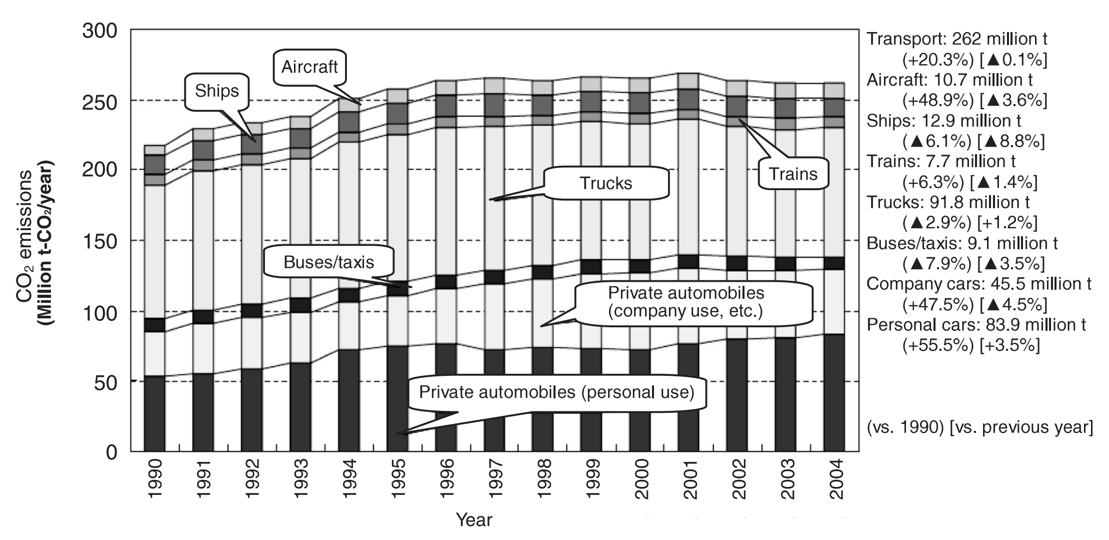


Figure 7 : Carbon dioxide emissions in the transportation sector

Source: Materials of the 35th Global Environment Committee, Central Environment Council, Ministry of the Environment[14]

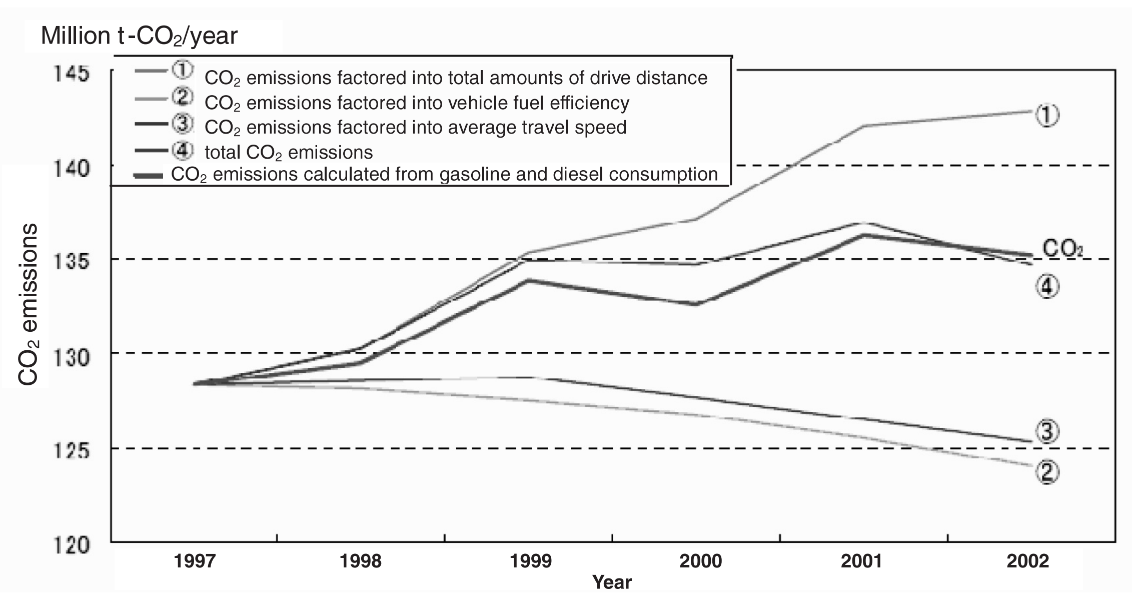


Figure 8 : Carbon dioxide emissions from private automobiles, by cause

Source: Materials of the 35th Global Environment Committee, Central Environment Council, Ministry of the Environment

Energy Conservation Law set "leading-runner" fuel consumption standards, manufacturer efforts have improved the average fuel efficiency of new private gasoline automobiles (mode of 10.15) from 12.3 km/l in 1995 to 15.4 km/l in 2004, an increase of about 20 percent[16].

Carbon dioxide emissions in relation to average driving speed are also gradually declining. This is strongly related to the widespread of ITS technology such as car navigation systems, VICS, and ETC. For example, the spread of ETC has sharply reduced tollgate congestion as a percentage of all congestion on expressways from 31 percent to a mere 4 percent[4], while route guidance provided by car navigation systems and VICS has reportedly reduced average travel time by 4.4 percent[17]. Reduced traffic congestion and increased average driving speed through ITS technologies should result in lower carbon dioxide emissions.

On the other hand, carbon dioxide emissions in relation to the third factor, total amounts of drive distance (vehicle kilometers), have increased rapidly in recent years, resulting in a failure to reduce overall emissions from private automobiles. ITS technology to date has not had a sufficient effect on private automobile drive distance (vehicle kilometers), in other words, on restraining demand.

Turning our attention to the nationwide distribution of carbon dioxide emissions, there are significant regional differences, with emissions in major cities and their environs strikingly high (Figure 9). This is because congestion in large cities has become chronic, reducing average driving speed and lowering fuel efficiency accordingly. Fuel efficiency for internal combustion engines is highest at about 50-60 km/h for gasoline vehicles and around 70 km/h for diesel ones (Figure 10). Average driving speed in major cities with chronic congestion is less than 20 km/h. Fuel wasted due to congestion totals around 9.1 million kl (crude oil equivalent) annually. This is about 11 percent of total fuel consumption[17]. There is still considerable room to reduce carbon dioxide emissions on an average-speed basis, especially in big cities.

Based on the above, the following are three effective approaches that can be linked to reducing carbon dioxide emissions in the transportation sector.

(i) Continue to improve fuel consumption performances of each individual automobile level.
(ii) In the transportation sector as well, control and optimize traffic demand for private cars.
(iii) Ease congestion in large cities through traffic flow measures.

ITS technology can play a large role in promoting approaches (ii) and (iii). Their further evolution is necessary.

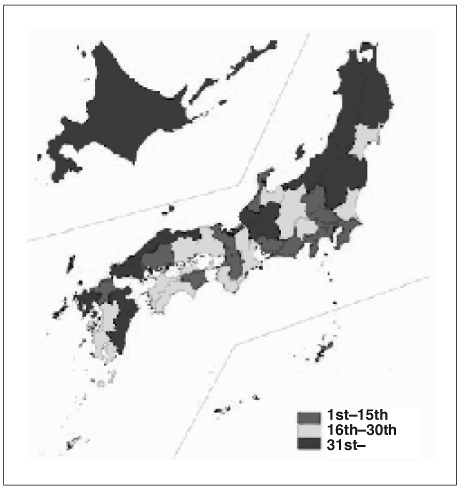


Figure 9 : Prefecture ranking by CO_2 emissions per vehicle kilometer

Source: Materials of the 35th Global Environment Committee, Central Environment Council, Ministry of the Environment

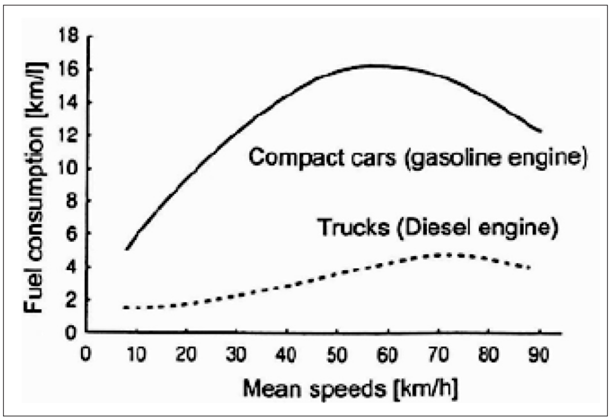


Figure 10 : Relationship between automobile driving speed and fuel consumption[18]

3 The evolution of ITS

3-1 *Towards second-stage ITS*

In order to achieve a sustainable mobility, the negative legacies of automobiles described above, traffic accidents and environmental impacts, must be overcome. While the broad penetration of car navigation systems, VICS, ETC, ASV, and so on as individual systems have clearly had significant effects, they cannot overcome these negative legacies as individual systems. By integrating traffic control systems with safe driving assistance systems, ITS is steadily shifting into its “second-stage," developing into a system that can resolve the negative legacies by joining "vehicles, roads, and people” into a triune entity in accordance with the definition of ITS (Figure 11).

No discussion of the evolution of ITS towards its second-stage is possible without considering the further use of electronics in automobiles. Figure 12 provides a summary of second-stage ITS from a technical perspective. After beginning with the mere replacement of mechanical parts, MPU (microprocessor) performance improved,

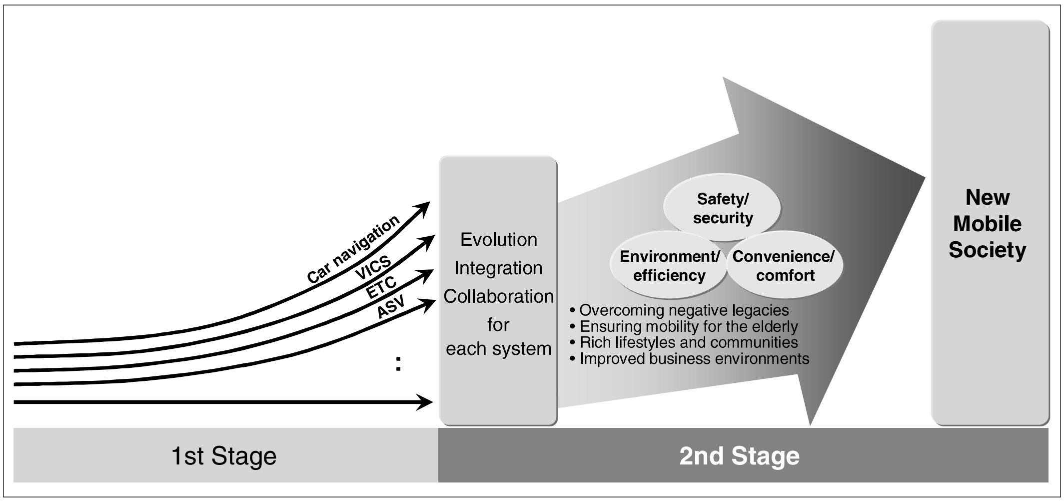


Figure 11 : Concept of second-stage ITS

Prepared by the STFC based on Reference[19]

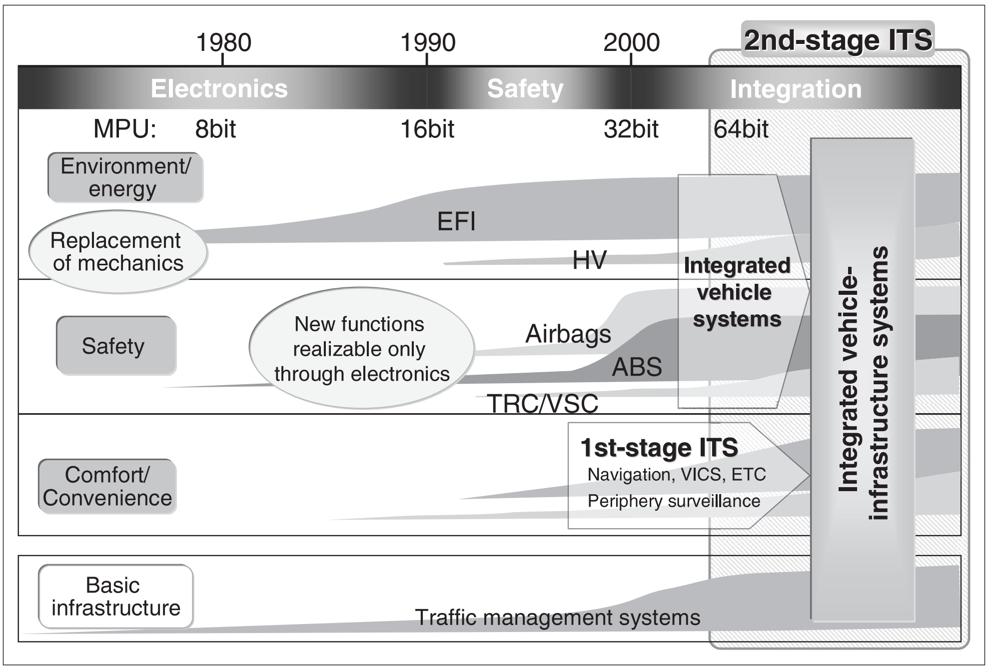


Figure 12 : The shift to second-stage ITS from a technical perspective

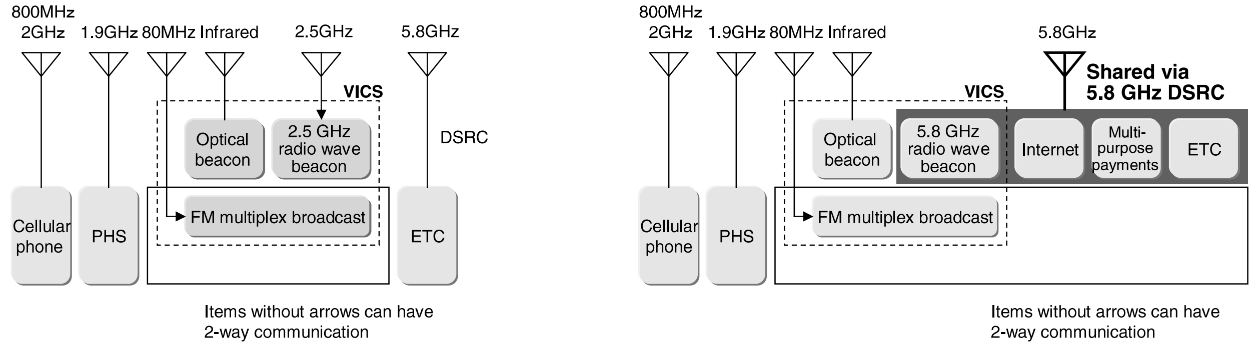
ABS: Antilocked Braking System
HV: Hybrid Vehicle
VSC: Vehicle Stability Control
EFI: Electronic Fuel Injection
TRC: Traction Control

Prepared by the STFC based on Reference[20]

and a shift to functions made possible only through electronics occurred. Development of integrated systems for vecicle such as ASV is progressing. In the future, it will not be an overstatement to say that automobiles are a mass of electronics. Information and communications technology will link integrated onboard vehicle systems with traffic control systems and other road infrastructure, enabling the achievement of vehicle-infrastructure integrated systems that coordinate automobiles and roads.

3-2 Sharing of communication protocols

For collaboration between systems, "road-vehicle communication" that transmits information between vehicles and roads is the first measure being adopted. In order to do this, sharing of communication protocols, a basic technology for road-vehicle cooperation systems, and the establishment of transmission speeds that enable communication even when cars are moving at high speed, are necessary. As depicted in Figure 13, 5.8-GHz wireless Dedicated Short Range Communication (DSRC) is being examined as a potential wireless communication protocol. Current onboard devices must incorporate three antennas to receive VICS communication regarding traffic information via optical beacons, radio wave beacons, and FM multiplex broadcasts, depending on the road and the local setup



(a) Current communication protocols

(b) Projected future communication protocols

Figure 13 : The present and future of communication protocols for ITS devices

Prepared by the STFC based on Reference[21]

Table 3 : Types of communication protocols

	5.8GHz DSRC 	Optical beacon 	Radio wave beacon 	FM multiplex broadcast 
Possible locations for setup and reception	General roads, expressways (projected)	General roads	Mainly expressways	NHK FM broadcast service area
Communication configuration	Two-way (roadside ⇔ car)	Two-way (roadside ⇔ car)	Two-way (roadside ⇔ car)	One-way (roadside ⇒ car)
Communication area	~30m	About 3.5 m	~70m	10–50 km radius
Frequency	5.8GHz	Infrared	2.5GHz	80MHz
Communication speed/transmission capacity (theoretical figure)	4Mbps/50KB	1Mbps/10KB	64kbps/8KB	8kbps/50KB
Applications	VICS and next-generation road services	VICS only		

Prepared by the STFC based on Reference[22]

conditions (Table 3). Furthermore, use of ETC requires a separate 5.8-GHz DSRC antenna. The mixing of multiple communication protocols raises costs and interferes with dissemination. The 5.8-GHz DSRC currently used for ETC is now being considered as a unified communication standard, which can be used not only for cooperated road-vehicle communications using radio wave beacons, but also for ETC, Internet, and multipurpose billing including parking lots. Practical application is projected for 2007.

3-3 *ITS evolution for traffic accident reduction*

Seventy-five percent of traffic accidents are related to errors in recognition, judgment, and operation, and thus based in actions taken immediately before accidents happen. As discussed in Section 2-2 above, research and development on improvements to ASV in order to reduce driver mistakes includes adding information provision functions that address errors in recognition, alarm and driving assistance functions that address errors in judgment, and operation assistance functions that address errors in vehicle operation. There is a limit, however, to the amount by which autonomous safety systems for individual vehicles such as ASV can reduce traffic accidents. Figure 14 shows the results of a simulation of traffic accident fatalities assuming the full implementation of autonomous safety systems for preventative action, accident avoidance, and collision mitigation. These results indicate that even if all vehicles were to be equipped with autonomous systems, fatalities cannot be entirely eliminated. This is because most traffic accidents occur due to errors in recognition or judgment at intersections with poor visibility, when passing, and so on. It is difficult to avoid such accidents solely though autonomous safety systems.

In order to further reduce fatalities, it is therefore necessary not only to improve autonomous safety systems, but also to achieve vehicle-infrastructure integrated systems that use information and communications between roads and vehicles, among vehicles, and between pedestrians and automobiles to aid driver recognition. This report will now discuss experiments with such systems.

(1) An experiment with cooperated road-vehicle ITS (driving assistance road system)

The Advanced Cruise-Assist Highway System Research Association technical research consortium is working on a safe driving assistance system using road-vehicle coopetarion called the Advanced cruise-assist Highway Systems (AHS).

On the Metropolitan Expressway, 21 percent of accidents occur on accident-prone curves (about 6 percent). In the Sangubashi curve area of the Metropolitan Expressway's No. 4 Shinjuku

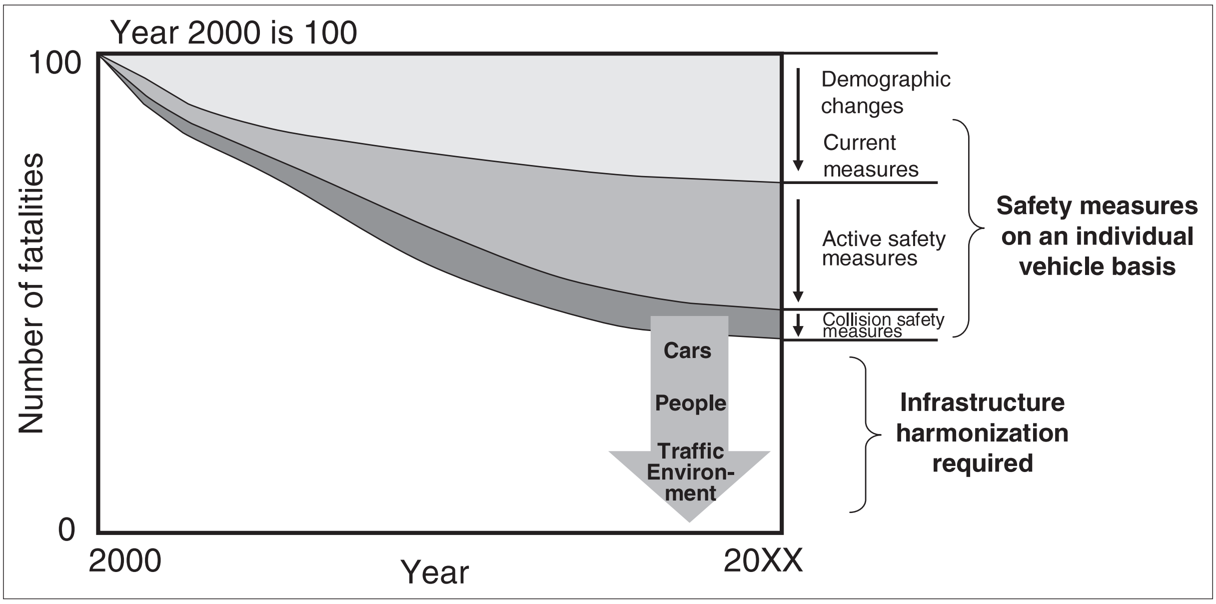


Figure 14 : Results of simulation of number of traffic accident fatalities

Prepared by the STFC based on Reference[23]

route, existing onboard devices (three-media VICS car navigation systems*3) were used in a three-month demonstration experiment with general vehicles beginning in March 2005. In the experiment, as depicted in Figure 15, when congestion occurs in the curve's vicinity, roadside infrared sensors detect the situation, and roadside VICS beacons 300 meters away send a warning about conditions around the curve to cars in the form of a simplified image. This system enabled a 60-percent reduction in accidents compared with the previous fiscal year. A questionnaire showed that 80 percent of elderly drivers found the system helpful. An electric bulletin board that constantly flashes a warning may come to be disregarded, but because this system only displays an alarm when there is actual congestion in the curve's vicinity, it has a powerful warning effect. This experiment was carried out with existing onboard devices, but in the future when 5.8-GHz DSRC is adopted and two-way communications speed improves, it will be technically feasible to control the entry of vehicles.

(2) An experiment with integrated pedestrian-vehicle ITS (system using IC tags)

Figure 16 depicts an example of a demonstration experiment with a pedestrian-vehicle integration system for communication between pedestrians and automobiles. Conventionally, drivers are unable to tell whether there are pedestrians in blind spots at intersections, but with integrated infrastructure systems, IC tags send signals

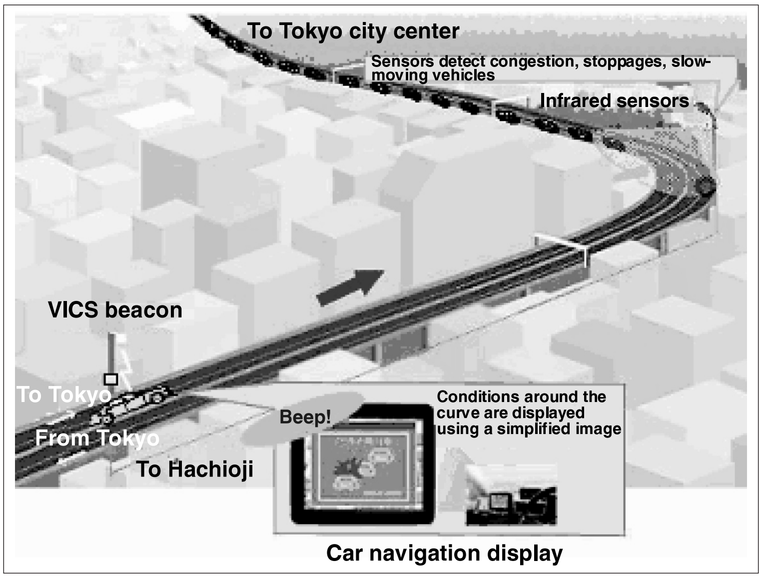


Figure 15 : Example of a road-vehicle cooperation system using ITS

Source: AHSRA webpage[24]

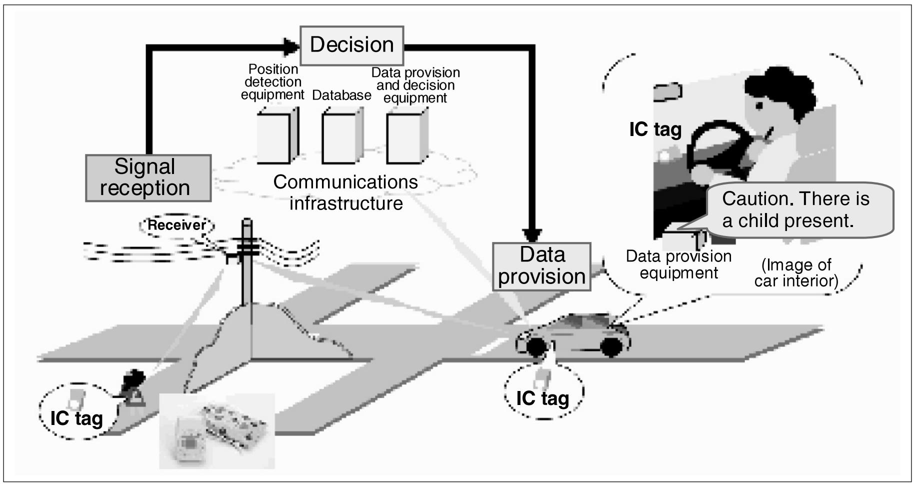


Figure 16 : Example of ITS response to an unseen person (pedestrian)

Source: Reference[25]

to receivers at intersections, and the data are provided to the vehicle's internal systems. This enables drivers to become aware of the presence of pedestrians before they can see them, with automatic braking applied in order to avoid accidents before they occur. Moreover, systems can be set up to warn pedestrians of the presence of automobiles as well. About 80 percent of drivers said they found the system useful.

On the other hand, if the information provided by an integrated pedestrian-vehicle ITS system is unclear, or if too much unnecessary data is provided, it can confuse drivers and actually increase the likelihood of driver errors. In addition, if drivers are over-reliant on the system, this may induce complacent driving without the necessary independent driver vigilance. Therefore, in order to achieve integrated pedestrian-vehicle ITS systems, a deeper understanding of the behavioral psychology of drivers, their perceptions, and their ability to process information is necessary, and appropriate human-machine interface (HMI) must be constructed. Integrated research in various fields other than information and communications technology, including cognitive science and ergonomics, is therefore being actively conducted by various academic groups (Table 4).

Table 4 : Activities of academic societies

Name	Research group	Research subjects
Institute of Electronics, Information and Communication Engineers	Technical Group on ITS Technology	Primary fields are ITS policy, ITS communications technology, car electronics, ITS road transportation infrastructure technology, ITS sensing technology, and ITS information technology
	Technical Committee on Pattern Recognition and Media Understanding (PRMU)	Research subjects are pattern media such as images and sound, from basic theory on recognition and understanding to methods and applied technologies
Information Processing Society of Japan	Special Interest Group of ITS	Primary research fields are traffic management, driving assistance, image processing, communication protocols, network technology, information provision, and applications
	Special Interest group of Computer Vision and Image Media (CVIM)	Research through sensory information processing
	Special Interest Group on Ubiquitous Computing System	Regarding human-centered services and ubiquitous information processing in urban information infrastructure, including automobiles
	Special Interest Group of Mobile Computing and Ubiquitous Networking (MBL)	Regarding mobile computing, basic theory and technology, communication protocols, computer architecture, operating systems, applications, applied cases, management and operation, and social scientific considerations, etc.
Institute of Electrical Engineers of Japan	Technical Committee on ITS	Primary research fields are traffic measurement systems, traffic management systems, traffic information systems, driving assistance systems
	Japan Society of Traffic Engineering, ITS Research Committee	Application of traffic engineering that utilizes ITS technology (traffic demand management, etc.) to traffic issues
Society of Instrument and Control Engineers	Research Committee for Smart Vehicle System	Creation of next-generation intelligent vehicles (smart vehicles) that are high-performance, safe, comfortable, and people- and environment-friendly through integration of ITS and other leading-edge infrastructure and systemization technologies
Japan Society of Civil Engineers	Special Committee on Practical ITS Research, Subcommittee on Transportation Infrastructure Information Business	Suggestions for ITS from a civil engineering perspective
Universities	ITS Center, Institute of Industrial Science, University of Tokyo	Multiscale traffic simulation, from macro to micro, in complex, realistic experimental traffic environments through combining traffic simulators (TS), driving simulators (DS), and the most advanced image information technology
	Regional ITS Infrastructure Research Center, Research Institute, Kochi University of Technology	Contribute to vitalization of regional society by planning, proposing, and promoting ITS measures appropriate to regional societies based on sharing of the results of regional ITS and industry-government-academia cooperation

3-4 The evolution of ITS for the reduction of carbon dioxide emissions

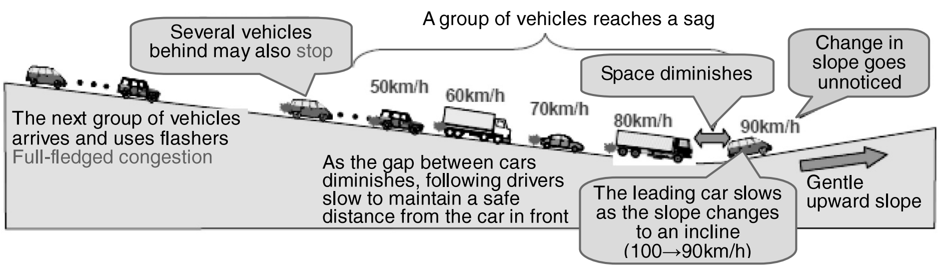
Development of new ITS technology integrating infrastructural and vehicle systems is also being carried out from the perspective of reducing carbon dioxide emissions. Below are examples of traffic demand control measures and traffic flow measures.

(1) Examination of a congestion prevention system using AHS technology

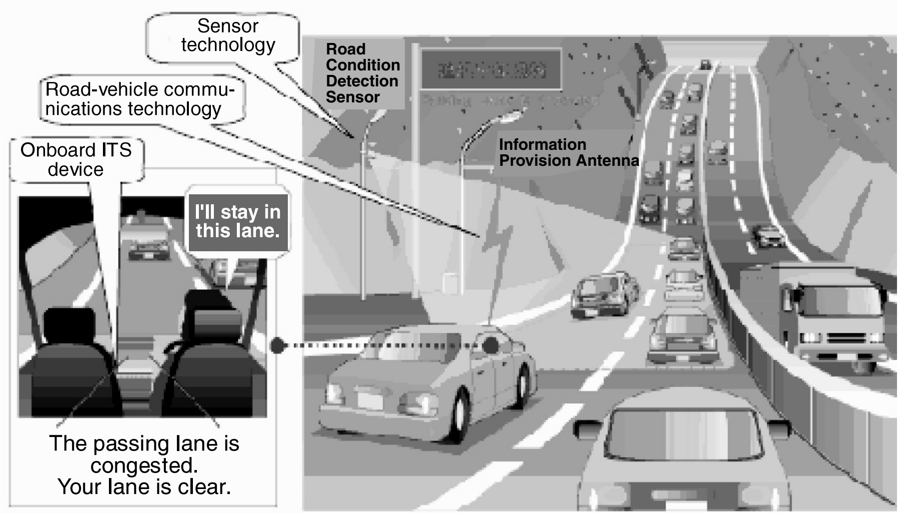
Areas of expressway congestion other than tollgates include sags, tunnels, and interchanges where traffic merges. Those places on expressways where downhill slopes become uphill slopes are called “sags.” Drivers are unconscious of the fact that they lose speed at such locations, causing congestion among the vehicles following them[26]. Similarly, the shift from light to dark at tunnel entrances causes drivers to slow down unconsciously, creating congestion among following vehicles (Figure 17). Development of the above-mentioned congestion prevention system using AHS technology is now being considered in order to prevent blocked traffic flow due to such driver psychology. This system uses sensors, road-vehicle communications technology, and onboard ITS devices to guide vehicles to lanes with more room and to caution the leading vehicles causing the congestion, thereby helping traffic to flow more smoothly.

(2) Study of road-vehicle cooperation real-time signal control

A problem with current signal control is its inability to respond flexibly to non-steady traffic conditions (accidents, construction, etc.). Harmonizing signal control with road-vehicle communications makes possible accurate collection of traffic data and effective traffic guidance and distribution through an advanced signal control method called “road-vehicle cooperation real-time signal control”[27,28]. This signal control method uses ITS technology to directly measure delays due to traffic waiting for



(a) Traffic congestion mechanism in a sag area



(b) Congestion prevention system utilizing AHS technology

Figure 17 : The traffic congestion mechanism in a sag area and a congestion prevention system utilizing AHS technology

Source: Reference[4]

signal changes and automatically adjusts signal parameters to minimize those delays. It enables signal control that responds flexibly to changes in traffic flow. Experiments with this system on actual roads led to improvements of 5-20 percent in the time required to pass through the usage area[29].

Overseas, Sweden devised a signal control system called the “Green Wave System” in the early 1990s (Figure 18)[30]. This system attempts to control automobile speed so that cars can always pass through intersections with a green light, achieving smooth traffic flow. The infrastructure system detects traffic flow and calculates the correct speed for vehicles to pass through controlled intersections without needing to stop based on the signal timing, then roadside beacons communicate this information to vehicles. Based on the data they receive, the vehicles automatically adjust their speed to maintain the proper distance from the cars ahead of them, enabling them to pass through intersections without stopping. At the time the system was proposed, ITS-related technology was still immature, so testing of an actual system was never carried out. In an Australian experiment with nonstop signal speed in 1987, the number of stops at signal lights fell 50 percent, resulting in fuel savings of 6-15 percent[31]. In the future, this system is expected to be integrated with two-way road-vehicle communications technology and adaptive cruise control (ACC; cruise control that also uses brakes) technology for practical implementation.

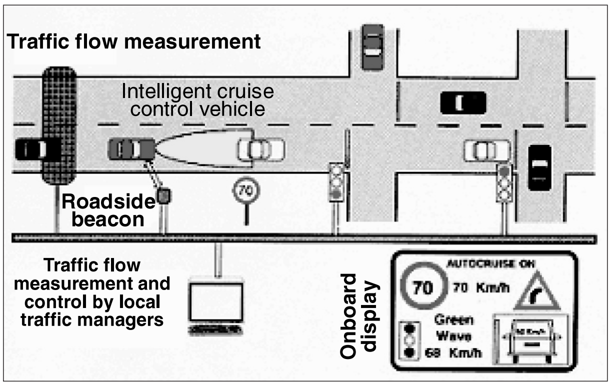


Figure 18 : Sweden’s signal synchronization speed control system (Green Wave System)

Source: Reference[30]

(3) Transportation Demand Management (TDM)

Economic development has been the priority in road policy to date. As automobile traffic demand increased, securing greater traffic capacity and easing congestion have been the primary issues, leading to the building of bypass roads and beltways. From now on, balancing conservation of the global environment with maintenance of economic activity will be important, and road policy that adds the perspective of correcting traffic demand to that of securing more capacity should be pursued.

“Transportation Demand Management” (TDM) is a policy of using fees, regulation, guidance, and other soft aspects to control traffic demand by changing driver behavior. Concrete measures include “park and ride,” “car sharing,” “road pricing,” and “use of public transportation.” While such TDM measures are acknowledged as effective in reducing carbon dioxide emissions, their use has not spread because they decrease user convenience and are not cost effective. In recent years, however, TDM measures using ITS technology have been implemented nationwide as part of urban renewal[32].

Let us examine “car sharing” as a case study. Car sharing involves the organized shared use of a single automobile by several members. It was seen as a way to reduce environmental impacts by lessening overdependence on automobiles and promoting use of public transportation, but the complexities of shared ownership prevented its spread[33]. Utilization of ITS in car sharing can ease some of this complexity, and car sharing enterprises are steadily spreading in Europe and the USA in particular. Because car sharing can reduce the cost burden for individual users, it has been successful as a means of promoting the spread of electric vehicles (EVs) and other low-pollution cars[34].

In Japan, although the number of cases of car sharing is gradually increasing, it has not spread to the extent seen in Europe and the USA. This is because factors such as (i) lack of understanding of the social benefits, (ii) the deep roots of car ownership as a status symbol, (iii) lack of awareness of car sharing as a means of comprehensive traffic demand management, (iv) difficulties securing parking, and (v) profitability

Table 5 : Energy conservation through ITS technology

Effect	ITS technology	Estimated CO_2 emission reduction	Notes
Smoother traffic flow through traffic management system	Signal control	1M t-CO_2 (*1)	Installation of traffic sensing signals
	ETC	06.M t-CO_2 (*1)	Reduction in tollgate congestion, elimination of stopped vehicles
Efficient driving through information provision system	Provision of traffic information (VICS)	1M t-CO_2 (*2)	Assuming VICS penetration of 20% and 4.4% reduction in travel time for equipped vehicles
	Route guidance (car navigation)	2M t-CO_2 (*2)	Assuming car navigation penetration of 30% and 2.4% reduction in route deviations for equipped vehicles
Efficient driving through vehicle control	Automatic cruise control system (ACCS)	0.02M t-CO_2 (*3)	Reduction in sag congestion on expressways, ACCS penetration 10%
	Vehicles with automatic cruise control	0.2M t-CO_2 (*1)	
Reduced amount of driving	Traffic demand management (TDM)	3.6M t-CO_2 (*1)	Lower share for automobiles in major cities
	Shared collection and delivery information provision system	1.1M t-CO_2 (*2)	Assuming 56.3% load rates in commercial cargo vehicles
	Car sharing	7.6M t-CO_2 (*4)	Assuming 5% car sharing rate

Calculated by the STFC from:
*1: Japan Automobile Manufacturers Association, "JAMA's Approach on Global Warming Countermeasures," JAMA Report No. 90
*2: Energy Conservation Center, "FY 1997 Energy-saving Measures and Effects through ITS"
*3: Energy Conservation Center, "FY 1996 ITS and Energy-saving Effects"
*4: Foundation for Promoting Personal Mobility and Ecological Transportation, "Report on examination of environmental impact reduction through car sharing and methods for its dissemination," March 2006

issues combine to create a vicious circle. None of these factors is unique to Japan, and all of them can be overcome by an accumulation of individual measures. In recent years, Japan has also seen an increasing number of people seeking lifestyles of health and sustainability (LOHAS) that consider mental and physical health and the global environment. Such people are likely to support car sharing as it becomes established.

(4) Probe data utilization service

Automobiles are equipped with up to about 150 kinds of sensors. The information obtained by these sensors is called "probe data." Automobiles themselves are considered mobile traffic monitoring devices. With probe data collected by wireless communications, vehicle behavior and position data can be understood and better traffic flow and behavior calculated, and even weather conditions and other natural phenomena can be monitored. Probe data are characterized by the fact that, unlike VICS, which is installed on main roads, they can provide information from small side streets as well as information on vehicles themselves. Collection of probe data can be accomplished through use of mobile phone networks or other existing communications infrastructure. Private sector businesses are leading the way in providing services using probe data. While ordinary VICS can provide traffic data for intervals of about 42,000 km, probe data can cover intervals of around 356,000 km[35]. In the future, integration of this data with car navigation systems and VICS functions will enable more detailed and accurate route guidance including factors such as weather conditions and data on individual lanes and road surfaces.

(5) Potential carbon dioxide reduction

As seen above, the adoption of ITS technology, which has evolved beyond conventional car navigation systems, VICS and ETC, and integrates infrastructure and vehicles, and the utilization of ITS combined with traffic measures, can help reduce carbon dioxide emissions. Table 5 shows the extent of this potential. The total potential reduction in carbon dioxide emissions from conventional car navigation systems, VICS, and ETC is 3.6 million tonnes, while the estimated potential reduction from second-stage ITS technologies is 13 million tonnes. Under Japan's plan to meet the goals of the Kyoto

Protocol, the transportation sector as a whole is to cut 46 million tonnes of CO_2. This indicates the significance of adopting second-stage ITS technology.

4 Trends in international standardization and Japan's role

There are two trends in initiatives on international standardization in the ITS field.

First, an initiative on international standardization in the ITS field is being formulated by the International Organization for Standardization's (ISO) technical committee TC204. TC204 comprises the 12 working groups (WGs) shown in Table 6. Japan is actively involved, participating as a voting member of TC204 and as the responsible country for WG3 and WG14.

The International Telecommunication Union (ITU) is an international organization that adopts rules and agreements on the use of frequencies on the ground and in space. Study Group 8 (SG 8) of the ITU's Radiocommunications Sector (ITU-R) carries out actual work on ITS. In May 2000, Japan's DSRC wireless communication protocol for ETC was adopted as ITU-R's international

Table 6 : ITS international standardization activities: ISO/TC204 working groups

Working group	Working group	Lead country
WG1	Architecture	UK
WG3	ITS database technology	Japan
WG4	Automatic vehicle and equipment identification	Norway
WG5	Fee and toll collection	Netherlands
WG7	General fleet management and commercial/freight	Canada
WG8	Public transport/emergency	USA
WG9	Integrated transport information, management and control	UK
WG10	Traveller information systems	UK
WG11	Route guidance and navigation systems	Germany
WG14	Vehicle/roadway warning and control systems	Japan
WG15	Dedicated short range communications	Germany
WG16	Wide area communications/protocols and interfaces	USA

Prepared by the STFC based on Reference[4]

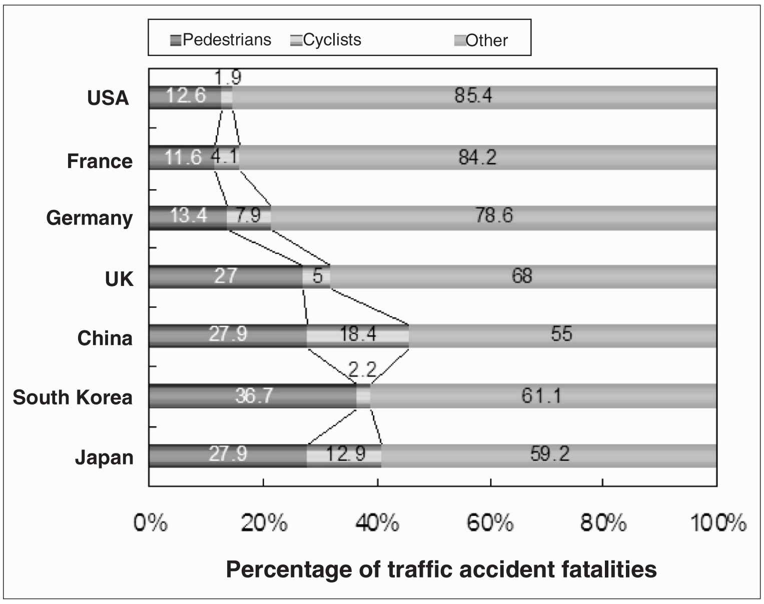


Figure 19 : Pedestrian fatalities as a percentage of all traffic accident deaths

Prepared by the STFC based on Reference[36]

recommendation. To date, Japan has succeeded in having the protocols it has developed and incorporated into international standards.

In the process of developing second-stage ITS infrastructure-integration, it inevitably involves adaptation to the local traffic conditions and needs. In the case of traffic accidents (Figure 19), for example, Japan has a very high percentage of accidents involving pedestrians, a trend found elsewhere in Asia. On the other hand, Europe and the USA have mainly vehicle accidents. Therefore, the advanced safety systems that Japan is pursuing, such as pedestrian-vehicle integration, may not always suit for Europe and the USA. Even then, for pursuing the international standardization, the collaboration with Europe and the USA must be carefully considered.

5 Future directions

As discussed above, the second-stage ITS, integrating vehicles and infrastructure and joining roads, vehicles, and people with information technology, is essential for overcoming the negative legacies of the automobile society, such as traffic accidents and environmental impacts. This report proposes the achievement of second-stage ITS from the following viewpoints.

(1) Research and development of human-machine interfaces that consider elderly people

Errors in recognition, judgment, and operation cause 75 percent of traffic accidents. As discussed above, elderly people have a high accident rate. Because Japan is the most rapidly aging country in the world, research and development that focuses on the elderly is vital. To date, research has centered on functional systems, such as airbags, lane-keep assist, and sensors, but now integrated interdisciplinary ITS research covering ergonomics and cognitive science from perspectives such as information processing, telecommunications, automated control, and traffic engineering is needed. In particular, the closed space of the automobile driver's seat, where people perform all their recognition, judgment, and operation control while moving, requires the most concentrated human-machine interface (HMI) in daily life. Further research on human-machine interfaces that are easy not only on elderly people but also on world standard users is necessary.

(2) Promotion of social acceptance of ITS implementation

In shifting to the vehicle-infrastructure integration system that is second-stage ITS, new onboard communications devices and capital investment in infrastructure are necessary. Unlike conventional ITS, which was primarily concerned with increased comfort and convenience, the benefits of second-stage ITS systems involve safety, security, reduced environmental impacts, and other aspects whose costs are difficult to measure. Greater efforts will likely be necessary in order to gain the acceptance of users and society for the new costs that will be incurred. Industry, government, and academia must work together to promote quantitative comparison of costs versus effects, sufficient assessment before implementation, ex-post evaluation, and information disclosure. Furthermore, just as emission regulations in the past promoted improved automobile performance, examination of possible regulations, for example, requiring new cars to install ITS devices or restricting the access of cars without the equipment to major urban areas is necessary. In any event, promotion of second-stage ITS implementation and diffusion will require public understanding. This can be brought about by educational activities on safety, energy, and the environment.

(3) Initiatives that contribute to sustainable development in Asia

As motorization proceeds in Asia, associated social problems such as traffic accidents and environmental impacts will become much more serious than ever before. The advancement of second-stage ITS must be expected to contribute to develop a sustainable transportation systems in Asia through strategic collaboration and cooperation within Asian countries.

Because second-stage ITS systems involve vehicle-infrastructure integration, they must suit the local traffic conditions and needs. The types of traffic accidents that occur in Japan more closely resemble those in other Asian countries than the kinds of accidents that occur in Europe and the USA, so the advanced safety systems of second-stage ITS developed in Japan probably match Asian needs better than European or American ones. Japan and other Asian countries can therefore develop common ITS technology bases. Another effective approach is to generate ideas for comprehensive experimental model cities with advanced vehicles and infrastructure from an early stage for areas in Asia that are ripe for development. Transportation infrastructure in the Asian region is currently incomplete. Therefore, it may be easier for these Asian countries to develop second-stage ITS infrastructures than that for Japan, with its completed infrastructure.

At the same time, if second-stage ITS systems are closely matched to Asian needs, the technology systems may not always suit for Europe and the USA. Even then, for pursuing the international standardization, the collaboration with Europe and the USA must be carefully considered.

Today's automobile industry faces international competition in a global market. In order to survive, Japan's continually developing automobile industry must remain a driving force behind Japan's entire economy. The future progress of motorization in Asia will create a favorable growth market for the automobile industry. Initiatives to collaborate with Asian countries on the development of second-stage ITS technology will not only contribute to sustainable development in Asia, they will also maintain the international competitiveness of Japan's automobile industry.

Acknowledgments

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Glossary

*1 VICS
an information system that transmits data on traffic congestion and restrictions edited and processed at the VICS Center to onboard car navigation devices in the form of text and images.

*2 ETC
a nonstop automatic collection system for use on toll roads. Antennas at tollgates communicate wirelessly with devices installed on vehicles to collect tolls.

*3 Three-media VICS car navigation systems
VICS that uses three media, optical beacons, radio wave beacons, and FM multiplex broadcasts.

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3

Recent Moves to Address the KOSA (Yellow Sand) Phenomenon

— Towards Solutions for a Problem that is an age-old Natural Phenomenon and has concurrently been Influenced by Anthropogenic —

Yoshika Yamamoto
Environment and Energy Research Unit

1 Introduction

To the Japanese, the KOSA (Yellow Sand) is seen as a tranquil sign of spring, as well as the first spring storm. KOSA (Yellow Sand) is often observed from early spring through early summer when low atmospheric pressure passes over East Asia. When the KOSA (Yellow Sand) phenomenon occurs, the sky fills with a yellow haze, so it is well known to the people of Japan. KOSA (Yellow Sand) was observed around Japan in the spring of 2006, and on April 18 was detected in the center of Tokyo for the first time since April 14, 2000, an elapse of six years. It was also observed on April 19, the first time in 18 years the phenomenon had been detected on two consecutive days. The last time that this had occurred was April 14 and 15, 1988. (See color photographs on the front cover; taken with the MODIS sensor on board NASA's Aqua/Terra Earth observation satellite and received and processed by the Japan Aerospace Exploration Agency [JAXA].) Desert sandstorms on the largest scale have struck China during the past several years, causing extensive damage and even deaths.

For three consecutives years from 2000 through 2002, the number of observations of the KOSA (Yellow Sand) phenomenon exceeded the records set during the previous 30 years. Furthermore, the KOSA (Yellow Sand) phenomenon was observed in northern Japan and in early autumn, in places and times it has rarely occurred in the past. This has caused a steady increase in society's interest in the phenomenon.

Recent research has found that KOSA (Yellow Sand) suspended in the atmosphere has profound direct and indirect effects on global climate. Along with being a natural disaster in the areas where the KOSA (Yellow Sand) phenomenon originates, the phenomenon affects air quality in areas to which KOSA (Yellow Sand) is carried and it affects global climate[1]. KOSA (Yellow Sand) had been considered a natural phenomenon, but some researchers point out that the rapid expansion of damage in China and elsewhere indicates a major anthropogenic influence. More detailed elucidation of the phenomenon is necessary. At this point, however, researchers do not fully understand even the physical and chemical properties of KOSA (Yellow Sand) itself.

2 KOSA (Yellow Sand) phenomenon

KOSA (Yellow Sand) is a phenomenon in which soil and mineral particles are picked up by the wind in arid and semi-arid regions such as Takla Makan Desert and Loess Plateau in inland China, and Gobi Desert spreading between China to Mongolian, and are carried to a height of several thousand meters. Prevailing westerlies then carry the particles to eastern Asia and the western Pacific region, including Japan, where they remain suspended in the atmosphere or fall to the ground.

The KOSA (Yellow Sand) picked up by the wind in the continent's arid and semi-arid regions does not merely cause major damage to agricultural production and living environments near the areas where it originates. It also impacts global climate by forming clouds of KOSA (Yellow Sand) suspended particulate acting as nuclei to form precipitation. Furthermore, some scientists theorize that the particulate falls to the ocean and significantly affects the oceanic ecosystem by altering the mineral supply to surface plankton[2]. However, the details of this phenomenon remain unclear.

The KOSA (Yellow Sand) phenomenon had been understood as a "natural phenomenon" in which the wind carried dust from the Yellow River basin, deserts, and so on. Recently however, the enormous increase in the frequency of its occurrence and the damage it causes, indicates that the relentless rapid spread of overgrazing and the expansion of cultivated areas through agricultural conversion are factors that influence the severity of the phenomenon. Scientists are rediscovering KOSA (Yellow Sand) as an environmental problem influenced by anthropogenic forest reduction, soil degradation, and desertification rather than being simply a natural phenomenon[2].

Table 1 : Definitions of KOSA (Yellow Sand) in various countries

[China]

Visibility	Name for weather when "KOSA (Yellow Sand)" appears	Terminology	Note: (http://www.weathercn.com/room/shuyu.jsp) (China Meteorological Administration, "Guide to Surface Weather Observation [2003]")
Less than 10 km	Dust weather Dust storm weather	Drifting dust	Weather phenomenon where sand or dirt particles are suspended in the air and horizontal visibility is less than 10 km
1-10 km		Blowing dust	Weather phenomenon where dust is lifted from the ground by wind, the sky is turbid, and horizontal visibility is 1-10 km (also called "high wind dust")
Less than 1 km		Dust storm	Weather phenomenon where dust is lifted from the ground by wind, the sky is rather turbid, and horizontal visibility is less than 1 km
Less than 500 m		Strong dust storm	Weather phenomenon where big (strong) winds lift dust from the ground, the sky is very turbid, and horizontal visibility is less than 500 m (Note: "big winds" are generally at least an 8 on the Beaufort scale [momentary wind speed of 17.2 m/s] and above)
Less than 50 m		Extreme dust storm	Weather phenomenon where raging (very strong) winds lift large amounts of dust from the ground, the sky is very turbid, and horizontal visibility is less than 50 m (Note: "raging winds" are generally at least a 10 on the Beaufort scale [momentary wind speed of 24.5 m/s] and above)

[South Korea]

Particle size, Density	Name for weather when "KOSA (Yellow Sand)" appears	Terminology	Note: (Republic of Korea Meteorological Administration 2002, Chu 2004)
1~1000μm	Hwangsa (Yellow Sand)	Sand	Evenly distribution in the air with little or no wind
1~10μm		Dust, KOSA (Yellow Sand)	Particle size 10 μm: suspended for a few hours to a few days Particle size 1 μm: suspended for a few years
		KOSA (Yellow Sand)	A phenomenon, usually occurring in spring, in which dust from arid and semi-arid areas such as the Badain Jaran, Tengger, Mu Us Shamo, Hunshandak, Kerchin, Gobi, and the Loess Plateau regions of Asian Continent floats and falls, impacting visibility and air quality. Three stages, levels 0, 1, and 2, depending on observation of visibility in visual. KOSA (Yellow Sand) density is used for forecasts. When the forecast is issued for an average hourly density of more than 300 μg/m^3 for over 2 hours, a KOSA (Yellow Sand) advisory is issued. A KOSA (Yellow Sand) watch is issued for greater than 500 μg/m^3, and a KOSA (Yellow Sand) warning for greater than 1,000 μg/m^3.

[Japan]

Particle size • Visibility	Name for weather when "KOSA (Yellow Sand)" appears	Terminology	Note: (Japan Meteorological Agency 2002)
	KOSA (Yellow Sand)	KOSA (Yellow Sand)	Generally, a phenomenon in which large amounts of dust blown from Asia's loess belt soar high in the air and fill the sky and gradually drift to the ground. In extreme cases, the sky turns yellow, the sun looks remarkably dark, snow appears colored, and objects on the ground are covered with dust. Visibility is 10 km or less as determined by visual meteorological observatories.

Prepared by the STFC based on the References[3, 4]

2-1 *Definition of KOSA (Yellow Sand)*

The term “KOSA” is used in Japan and Korea, but in China it is not used by the government or the public, with the exception of some researchers[4].

As described in Table 1, in Japan “KOSA (Yellow Sand)” recognize to the atmospheric phenomenon of large amounts of dust blown from the continent’s loess region soar high in the air and filling the sky and the decreased visibility accompanying that phenomenon. In South Korea, three stages of KOSA (Yellow Sand) warnings are issued depending on the density of the matter suspended in the air. In the most severe stage, people are warned not to go outside. In China, there are five stages of “dust storm weather” based on standards for wind strength and density as determined by visibility. Damage from dust storms is recognized.

2-2 *The mechanism of KOSA (Yellow Sand) formation*

The mechanism by which KOSA (Yellow Sand) is formed is associated with temperate-zone low pressure activity. The KOSA (Yellow Sand) phenomenon begins when dust is swept up in areas where strong winds blow from high pressure to low pressure centers and frontal zones[3] (see Figure 1).

Weather conditions such as wind strength are not the only factors that determine the formation of the KOSA (Yellow Sand) phenomenon and how much KOSA (Yellow Sand) it carries. Surface conditions on the ground subjected to the strong winds are an important factor. These surface conditions include topography, the existence of vegetation on the ground, surface roughness and the existence of snow cover, amount of soil moisture, and soil particle size. These conditions have a major effect on the amount of sand carried. The Japan Meteorological Agency has determined that the three major influences on the formation of KOSA (Yellow Sand) and the amount carried are (i) soil conditions in generating areas such as dryness, vegetation, and snow cover, (ii) the existence of strong winds raising dust in generating areas, and (iii) prevailing westerlies. The exact mechanism and the priority of its aspects, however, are still unknown.

Once KOSA (Yellow Sand) particles originating

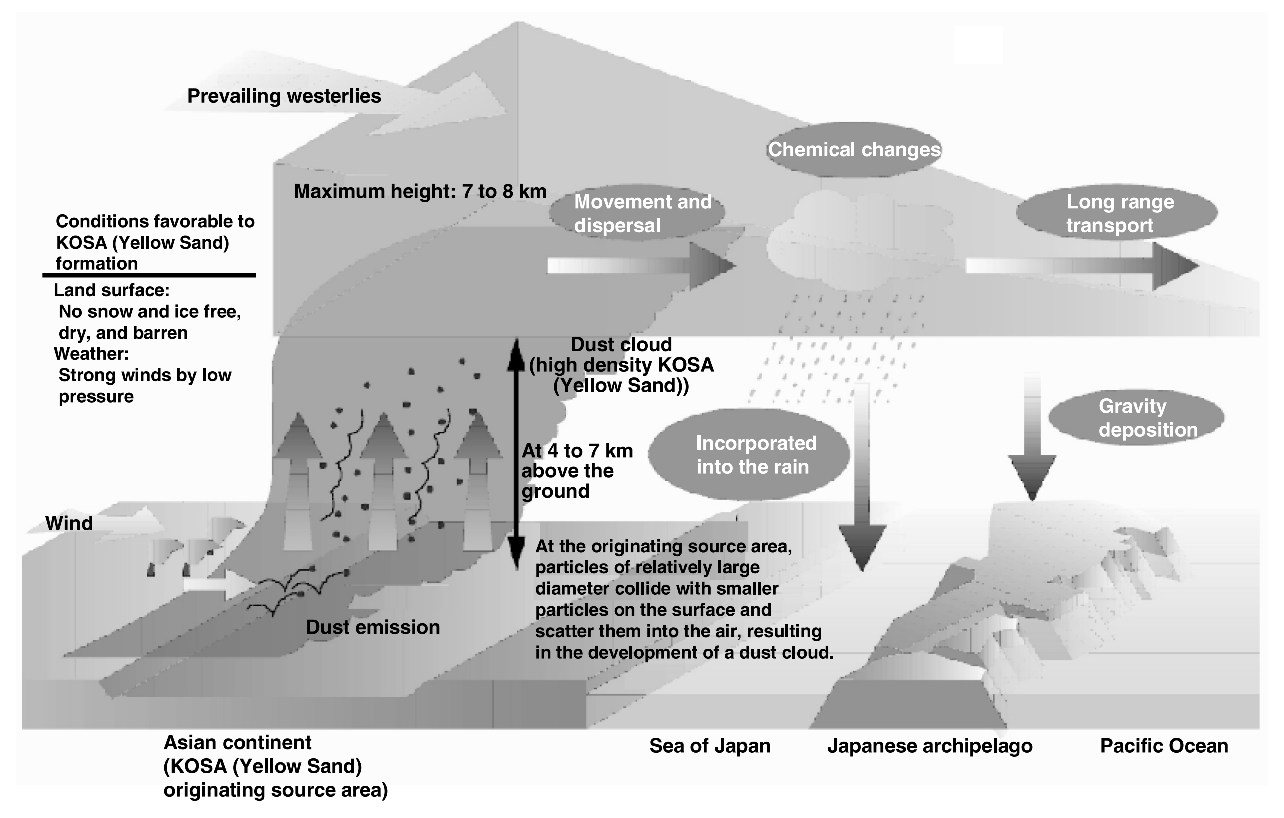

Figure 1 : Formation Mechanisms of KOSA (Yellow Sand)*

* KOSA (Yellow Sand) is referred to as “Dust and Sandstorms” in Ministry of the Environment

Source: Reference[2]

in Northeast Asia are carried into the atmosphere, prevailing westerlies transport them. Gravity causes the relatively large particles (with diameters of 10 μms or greater) to fall quickly, but winds in the upper atmosphere carry smaller particles (with diameters of a few μms or less) over great distances. Earth observation satellites have observed KOSA (Yellow Sand) formed in East Asia crossing the North Pacific to North American continent. In some cases, it has even crossed the North Atlantic and traveled as far as the European Alps[1].

Similar phenomena can occur anywhere in the world when the conditions for soil particles to rise into the air are met[1]. Phenomena similar to KOSA (Yellow Sand) are found in many parts of the world, especially near large deserts. The world's four major dust belts are in Central Asia, North America, Central Africa, and Australia[5]. The dry sirocco winds that blow from Africa's Sahara Desert to southern Italy affect a particularly extensive area. They carry fine particulate matter from the Sahara to the Mediterranean, where it causes red rain to fall. This dust is the base material of the red soil (terra rosa) all around the Mediterranean[3].

2-3 *Characteristics of KOSA (Yellow Sand) particles*

Most KOSA (Yellow Sand) particles in the atmosphere are not composed of simple mineral particles. Instead, they are composed of particles of clay minerals that clump together, or clay mineral particles with rough-grained substances such as quartz and feldspar on their surfaces[3]. As for the mineral composition of the KOSA (Yellow Sand) particles that reach the atmosphere surrounding Japan, the primary minerals are rock-forming minerals such as quartz and feldspar, with many clay minerals such as mica (illite), chlorite, and kaolinite. The peak of the size distribution of the KOSA (Yellow Sand) that reaches Japan is a diameter of about 4μm[2]. Analysis of the chemical composition of KOSA (Yellow Sand) particles has found ammonium ions (NH_4^+), sulfate ions (SO_4^{2-}), and nitrate ions (NO^{3-}), which are not believed to exist in the soil where the particles originate. This indicates the possibility that KOSA (Yellow Sand) particles adsorb anthropogenic air pollutants during transport[2]. The process that forms the particles' surfaces is believed to be extremely complex, but it remains largely unknown.

3 The impact of the KOSA (Yellow Sand) phenomenon

3-1 *Frequency of KOSA (Yellow Sand) phenomenon formation*

KOSA (Yellow Sand) is carried to the Japanese archipelago year-round, but it is most common from March through May.

Looking at the number of visual observations of KOSA (Yellow Sand) conducted annually in Japan

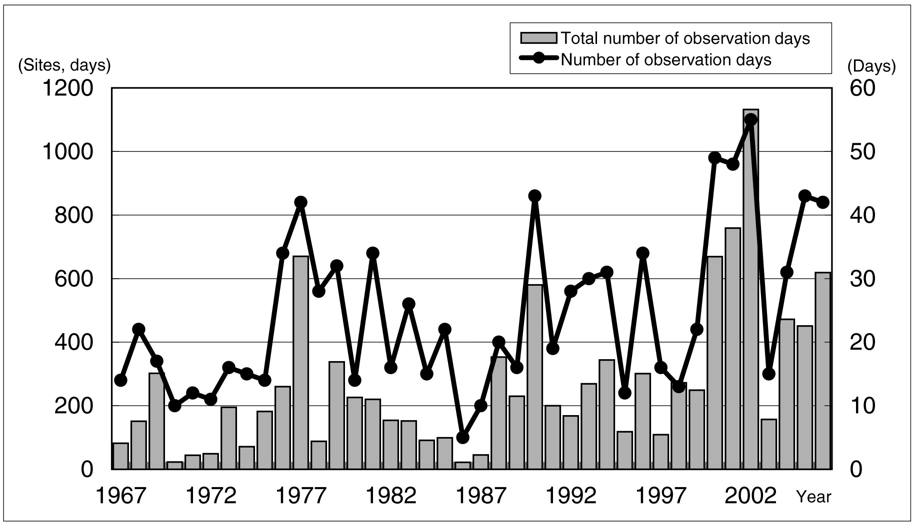

Figure 2 : Annual KOSA (Yellow Sand) total number of observation days and number of observation days*1

As of May 31, 2006, at 103 domestic observation points

Prepared by the STFC based on Japan Meteorological Agency observation data from 1967 through May 31, 2006 (see Figure 2), there were few observations after 1991 until there was a sudden increase over the period from 2000 to 2002. KOSA (Yellow Sand) total number of observation days*1 at Japan's 103 monitoring stations rarely exceeded 300 days annually until the late 1980s, but frequently surpassed that number after 1988. The totals were particularly high in the three years from 2000 to 2002, reaching 669, 759, and 1,132, respectively. As of May 31, 2006, there have been over 600 total number of observation days, with over 40 number of observation days*1.

As for the mechanism that causes changes in the frequency of KOSA (Yellow Sand) occurrence, research is focusing on changes in surface conditions such as snow cover, soil moisture, and vegetation and large-scale fluctuations in air circulation environments, but the causes remain unclear at this time[1].

3-2 *Major causes of the KOSA (Yellow Sand) phenomenon*

China's State Forestry Administration has suggested the following factors as possible causes of the frequent occurrence of the KOSA (Yellow Sand) phenomenon in northern China during the spring of 2006[6]. (i) In many parts of the northern Chinese desert zone of the central Inner Mongolia Autonomous Region and the Xinjiang Uygur Autonomous Region, early spring temperatures were 1-2°C above average. Frozen ground therefore thawed more quickly than normal, and moisture rapidly evaporated from the soil. (ii) Precipitation in much of northern China's desert region from winter through spring was 30-80 percent below average, making it the second-driest year in the last 50. This caused the topsoil to dry out, reducing moisture in the soil. (iii) Stronger than normal Siberian cold air frequently passed over the desert region, and low pressure occurring near Mongolia caused large amounts of sand to be swept up in frequent sandstorms. In short, the main causes in China were changes in weather.

Historically, the facts that there is little rainfall in winter and no plant growth from winter to early spring in the Gobi (a sand and gravel desert in China and Mongolia) and the semi-arid lands of the Loess Plateau and the Hexi Corridor, the areas where the phenomenon originate[3], have been seen as providing conditions that make it easy for soil particles to be swept up into the sky. Although many aspects of the causes of KOSA (Yellow Sand) remain unclear, it is possible that there is also a relationship with soil degradation due to over-cultivation, overgrazing, and excessive water pumping in northwestern China.

3-3 *The amount of damage caused by KOSA (Yellow Sand)*

The KOSA (Yellow Sand) problem is a shared issue for the countries of northeastern Asia. The closer to the originating source area, the greater the damage it causes (see Figure 3).

(i) An instance of damage caused by dust storm weather in China

In China, which includes areas where KOSA (Yellow Sand) originates, it is seen more as a weather-related hazard in the form of dust storms accompanied by high winds than as a dust-fall phenomenon (see Table 1).

A dust storm in northwestern China in May

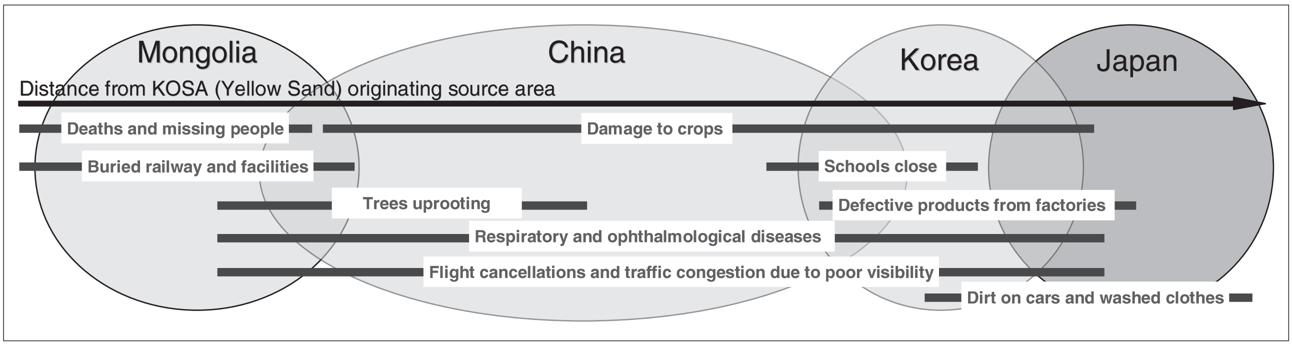

Figure 3 : Types of damage caused by KOSA (Yellow Sand) in each country

Prepared by the STFC based on Reference[2]

1993 caused the greatest harm to people and livestock of any such event in recent years. Most of the damage was in the form of collapsed buildings, buried railways, fallen electric poles and trees, and buried fields and orchards that caused agricultural losses.

The dust storm caused extensive damage in 74 municipalities in Gansu province and three autonomous regions of Xinjiang Uygur, Inner Mongolia, and Ningxia Huizu. In Gansu province, wind gusts reached a maximum momentary wind speed of 34 m/s, with a 300 meter high wall of dust reducing visibility to almost zero. The dust storm paralyzed transportation and communications networks, caused water and power outages, damaged or destroyed homes and buildings, and covered farmland with sand. A survey by China's Ministry of Forestry at the time found that the dust storm had killed 85 and injured 264. It damaged 373,000 hectares of crops and killed or caused to go missing 120,000 head of livestock. Estimated direct damage totaled 560 million Yuan (about ¥7.3 billion at 1 Yuan = ¥13). In addition to direct damage, sand dunes advanced by one to eight meters, invading farms and pastures. The dust is also believed to have affected the health of people living in the area[3].

(ii) An instance of damage caused by KOSA (Yellow Sand) in Korea

In Korea, which is near the area of origination, the KOSA (Yellow Sand) phenomenon often causes the density of particulate matter in the air to exceed environmental standards. Korea considers the KOSA (Yellow Sand) phenomenon to be a serious environmental problem[1]. In 2002 in particular, a major occurrence caused extensive socioeconomic damage. In Seoul in March 2002, the density of PM10*2 (particulate matter) reached 2,266 μg/m^3. KOSA (Yellow Sand) caused the first issuance of a school closure order, shutting a total of 4,949 kindergartens, elementary, middle, and high schools. Poor visibility caused the cancellation of 102 flights, and precision equipment factories had to be shut down. Hospitals saw a sudden increase in patients with respiratory, dermatology, and ophthalmological diseases. This 2002 KOSA (Yellow Sand) incident caused a sudden increase in interest in the phenomenon in Korea, which passed laws to respond to the problem[3].

(iii) An instance of damage caused by KOSA (Yellow Sand) in Japan

The primary forms of damage caused by KOSA (Yellow Sand) in Japan are air pollution from particulate matter, poor visibility that interferes with air transportation, and KOSA (Yellow Sand) particles sticking to cars and washed clothes[3]. To date, there have been no reports of damage to crops or livestock, but recently there has been continued concern that it may damage crops. Although KOSA (Yellow Sand) may neutralize acid rain, it also absorbs air pollutants, serving as a medium for their transportation.

3-4 Recent interest in the KOSA (Yellow Sand) phenomenon

The environmental impacts of KOSA (Yellow Sand) have diversified as it has expanded in scale and society has advanced (see Table 2). As science has developed, it has recently begun to focus attention on some aspects of the phenomenon. For example, in the past there was little interest in the effects of KOSA (Yellow Sand) on human health. As the scale of the KOSA (Yellow Sand) phenomenon has expanded, it has arrived in heavily populated urban areas, revealing hitherto unknown problems[3]. In China and Korea, it has begun to affect people's health, leading to increased interest and the beginning of research. In Japan, however, general interest remains low.

(1) The effects of KOSA (Yellow Sand) on health

Chinese medical experts report that dust does its greatest harm to the human respiratory system. In addition to mineral components, dust particles can include bacteria, fungi, chemical pollutants, and other substances. Microscopic particles in dust can penetrate lung tissue, with people with low immunity being the most easily affected[3].

Moreover, in Korea a study of the three-month periods of March to May in 1995 through 1998 compared death rates in Seoul during periods when KOSA (Yellow Sand) was observed and

Table 2 : KOSA (Yellow Sand) impacts

Field	Examples
Industry	Factory air conditioning (especially precision machinery)
Transport	Decreased transportation volume of transportation and traffic (especially air transport) or temporary cancellations due to poor visibility. Buried roads. Damage to water line, drainage and water supply system.
Schools	Some school closed (due to unsafe commuting and health concerns)
Health	Health damage and deaths due to difficulty in breathing
Construction	Buried, collapsed, and damaged buildings. Damaged power lines, etc.
Agriculture	Deaths of sheep and other livestock (unable to flee due to being penned, or trapped under by collapsing buildings). Damage to orchards and fields. Damage to plastic greenhouses.
Social life	Need for air conditioning (to clean dirty outside air). Need for lighting (due to darkened daylight conditions).
Scenery	Discovery of unique scenery. Sense of the season.
Oceans	Provision of nutrients and minerals to plankton
Acid rain	Neutralization effect
Global warming	May accelerate warming or influence a cooling effect depend on the situation (research is underway)

Prepared by the STFC based on Reference[4]

not observed. The epidemiological study found that the death rate for those 65 and older increased when KOSA (Yellow Sand) was present, especially for those with cardiovascular or bronchial illnesses[3].

In Japan, there have been few epidemiological survey reports or research results regarding the effects of KOSA (Yellow Sand) on human health. However, according to recent research that inserted KOSA (Yellow Sand) into the tracheas of mice to examine the pathological effects, KOSA (Yellow Sand) tends to worsen inflammation of the pulmonary airway[3]. Furthermore, experiments with mice have shown that KOSA (Yellow Sand) aggravates hay fever, bronchial asthma, and other allergy symptoms. The impact of KOSA (Yellow Sand) on health is thus beginning to attract attention. Because the KOSA (Yellow Sand) particles that reach Japan are smaller than those in Korea, they may enter the lungs more easily. Inhaling even a small amount may worsen symptoms.

(2) The relationship between KOSA (Yellow Sand) and acid rain

The possibility that KOSA (Yellow Sand) in the atmosphere absorbs sulfur oxides (SOx) and nitrogen oxides (NOx) had previously been considered[4]. Recent observations have confirmed that KOSA (Yellow Sand) particles that cross from China to Japan do absorb many pollutants that cause acid rain, such as nitrogen oxides and sulfur oxides. KOSA (Yellow Sand) collected in advance in China's interior did not include substances that cause acid rain. This indicates a high likelihood that while they drift from China to Japan, KOSA (Yellow Sand) particles somehow react with factory smoke, automobile emissions, and other sulfur compounds in the atmosphere to absorb and neutralize pollutants that cause acid rain. In other words, this absorption effect appears to play a positive role by enabling the alkaline components of KOSA (Yellow Sand) to neutralize substances that cause acid rain and thereby mitigate their environmental impact.

(3) The relationship between KOSA (Yellow Sand) and marine microbial ecosystems

KOSA (Yellow Sand) reportedly has the effect of supplying the Pacific Ocean with minerals and nutrients[3]. Because KOSA (Yellow Sand) particles contain iron and other essential trace elements, KOSA (Yellow Sand) that falls onto the ocean surface provides nutrients for marine surface-layer phytoplankton and serves as a limiting factor in plankton growth. Marine surface-layer phytoplankton play a major role in carbon cycling between the atmosphere and the oceans. Furthermore, plankton generates dimethyl sulfide (DMS), which is related to the formation of clouds over the ocean. In this way, KOSA (Yellow Sand) may play an important indirect role in fluctuations in radiative forcing. An international research program to elucidate this relationship, the Surface Ocean-Lower Atmosphere Study (SOLAS), has begun. Evaluation is now underway on the impact of KOSA (Yellow Sand) on climate through the nutrients it provides to the ocean[1].

(4) Relationships with global environmental problems

In recent years, KOSA (Yellow Sand) has been drawing attention as a global environmental problem. The reason for this is because KOSA (Yellow Sand) particles scatter and absorb sunlight and may thus be a major influence on global temperature. It is unknown whether the effect of KOSA (Yellow Sand) on solar radiation is sufficient to affect the global environment and global climate[4]. However, the KOSA (Yellow Sand) phenomenon appears to be connected to global environmental problems through various processes (see Figure 4).

For example, through the process of scattering and absorbing solar and infrared radiation, KOSA (Yellow Sand) particles in the atmosphere have effect to heat or cool the Earth's atmosphere (direct radiative forcing effects). Furthermore, attention is beginning to focus on the fact that KOSA (Yellow Sand) particles in the upper atmosphere become ice nuclei, which are related to the formation of cirrus clouds, and the fact that the mixing of KOSA (Yellow Sand) particles that travel long distances with human-originated particles plays a role in forming cloud nuclei (indirect radiative forcing effects). Whether the effect is heating or cooling may depend on the vertical distribution of KOSA (Yellow Sand) particle size in the atmosphere, the particles' optical properties (scattering and absorption properties), ground surface albedo (reflectivity), and so on[1]. At this time, however, it is unclear whether KOSA (Yellow Sand) has an overall effect of accelerating global warming or of cooling the

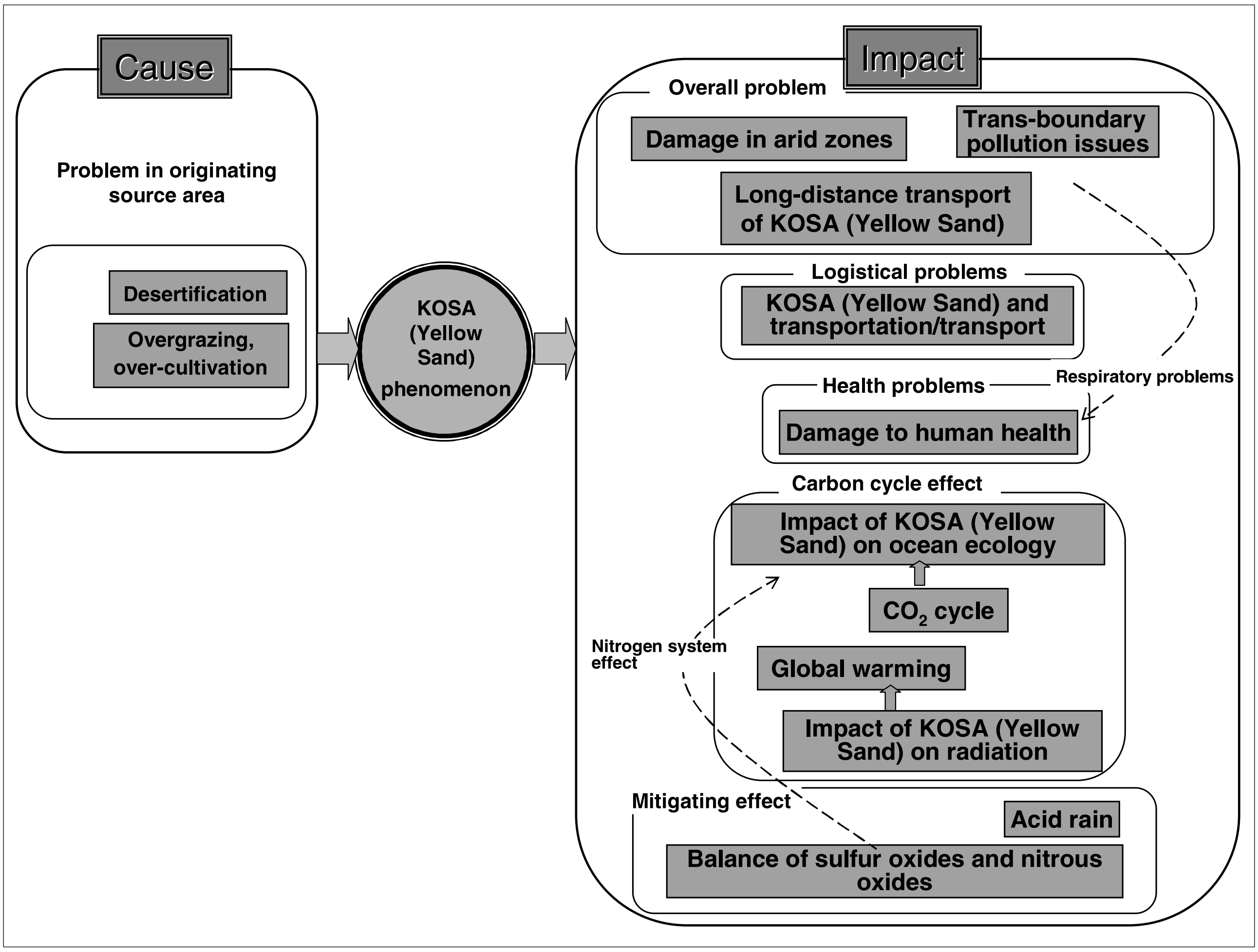

Figure 4 : KOSA (Yellow Sand) in global environmental problems

Prepared by the STFC based on Reference[4]

Earth.

Many aspects of the causes of KOSA (Yellow Sand) are still unexplained, but some researchers point to an association with soil degradation in northwestern China. In recent years, low rainfall and high temperatures have promoted rapid desertification in northwestern China, which in turn may be creating conditions that make it easy for the KOSA (Yellow Sand) phenomenon to occur. There is therefore a growing awareness in Japan that KOSA (Yellow Sand) is not simply a seasonal weather phenomenon, but instead is an environmental problem related to forest reduction, soil degradation, and desertification[3].

In particular, high temperatures and low rainfall in inland China is considered a likely cause of the large amount that reached Japan in 2006. According to the Japan Meteorological Agency, average March temperatures in eastern China and Central Asia were abnormally high, with high pressure creating clear skies and scant precipitation. In addition to dryness in inland China, meandering prevailing westerlies in 2006 appear to have created the ideal conditions for KOSA (Yellow Sand) to fall in Japan.

4 Measures against the KOSA (Yellow Sand) phenomenon

4-1 Social problem arising from KOSA (Yellow Sand)

Although KOSA (Yellow Sand) is a shared problem for the countries it affects, the degree of awareness is different in each country. In China, the damage is so severe that people have died, and it is widely recognized that the phenomenon is connected with soil degradation and desertification. In Japan, the public is aware of poor visibility and dust sticking to cars and washed clothes, but researchers clearly recognize the phenomenon as a form of air pollution. Like Japan, Korea has no domestic source of KOSA (Yellow Sand). In contrast to Japan, however, Korea focuses on KOSA (Yellow Sand) as a weather hazard, especially since experiencing huge economic damage during the major incident in 2002. In Mongolia, moving sand directly threatens local people's livelihoods. In each country, therefore, different social problems arise.

4-2 KOSA (Yellow Sand) countermeasures

KOSA (Yellow Sand) countermeasures can be divided into those taken in originating source areas and those taken in affected areas[3].

Originating source areas are where KOSA (Yellow Sand) is formed and the areas surrounding them. These areas, located in inland China and Mongolia, are directly impacted by KOSA (Yellow Sand). In addition, originating source areas can be divided into those areas where preventative measures are possible (areas where anthropogenic impact has degraded the environment) and areas where countermeasures are unlikely to be technically or economically feasible (arid and extremely arid desert zones)[3].

Affected areas are distant from the source of the KOSA (Yellow Sand) but influenced by it, with that influence apparent through medium- and long-term climactic and environmental changes. The main areas are Japan, Korea, and China's coastal region[3].

KOSA (Yellow Sand) countermeasures can be divided into short-term measures such as forecasts and warnings, and long-term measures such as protecting ecosystems in originating source areas. Effective countermeasures vary greatly depending on targets (wind speed, soil moisture, vegetation rate, etc.) and goals to control and defend[3]. It is therefore important to consider priorities, determine what countermeasures should be taken in the short, medium, and long term, and proceed systematically.

(1) Countermeasures in originating source areas

In originating source areas, first it is important to reduce flying dust through long-term countermeasures that control the formation of KOSA (Yellow Sand) through conservation of vegetation and changes in land use. In areas in China that are considered primary sources of KOSA (Yellow Sand), these include technological countermeasures, protection of natural ecosystems, and promotion of the natural regeneration of trees and other vegetation to protect plants that cover sandy soil. Furthermore, excessive tree cutting for firewood, pasturing, and clearing land for cultivation are strictly forbidden by strengthened laws[7].

Table 3 summarizes concrete countermeasures in originating source areas.

On the other hand, the KOSA (Yellow Sand) phenomenon is a long-standing weather phenomenon that has existed since ancient times before the advance of desertification. There is no way to eliminate the KOSA (Yellow Sand) formed in the Earth's desert macroclimates. The originating source areas where KOSA (Yellow Sand) countermeasures are implemented are therefore arid climates near desert areas, where new soil degradation and loss of vegetation generate flying sand and where desertification is advancing. Desertification is not necessarily the only cause of the KOSA (Yellow Sand) phenomenon, so it may not be possible to apply all the countermeasures. Because some aspects of the cause and effect relationship between desertification and KOSA (Yellow Sand) remain unexplained, however, the methods already used as desertification countermeasures are likely to form the basis of any future examination of KOSA (Yellow Sand) source countermeasures.

(2) Countermeasures in affected areas

In affected areas, the goal is to reduce damage from KOSA (Yellow Sand). First, forecasts and warnings regarding KOSA (Yellow Sand) are important, and the information they provide differs by country. Currently, Japan offers "KOSA (Yellow Sand) information," Korea provides "KOSA (Yellow Sand) forecasts," and China gives "dust storm weather forecasts."

(i) China's dust storm weather forecasts[3]

Currently, dust storm weather forecasts are carried out by using satellite images to monitor the movement of dust. Next-day forecasts are therefore the only kind available. There are now five types of Chinese dust weather forecasts and these are related to accuracy and timing: current conditions and warnings, very short-term forecasts and warnings, short-term forecasts and warnings, medium-term forecasts, and seasonal outlooks.

(ii) Korea's KOSA (Yellow Sand) forecasts[3]

Korea has been making KOSA (Yellow Sand) forecasts since April 2002. In order to perform KOSA (Yellow Sand) forecasts, the Korea Meteorological Administration analyzes airborne dust and weather-satellite images from KOSA (Yellow Sand) originating source areas and

Table 3 : Primary countermeasures in originating source areas

Measure	Category	Description
Rehabilitating and improving the land surface	Reforestation/planting	Reducing barren land through reforesting and planting degraded land
	Crop changes	Preventing land surface loosening caused by spring ploughing (the cultivation of perennial crops, etc.)
Controlling the movement and encroachment of sand by wind	Creating tree windbreaks	Planting trees with strong windbreak effects at appropriate intervals
	Straw checkerboard	Reducing ground level wind velocity by inserting straw bundles into the sand in a checkerboard pattern
	Stabilization of sand dunes	Controlling the movement of sand using creeping plants
Mitigating human impacts	Fencing of land	Rehabilitating vegetation by erecting a fence around degraded land and restricting the entry of people and domestic animals (grazing ban)
	Felling of trees and land reclamation, limits on number of livestock	Laws enforcing the prohibition of land reclamation and felling of trees
	Efficient energy use, use of new forms of energy	Maximizing the heat efficiency of cooking stoves and the insulation efficiency of houses in order to reduce the cutting of trees for fuel
	Resettlement of people	Supporting the resettlement of people from degraded land
Improving the environmental capacity of the soil	Fertilization	Improving land productivity by the application of farm animal manure
	Water management and water-saving technology	Introducing water-saving and water management techniques for the efficient use of water
	Artificial rain	Increasing rainfall

Prepared by the STFC based on References[2, 3] monitors horizontal distribution. In addition, the Administration predicts the passage of KOSA (Yellow Sand) over Korea and the deposition of sand based on predicted airflow and atmospheric pressure patterns. The Ministry of Environment and the Meteorological Administration monitor the density of particulate matter of 10 μm or less. For forecasting, the Meteorological Administration uses a data transfer system that shares information in real time (at five-minute intervals) from these continuous measurements and applies the data to the KOSA (Yellow Sand) forecast/warning system in its weather data system (see Table 1) .

(iii) Japan's KOSA (Yellow Sand) information

The Japan Meteorological Agency began releasing information on KOSA (Yellow Sand) in January 2004. When the KOSA (Yellow Sand) phenomenon is predicted to affect transportation or people's everyday lives over a wide area, the agency announces weather information such as "meteorological information related to KOSA (Yellow Sand)"[1]. In addition, the Japan Meteorological Agency's website[8] provides a distribution map of points near Japan where the KOSA (Yellow Sand) phenomenon has been observed (KOSA (Yellow Sand) observation status map) and a map predicting the distribution of KOSA (Yellow Sand) based on a forecasting model (KOSA (Yellow Sand) forecast map).

4-3 The KOSA (Yellow Sand) monitoring network

In order to note the occurrence of KOSA (Yellow Sand) as early as possible and to ascertain the status of its development and movement, the creation of an international KOSA (Yellow Sand) monitoring network stretching from northwestern China's continent to the Japanese archipelago has begun. The network is appropriately installing three types of monitoring equipment to measure the density of particulate matter of 10μm or less, visibility (the distance that can be seen) and LIDAR. The network emphasizes the transmission of monitoring data to relevant organizations for reliable, accurate monitoring of KOSA(Yellow Sand)[2].

The formation and transport of KOSA (Yellow Sand) depend on a combination of regional weather, geography and soil properties, land usage, and other factors. Research on the formation mechanism and transport process is underway[3]. At this point, however, it is difficult even to accurately pinpoint individual originating source areas for the KOSA (Yellow Sand) phenomenon. The first necessity is therefore to collect and sort monitoring data on the atmosphere, land surface, vegetation, and human activities[3] in KOSA (Yellow Sand) originating source areas and along the routes of KOSA (Yellow Sand) movement. It is also necessary to analyze the physical properties (e.g. particle size distribution, particle shapes, surface structure, etc.) and chemical properties (e.g. chemical composition, mineral composition, absorbed/adhered substances, etc.)[3] of the particles carried by the KOSA (Yellow Sand) phenomenon and to collect more data.

Research methods can be roughly divided into the following two types.

(i) KOSA (Yellow Sand) monitoring

There are currently a variety of monitoring methods used to understand the KOSA (Yellow Sand) phenomenon and forecast its occurrence. In more concrete terms, these include continuous measurement such as remote sensing and batch measurement that measures and analyzes actual KOSA (Yellow Sand) particles obtained by sampling. Continuous measurement primarily obtains data on optical and physical properties, while batch measurement primarily obtains data on chemical properties[3] (see Table 4).

LIDAR and satellite observation are used in KOSA (Yellow Sand) monitoring.

LIDAR (Light Detection And Ranging) is a form of radar that uses laser light rather than radio waves. It is a type of remote sensing device that makes it possible to measure KOSA (Yellow Sand) passing above from the ground. By observing the way in which laser light emitted from the ground is scattered by tiny particles in the air, researchers can obtain data on the vertical density distribution of KOSA (Yellow Sand) and its changes over time. This gives them information on the three-dimensional structure of KOSA (Yellow Sand) and on its movement.

In addition, use of a polarized laser enables researchers to distinguish between the shapes of KOSA (Yellow Sand) particles and ordinary air pollutants. Except in the presence of clouds or heavy dust, LIDAR has the ability to carry out continuous, unmanned, real-time monitoring of all KOSA (Yellow Sand) that passes through the troposphere above observation points[2].

In addition to KOSA (Yellow Sand) monitoring from ground stations, airplanes and helicopters, balloons, ships, and mountains all serve as platforms for KOSA (Yellow Sand) monitoring. Source weather monitoring and surface and groundwater monitoring are carried out to obtain KOSA (Yellow Sand) originating source area weather information and surface data, as are on-site investigations and social surveys.

(ii) KOSA (Yellow Sand) transport models

Simulations using KOSA (Yellow Sand) transport models are necessary in order to predict the formation and transport of KOSA (Yellow Sand) and to forecast its arrival. In recent years, it has become apparent that although the KOSA (Yellow Sand) phenomenon is a natural phenomenon, human influence has increased the frequency with which it occurs. KOSA (Yellow Sand) transport models also provide data useful

Table 4 : Summary of primary KOSA (Yellow Sand) monitoring methods

		Method	Target of measurement
Continuous measurement	Observation of optical properties	LIDAR	• Altitudinal distribution of KOSA (Yellow Sand): Provides dynamic atmospheric information on the three-dimensional structure and transportation conditions of the KOSA (Yellow Sand) phenomenon. • Also measures aerosols from other sources.
		Satellite observation	• Optical thickness of aerosol, albedo, normalized difference vegetation index (NDVI), etc.
		Actinometers, radiometers	• Amount of solar radiation. Amount of infrared radiation from ground surface and atmosphere.
		Nephelometers, aerosol absorption meters	• Scattering condition by bearing of dust. • Absorption coefficient of dust.
	Measurement of physical properties	Mass concentration meters, particle counters	• Mass concentration and particle size distribution of aerosol.
	Measurement of chemical properties	Aerosol TOF/MS analyzers	• Ionizing chemical components in aerosol.
	Observation of visibility	Visibility meters	• Visibility (degree of turbidity in the atmosphere near the ground).
Batch measurement	Sampling observation	Andersen samplers	• Dust amount and size distribution. • Collected samples are used for element analysis and mineral type measurement. • Direct observation with an electron microscope to observe particle shape.
		High-volume samplers	• Dust amount. Used to sample trace substances above the threshold of analysis. • Collected samples are used for element analysis and mineral type measurement. • Direct observation with an electron microscope to observe particle shape.
		Low-volume samplers	• Dust amount. Used to find the average value of floating dust volume over long periods of time. • Collected samples are used for element analysis and mineral type measurement. • Direct observation with an electron microscope to observe particle shape.
		Various impactors for observation of individual particles	• Dust particle shape, surface conditions, and size. • Chemical composition. • Mineral composition.
Visual observation		Routine observation by meteorologists	• Occurrence of KOSA (Yellow Sand) phenomenon. Size and strength of KOSA (Yellow Sand) phenomenon.

Prepared by the STFC based on Reference[3]

for distinguishing among such multiple causes. Transport models that deal with the arrival of KOSA (Yellow Sand) basically comprise weather models, source models, and advective diffusion models (deposition models in some cases)[3]. In addition to use as weather information, the results are used to estimate sources and predict influence on future climate change.

The primary KOSA (Yellow Sand) transport models are those of the Meteorological Research Institute (MASINGAR: Model of Aerosol Species in the Global Atmosphere) and Kyushu University.

MASINGAR adds KOSA (Yellow Sand) release, transport, and disappearance processes to the global model (MRI/JMA98) developed by the Meteorological Research Institute and the Japan Meteorological Agency. The model's horizontal resolution is about 110 km, while its vertical resolution covers 30 layers (from the ground to about 23 km). It divides KOSA (Yellow Sand) into 10 stages based on particle sizes of 0.1-10 μm. The Japan Meteorological Agency has been utilizing its results to provide information on the KOSA (Yellow Sand) phenomenon since January 2004[1].

The model for predicting KOSA (Yellow Sand) arrival developed at Kyushu University utilizes a weather model and the Regional Atmospheric Modeling System (RAMS) developed at Colorado State University in the USA. The model's vertical grid spacing is therefore very close. Because it can handle the atmospheric boundary layer in detail, it is widely used to predict air pollution[3].

4-4 *Domestic and international system building and infrastructure development for KOSA (Yellow Sand) countermeasures*

(1) Systems and infrastructure in Japan

Relevant agencies such as the Ministry of the Environment, the Japan Meteorological Agency, the Ministry of Agriculture, Forestry and Fisheries, and the Forestry Agency are currently carrying out a number of initiatives. In addition, various research institutes and universities are engaged in research on KOSA (Yellow Sand) monitoring, modeling, and source countermeasures.

Relevant government agencies are working in close cooperation on various policies concerning the KOSA (Yellow Sand) problem. In order to promote such cooperation, in February 2005 they formed a liaison council on KOSA (Yellow Sand) countermeasures[3]. The liaison council comprises the Ministry of Foreign Affairs, the Ministry of Education, Culture, Sports, Science and Technology, the Ministry of Agriculture, Forestry and Fisheries, the Forestry Agency, the Japan Meteorological Agency, and the Ministry of the Environment. Currently, the Ministry of the Environment is carrying out research to explain the precise nature of the KOSA (Yellow Sand) phenomenon, while the Japan Meteorological Agency releases meteorological data related to KOSA (Yellow Sand). The Ministry of Agriculture, Forestry and Fisheries carries out basic studies on KOSA (Yellow Sand) source countermeasures through sustainable farming and rural development, and the Forestry Agency studies the degradation and restoration of vegetation in originating source areas[3]. While carrying out varied research such as meteorological and climatological research on KOSA (Yellow Sand), soil degradation surveys in originating source areas, research on the chemical and mineral composition of KOSA (Yellow Sand) particles, and research on reactions that occur on the surface of the particles, Japanese universities and research institutes need to establish greater organic cooperation and collaboration.

(2) International cooperation systems

KOSA (Yellow Sand) is an environmental problem that transcends national borders, so cooperation and collaboration with China, Korea, and Mongolia and with international agencies is necessary in order to implement effective research and countermeasures. In particular, since Japan has no KOSA (Yellow Sand) originating source areas, joint activity through international cooperation on collection of source data and implementation of countermeasures is essential.

(i) The ADB/GEF Project on Prevention and Control of Dust and Sandstorms

The ADB/GEF Project on Prevention and Control of Dust and Sandstorms was carried out from 2003 through March 2005. One of the preliminary investigations of the Global

Environment Facility (GEF), it was to launch a joint project of four international organizations, the United Nations Environment Programme (UNEP), the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP), the United Nations Convention to Combat Desertification (UNCCD), and the Asian Development Bank (ADB), and four countries, Japan, China, Korea, and Mongolia[2]. Utilizing GEF and ADB funds, the project collected and evaluated data related to KOSA (Yellow Sand) and created a master plan for KOSA (Yellow Sand) countermeasures. The project received $1 million in funding, $500,000 from the GEF's Medium-Sized Project fund, and $500,000 from the ADB's technical cooperation funds[3].

(ii) Japan-China-Korea Tripartite Environment Ministers Meeting[3]

At the Third Tripartite Environment Ministers Meeting among Japan-China-Korea (TEMM) in Tokyo in April 2001, the Ministers agreed to promote systematic research cooperation in order to find solutions to the KOSA (Yellow Sand) problem. At the Fourth Meeting (April 2002 in Seoul), the three countries agreed to work to strengthen KOSA (Yellow Sand) monitoring and collaboration with international organizations. Furthermore, at the Fifth Meeting (December 2003 in Beijing), they once again acknowledged the importance of local cooperation on KOSA (Yellow Sand) countermeasures. They agreed that appropriate steps should be taken based on the results of the ADB/GEF Project on Prevention and Control of Dust and Sandstorms. They particularly noted the immediate necessity of each country considering a system for KOSA (Yellow Sand) monitoring and early warning. At the Sixth Meeting in December 2004, the Environment Ministers of Japan, China, and Korea were joined by the Mongolian Minister of Nature and Environment and the four international organizations that participated in the ADB/GEF Project on Prevention and Control of Dust and Sandstorms. Held in Tokyo, it was the first ministerial-level meeting by the four relevant countries on the KOSA (Yellow Sand) problem. The Ministers agreed on the need to build a network of experts to examine technical issues related to KOSA (Yellow Sand).

(iii) Bilateral cooperation[3]

Since 1996, the Sino-Japan Friendship Centre for Environmental Protection and the Japanese Independent Administrative Institution National Institute for Environmental Studies have been involved in a cooperative project. They have carried out on-site studies of desert and arid zones, created standards for KOSA (Yellow Sand) specimens, studied KOSA (Yellow Sand) particle size distribution, formulated the basic concept for a monitoring network, and researched KOSA (Yellow Sand) measurement methods. Currently, they are engaged in research on KOSA (Yellow Sand) transport routes, transport modes and amounts formed, the percentage contribution of KOSA (Yellow Sand) in the particulate matter in the air of specified areas, and creation of proposals for KOSA (Yellow Sand) prevention.

In addition, the Japan-China joint project Aeolian Dust Experiment on Climate impact (ADEC) implemented in 2000 to study the effects of aeolian dust*3 on climate. Cooperative research was carried out by the Japan Meteorological Research Institute on the Japanese side and a research organ of the Chinese Academy of Sciences on the Chinese side. Utilizing a global-scale dust model, the project predicted the amount of aeolian dust supplied to the atmosphere, its three-dimensional distribution in the atmosphere, and the amount of dust deposited on the ground, and evaluated the direct effects of radiative forcing.

As for cooperation between Mongolia and Japan, the Japanese Independent Administrative Institution National Institute for Environmental Studies is working with the National Agency for Meteorology, Hydrology and Environment Monitoring of the Mongolian Ministry of Nature and Environment on KOSA (Yellow Sand) observation with LIDAR.

Korea and China carry out joint KOSA (Yellow Sand) observation by establishing KOSA (Yellow Sand) observation stations and monitoring points in China, and providing observation data to Korea. Furthermore, Korean support is advancing afforestation and grassland recovery projects in western China.

5 Future initiatives on KOSA (Yellow Sand) countermeasures

The short-term, direct effects of KOSA (Yellow Sand) on the environment and industry are relatively clear. However, many aspects, such as long-term effects related to climate change and environmental science effects (neutralization of acid rain, transport of nutrients, etc.) related to KOSA (Yellow Sand) matter cycling, are still unclear. In particular, the combined effects and influence of other phenomena (e.g. absorption and transport of air pollutants by KOSA (Yellow Sand) particles) are almost entirely unexplained[3]. In Japan's future initiatives on the KOSA (Yellow Sand) problem, therefore, elucidation of the phenomenon, monitoring, and countermeasures are important as basic strategies.

(1) Construction of domestic and international systems for collaboration and cooperation on infrastructure development for KOSA (Yellow Sand) countermeasures

In order to effectively promote KOSA (Yellow Sand) countermeasures, it is first necessary to promote interagency cooperation within the Japanese government. In particular, the functioning of the above-described interagency liaison council on KOSA (Yellow Sand) countermeasures that was formed in February 2005 must be improved. Universities and other research institutions have been studying the KOSA (Yellow Sand) phenomenon, but their findings have not been sufficiently incorporated into policy. As one of the approaches Government-affiliated research institutions studying KOSA (Yellow Sand) require clear indications of the government's needs. Furthermore, construction of a system of cooperation by which researchers can input promptly technical advice and findings useful in international cooperation to government agencies is essential[3]. Government and research institutions must frequently exchange information and work in close cooperation.

Because KOSA (Yellow Sand) is a trans-boundary environmental problem, cooperation among the relevant countries is also essential. In particular, international cooperation is necessary in order to carry out effective monitoring for source countermeasures and KOSA (Yellow Sand) forecasts. Working to share the KOSA (Yellow Sand) data held by various organizations, establishing a KOSA (Yellow Sand) monitoring network, and contributing to each country's effective KOSA (Yellow Sand) countermeasures is likely to promote international cooperation. Moreover, development of networks requires the strategic promotion of the selection and deployment of monitoring devices and development of technology for real-time sharing of the data obtained[3].

At the same time, cooperation that complements but does not overlap existing efforts and frameworks that are related to KOSA (Yellow Sand) countermeasures, such as those of the Acid Deposition Monitoring Network in East Asia (EANET)[9] and Earth observation networks[10], is needed so that each project can proceed effectively.

Human exchanges and human resources development related to KOSA (Yellow Sand) currently vary significantly from one country to another. First, each country must build capacity. In particular, working to acquirement and dissemination basic knowledge of the KOSA (Yellow Sand) problem to citizens and technicians from local governments in originating source areas is the most important step in effectively promoting KOSA (Yellow Sand) countermeasures. However, in order to carry out source countermeasures, multifaceted approaches adapted to individual originating source areas are necessary. These include the identification of the originating source areas, the evaluation of the economic impact of the measures, and dealing with existing social and industrial structures in order to prevent soil degradation. The cooperation of stakeholders from experts to indigenous peoples is therefore essential, and international human exchange is vital.

(2) Promotion of effective study and research

Because it is not easy to quantify the direct and indirect effects of KOSA (Yellow Sand) countermeasures, many aspects remain scientifically unclear. In particular, obtaining real-time data on the KOSA (Yellow Sand) phenomenon is important. The necessary data span weather data, surface data, chemical composition, and so on, and are collected and held by a variety of agencies. It is therefore important for research institutions in each country to share the KOSA (Yellow Sand) data they hold individually and to carry out joint research in order to find effective measures to remedy the problem. In addition, depending on their goals, KOSA (Yellow Sand) countermeasures may be short-term and temporary or long-term and ongoing. When selecting the methods to be used as countermeasures, they need to be appropriate to the land conditions in each area. In particular, control measures in KOSA (Yellow Sand) originating source areas are an urgent issue requiring an immediate response.

(3) Examination from a socioeconomic perspective

In the short- and medium-term, there is a strong tendency to put efforts into measures against damaged farmland and other primarily impacts in source and affected areas. Attention should be paid, however, to what kind of secondary effects and side effects they bring about. As industrial activity in Northeast Asia intensifies, the KOSA (Yellow Sand) phenomenon will become even more closely linked to society and the economy. It is therefore necessary to turn attention towards evaluating the effects of the KOSA (Yellow Sand) phenomenon on economic and production activities. In recent years, production facilities that require highly clean environments, such as those in the semiconductor industry, have seen increases in defective product, clogged filters, and so on during periods when KOSA (Yellow Sand) is present[3]. In Korea, precision manufacturing plants have had to suspend operations. At the same time, the KOSA (Yellow Sand) phenomenon may be related to climate change as it carries minute particles over long distances. Future efforts must be clearly divided into categories such as climate, environment, health, and industry, and combined impacts and countermeasure effects must be evaluated and studied.

Acknowledgments

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Glossary

*1 Total number of days KOSA (Yellow Sand) was observed
Accumulated number of days on which KOSA (Yellow Sand) was observed at any Japanese monitoring station. (E.g., if five different monitoring stations observed KOSA (Yellow Sand) on the same day, that would equal a total of five observation days.)
Number of days KOSA (Yellow Sand) was observed
A day on which KOSA (Yellow Sand) was observed at any Japanese monitoring station. (Observations at multiple stations on the same day count as one observation day.)

*2 PM10
This term refers to total amount of particulate matter that is suspended in the atmosphere and is smaller than 10 μm in diameter. It is widely used in fields related to air pollution and the atmospheric environment.

*3 Aeolian dust
Particulate matter suspended in and transported by the air.

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4

Trends in Research and Development on Plastics of Plant Origin
— From the Perspective of Nanocomposite Polylactic Acid for Automobile Use —

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1 Introduction

The age of mass production and mass consumption is ending and the conservation, reuse, and recycling of resources have become an important issue for the creation of a regenerating and recycling-oriented society. To solve the problems regarding energy consumption and global warming, the recycling of resources, and environmental burdens, it is necessary for business enterprises to take specific measures by setting up targets in various fields of business activities including product design and development, procurement and production, sales, and recycling of resources. In the automobile industry, since further global motorization is expected to proceed, making proactive efforts to reduce environmental burdens in the total life cycle of automobiles including the development, production, use, disposal, and recycling is strongly required. It is an absolute must to promote the reduction of the global carbon dioxide emission and establish a sustainable society based on earth-friendly technologies aiming at a regenerating and recycling-oriented society[1].

In the “Third Science and Technology Basic Plan,” the development of innovative materials and components, which are responsible for the next-generation contributing to the maintenance and enhancement of industrial competitiveness, is listed as a theme in the nanobiotechnology field aiming at solving issues on scarce and deficit resources, measures for handling harmful substances, and improvement and conservation of the environment. The purpose of these themes is to realize a sustainable recycling-oriented society maintaining a balance between environment and economy[2]. The “Biomass-Nippon Strategy” aims at promoting the effective utilization of plastics of plant origin as a technology for converting biomass to products such as plastics[3], and recommends the utilization of biomass as a substitute for products of fossil origin as one of the measures for reducing the emission of carbon dioxide, which is a greenhouse effect gas, among those that have been investigated.

In this report, the trends in the research and development of polylactic acid, which is one of the plastics of plant origin presently attracting widespread attention as a carbon neutral material*1, are described particularly from the perspective of nanocomposite material for automobile use. Properties of polylactic acid as an industrial material are explained through the present status of its applications to interior materials for automobiles. Furthermore, the effect on the worldwide sugar yield from biomass when all the plastics for the automobile application are replaced with polylactic acid is considered.

2 Plastics of plant origin as carbon neutral materials

Plastics of biomass origin are produced using biomass as the raw material, and broadly classified into three categories: those of microbe origin that are polymerized by microorganisms in their body, those of natural product origin for which biomass itself is used as polymers, and those that are chemically synthesized using

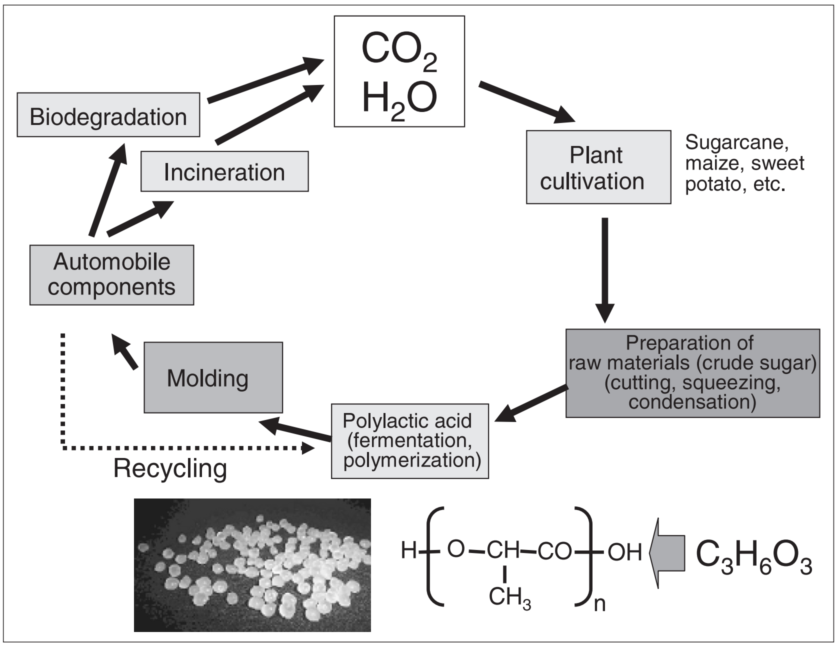


Figure 1 : Carbon cycle in the use of plastics of plant origin (polylactic acid)

Prepared by the STFC based on References[7, 8] with partial modification and addition

monomers of biomass[4-6]. Among these plastics, the plastics of plant origin refer to those that use plants as the raw materials, and account for the major part of plastics of biomass origin excluding those that use fossil resources as the raw materials. The carbon dioxide generated by the decomposition of plastics of plant origin originally existed in the atmosphere, and does not contribute to the increase of carbon dioxide in the total life cycle excluding the energy consumption during the production stage. Therefore, the plastic of plant origin can be defined as a carbon neutral and renewable material.

Polylactic plastic is a material of plant origin that has recently been attracting attention as a promising material for buildings, enclosures for home electric appliances, and interior and exterior materials for automobiles. Figure 1 shows the carbon cycle of a plastic of plant origin taking polylactic acid as an example[7, 8]. Polylactic acid is produced mainly from the sugar obtained from maize, sugarcane, sweet potato, etc., by polymerizing lactic acid which has a structure consisting of three carbon atoms. These carbons are originally derived from the carbon dioxide in the atmosphere so that the absolute amount of carbon in the atmosphere is not affected whether it is biodegraded or incinerated; therefore, polylactic acid can be said to be a carbon neutral material. Furthermore, if the components made of polylactic acid are efficiently recovered from used cars at low cost, it becomes possible to regenerate high-purity lactic acid monomers from these recovered components. The recycling of polylactic acid products enables not only the effective utilization of limited plant resources, but also the reduction of carbon dioxide generated in the incineration of components.

3 Present status of research and development on plastics of plant origin

3-1 Reasons why polylactic acid attracts attention

Figure 2 schematically shows the advantages of polylactic acid among other plastics of plant origin from the perspectives of material supply and industrial merits. Lactic acid is produced by fermenting sugar, which is generated by decomposing starch obtained from maize, sugarcane, sweet potato, etc., using enzymes. Then the lactic acid is polymerized to produce polylactic acid, and various types of plastic products are manufactured through the reforming and fabrication processes. These plastics are biodegradable since they are decomposed by bacteria in several months and return to the soil. Polylactic acid can be

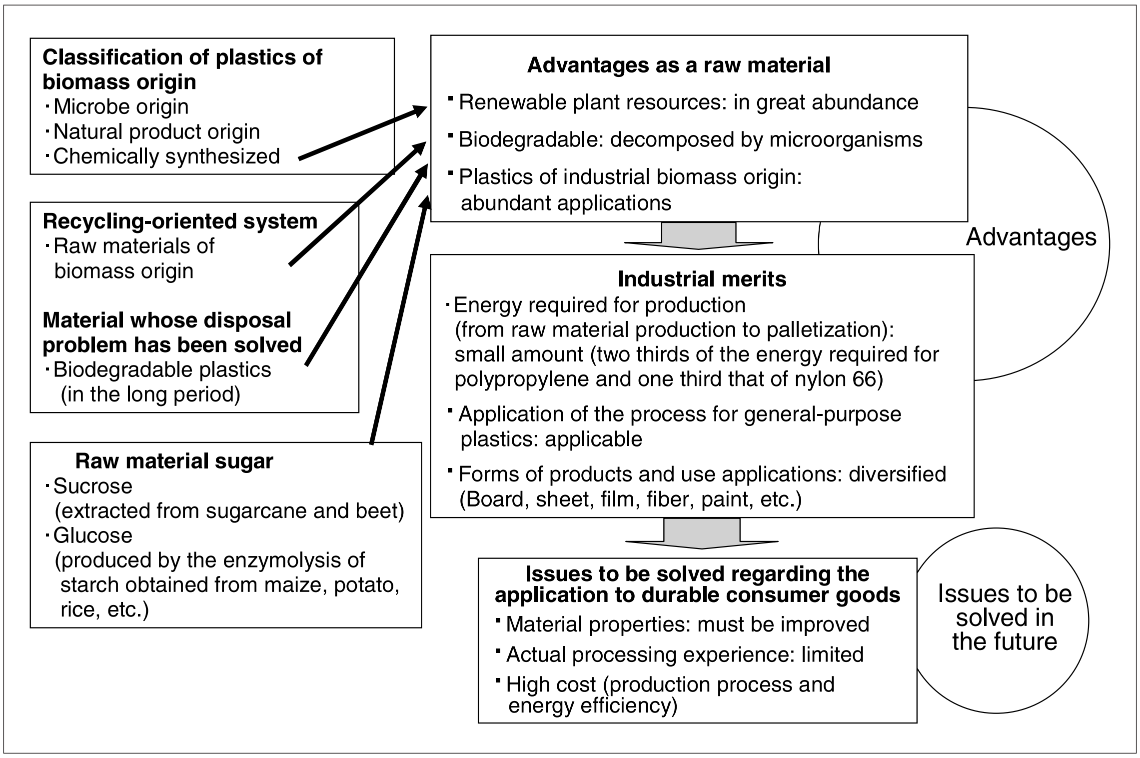


Figure 2 : Advantages of polylactic acid as an industrial material and issues to be solved

Prepared by the STFC

synthesized not only from starch, but also from abundant renewable biomass resources such as disposed paper, leftover food, residual lumber, lumber from thinning, straw, and chaff, and it is one of the most popular plastics of plant origin used as industrial materials. Polylactic acid has many advantages as follows: the energy required for the production of material and palletizing is low compared with that required for the plastics of petroleum origin; the production process for the plastics of petroleum origin can be applied; and forms of products and use applications are diversified. However, in order to apply polylactic acid to durable consumer goods, further improvement of the material properties including heat resistance and mechanical strength is indispensable. Other issues to be solved in the future include insufficient experience in the production process and high cost compared with the plastics of petroleum origin[6, 9, 10].

3-2 Application of polylactic acid to interior components for automobiles

The advantage to the recycling-oriented society brought about by the application of components made of polylactic acid is considered to be enormous. In particular, since the automobile industry is going to apply such components on a full scale, components developed in the automobile industry are expected to broadly expand into other industries. Figure 3 shows a spare tire cover made of kenaf-fiber-reinforced polylactic acid and a floor mat made of polylactic acid fiber, both of which have already been used for Japanese commercial automobiles[7, 11]. Kenaf is a fiber-rich annual grass that grows rapidly in the temperate and tropical zones. It absorbs a lot of carbon dioxide and abundantly contains useful cellulose and long, strong fibers are obtained from the stems. The spare tire cover shown in the chart is made of kenaf-fiber-reinforced polylactic acid. The combination of polylactic acid and kenaf fiber prevents the deterioration in elasticity modulus at high ambient temperature and improves impact resistance. Polylactic acid is hydrolysable and it has been found that the degree of hydrolysis is affected by the remaining lactide, which is a dimmer of lactic acid monomers, in the polylactic acid. By drastically reducing the content of the remaining lactide, the resistance of the spare tire covers to humidity, which is one of the important environmental service conditions for automobiles, is secured for a long period[7].


Spare tire cover made of kenaf-fiber-reinforced polylactic acid

Floor carpet made of polylactic acid fiber

Figure 3 : Components made of polylactic acid used for Japanese commercial automobiles

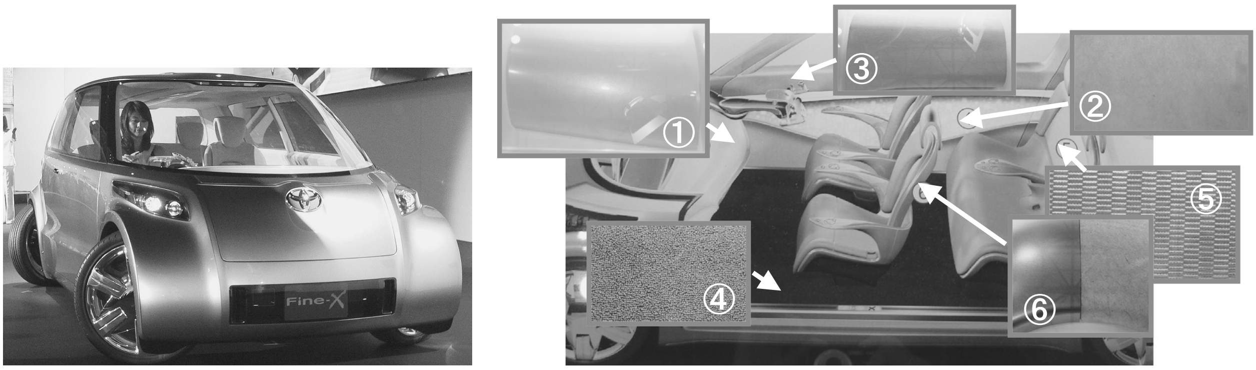
Prepared by the STFC based on References[7, 11] with modification

The life cycle assessment of automobile components made of polylactic acid shows that the emission of carbon dioxide is reduced by about as much as 85% compared with the components made of polypropylene which is a plastic of petroleum origin[11, 12]. Therefore, the adoption of components made of polylactic acid not only significantly reduces the energy consumption in the production process, but also reduces the emission of carbon dioxide because carbon, a component of carbon dioxide, circulates in the life cycle of the products, which means that polylactic acid is an earth-friendly material.

The components made of polylactic acid shown in Figure 3 may cover only a small portion of the total components used for automobiles, but the application is expected to be expanded into other components and vehicle types so that a recycling-oriented society is realized in the future. Material properties will be improved in the course of research and development searching for the mechanisms of the development on the properties of polylactic acid. For example, research and development to prepare all the interior components for automobiles using only materials of plant origin is under progress. Figure 4 shows the interior components of plant origin for a concept car[13]. These components are made mainly of polylactic acid using only plants as the raw materials (plant content: 100%), and kenaf-fiber-reinforced polylactic acid is used for some of the components as in the case of Figure 3.

3-3 Improvement of material properties of polylactic acid by kenaf-fiber reinforcement

To use polylactic acid as a material for the interior components of automobiles, high heat resistance must be achieved and impact resistance, which is the most important mechanical property, must be comparable to or higher than those of polypropylene. However, the impact resistance of simple polylactic acid is as low as 50% less than that of polypropylene. Figure 5 shows an example of a component with improved shock resistance that has been developed aiming at significantly high impact resistance and 100% plant content[12]. The material used was prepared by mixing kenaf fiber and polylactic acid fiber in a weight ratio of 7:3 and heating the mixture so that the polylactic acid fiber was melted. After that, the mixture was pressed at room temperature to form the component. The shock resistance of the composite polylactic acid reinforced with kenaf fiber was three times higher than that of polypropylene. Figure 5 shows the surface condition and cross-sectional structure of kenaf-fiber-reinforced polylactic acid. It seems possible to improve the mechanical properties other than impact resistance by densifying the matrix resin of polylactic acid, which bonds the kenaf fibers, with an improved filling method.



Component	Material	Material constitution and characteristics
1. Upper part of instrument panel, package tray	Polylactic acid	Transparent material
2. Inner lining (ceiling, pillar, trim), seat	Extra-fine polylactic acid fiber	Suede-touch skin material
3. Door trim ornament	Hemp	Japanese-paper-like skin material
4. Floor	Polylactic acid fiber	Carpet material
5. Seat back	Polylactic acid fiber	Meshed seat back material
6. Seat back board	Kenaf-fiber-reinforced polylactic acid	Board material

Figure 4 : Future interior components made of plant-origin materials equipped on a concept car

Prepared by the STFC based on Reference[13] with modification

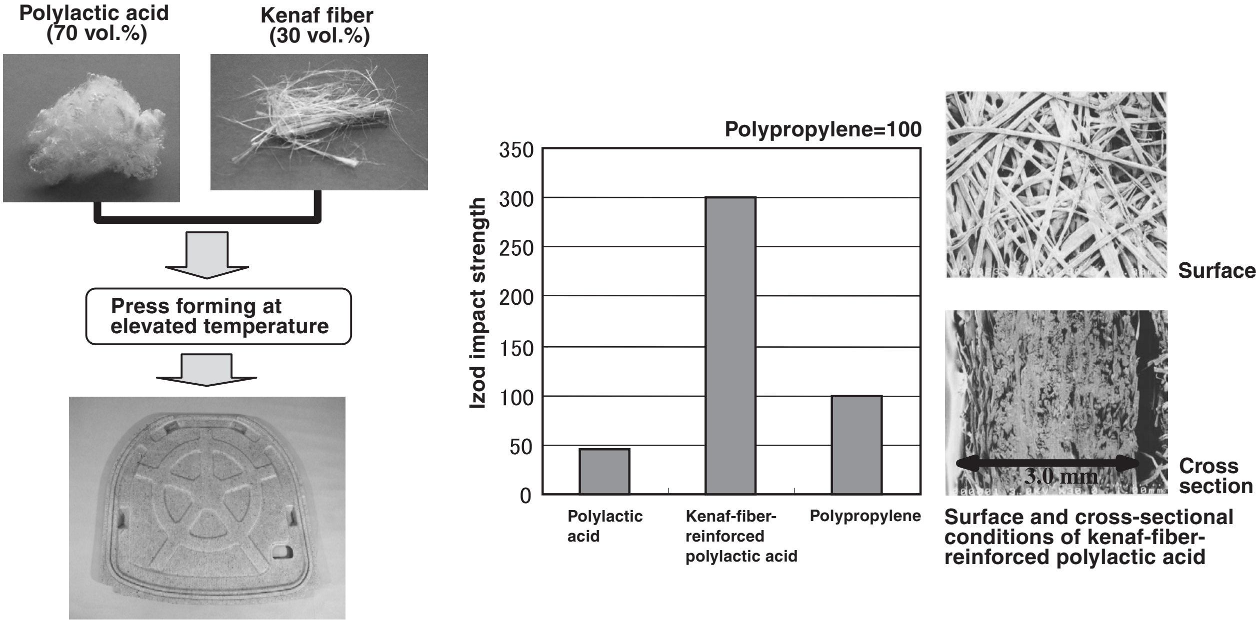


Figure 5 : Production process for a component (spare tire cover) made of kenaf-fiber-reinforced polylactic acid and Izod impact strength of the material

Izod impact strength: a rectangular specimen with a notch at the center is fixed and a hammer is used on the notched side to break the specimen. Izod impact strength is calculated from the energy required for the fracture.

Prepared by the STFC based on Reference[12] with modification

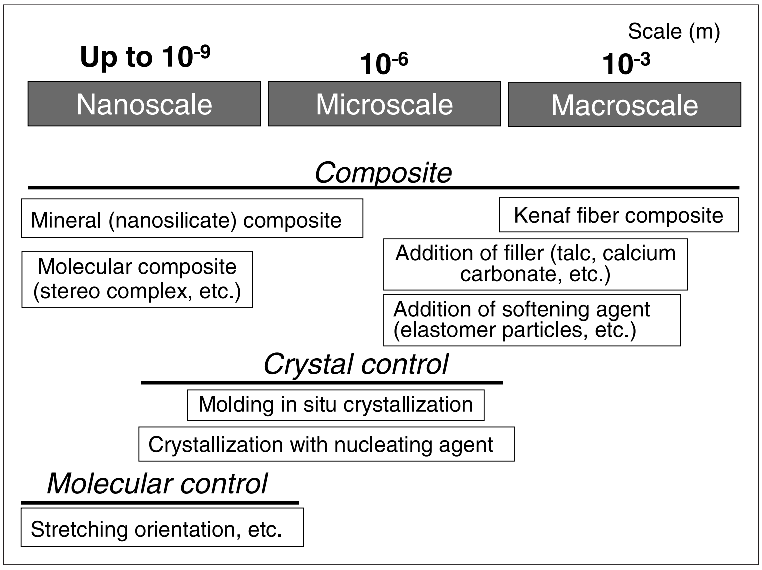


Figure 6 : Major methods to improve mechanical properties of polylactic acid

Prepared by the STFC

4 Themes of research and development for the improvement of material properties of polylactic acid

4-1 *Improving material properties by a nanoscale composite process*

Efforts are being made to improve the mechanical properties of polylactic acid from the perspectives of composite process, crystal control, and molecular control of the material structure on a nanoscale, microscale, and macroscale. Figure 6 shows the specific methods on each of these scales[12]. The following is an example of research and development for material improvement using a composite process on a nanoscale. As the crystallinity increases, thermal distortion temperature rises so that crystallization proceeds during the injection process, which results in improved heat resistance[14]. In the past, the crystallization speed of polylactic acid was so low that it was necessary to obtain easily crystallizing polylactic acid in order to improve the heat resistance. To improve the heat resistance from the perspective of the nanoscale composite process, it is important to study methods to form composite with nano constituents of inorganic clay so that crystallization is promoted.

It is also extensively being studied to uniformly disperse nanoscale inorganic additives as filler among the organic molecules. In the past nanocomposite synthesis process, inorganic materials (such as montmorillonite, which is a type of clay, and synthesized mica) that have a microstructure of laminated plate crystals have been used as the filler. These inorganic materials are added to the organic monomers after being modified by the ion exchange process using organic cation compounds, and then the monomers are polymerized with the filler being uniformly dispersed[15]. Figure 7 shows the crystal structure of sodium montmorillonite, which is natural mineral clay and a type of silicate having a nanoscale laminar silicate structure[15, 16].

Figure 8 schematically shows an example of the production process for preparing nanocomposite of polylactic acid using sodium montmorillonite[16]. In this process, nanoscale sized clay is dispersed in the polymer so that the interaction between the constituents is increased and the softening of polylactic acid under a high temperature environment is suppressed thereby improving the heat resistance of the composite. Sodium montmorillonite is used as the clay and organic ammonium salts are used for the organizing process. Clay is added before polylactic acid is polymerized from the lactide. The layer interfaces of the clay being added are organized to increase the affinity with the monomer. As a result, the lactide penetrates between the clay layers causing ring-opening polymerization, and the laminated structure of

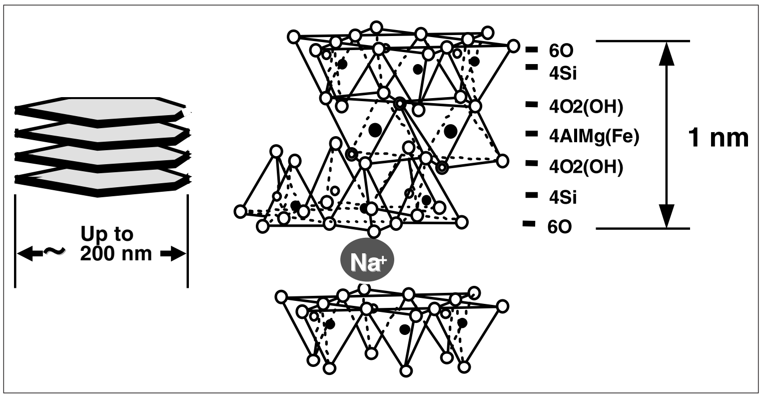


Figure 7 : Crystal structure of sodium montmorillonite

Prepared by the STFC based on References[15, 16] with modification

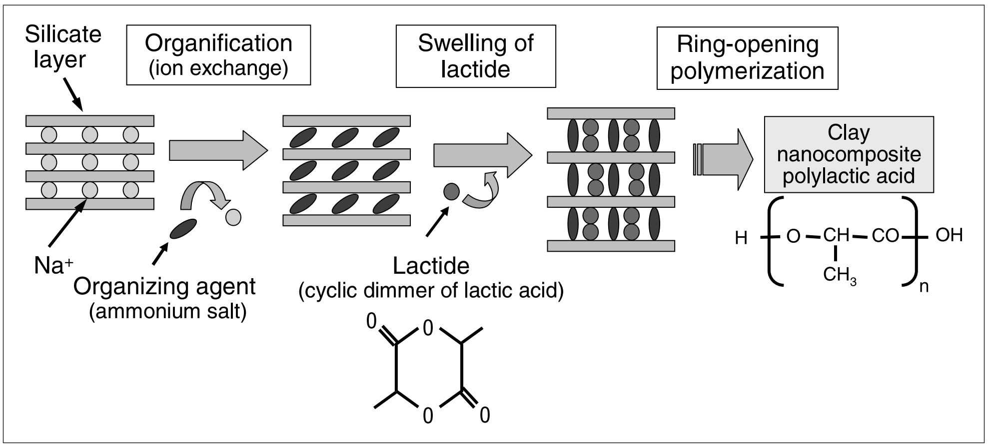


Figure 8 : Schematic diagram for synthesis process of clay nanocomposite polylactic acid

Prepared by the STFC based on Reference[16] with modification

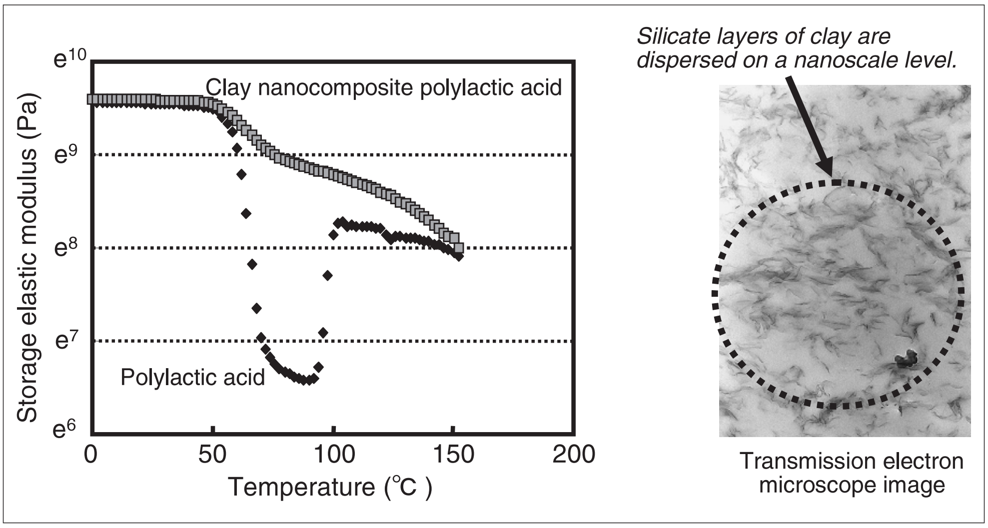


Figure 9 : Viscoelasticity and transmission electron microscope image of clay nanocomposite polylactic acid

Storage elastic modulus: refers to the part of the mechanical properties of a polymer that has elasticity combined with viscosity corresponding to elasticity. The temperature dependency of this property is obtained by applying dynamic load to the material and measuring the transmitted force.

Prepared by the STFC based on References[8, 14, 16] with modification

the clay is separated layer by layer, which results in nanoscale dispersion in the polylactic acid[14, 17].

Figure 9 shows the viscoelasticity characteristics and a transmission electron microscope image of clay nanocomposite polylactic acid formed by high-temperature injection molding[8, 14, 16]. To prepare the sample, molding conditions such as the mold temperature and cooling time were optimized to cause crystallization in the mold, and the elasticity modulus of polylactic acid at high temperature was drastically increased with the additional effect of reinforcement by the nanodispersed silicate layers. The clay nanocomposite polylactic acid enables crystallization at practical temperatures so that the heat resistance is significantly improved. The transmission electron microscope image of the clay nanocomposite polylactic acid indicates that the silicate layers of clay are dispersed on a nanoscale in the polylactic acid. This shows that the silicate layers are separated layer by layer and uniformly dispersed on a nanoscale, but not that the ring-opening polymerization occurs predominantly outside the layers while the layer structure is maintained[14, 17].

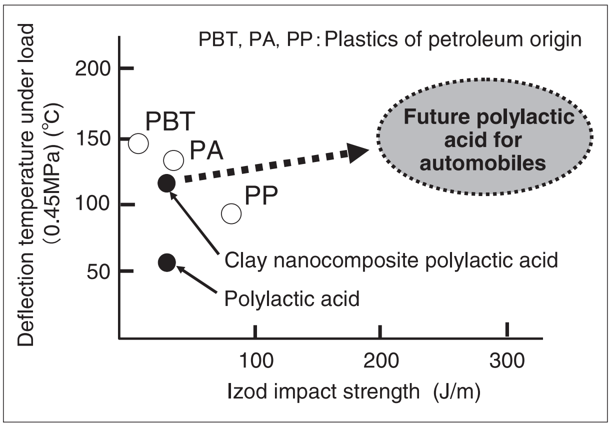


Figure 10 : Relationship between the deflection temperature under load and shock strength of clay nanocomposite polylactic acid

Deflection temperature under load: the temperature at which deflection reaches the specified value (0.32 mm) when the temperature of the specimen immersed in a liquid heating medium is raised under a bending stress (0.45MPa).

Prepared by the STFC

4-2 *Nanocomposite technologies to further improve mechanical properties*

Figure 10 shows the relationship between the deflection temperature under load and the impact strength of clay nanocomposite polylactic acid by high-temperature injection molding in comparison with that of the plastics of petroleum origin. At present, simple clay nanocomposite polylactic acid can improve the deflection temperature under load but it cannot improve shock strength, and composite processing with plant fiber such as kenaf is indispensable when applying to structural materials.

Figure 11 shows the future orientation for material design and strength assessment of polylactic acid toward significant improvement in mechanical properties. To realize the full-scale use of kenaf-fiber-reinforced polylactic acid as a structural material, it is necessary to obtain the optimum composite effect by statistical treatment considering the variation of the strength of kenaf fiber[18]. It is also necessary to understand the mechanical properties under various conditions of the service environment in which automobiles are operated. It has been shown that the shock strength of kenaf-fiber-reinforced polylactic acid is three times higher than that of polypropylene, and further expansion into the applications for structural materials is expected when the material structures on the microscale and

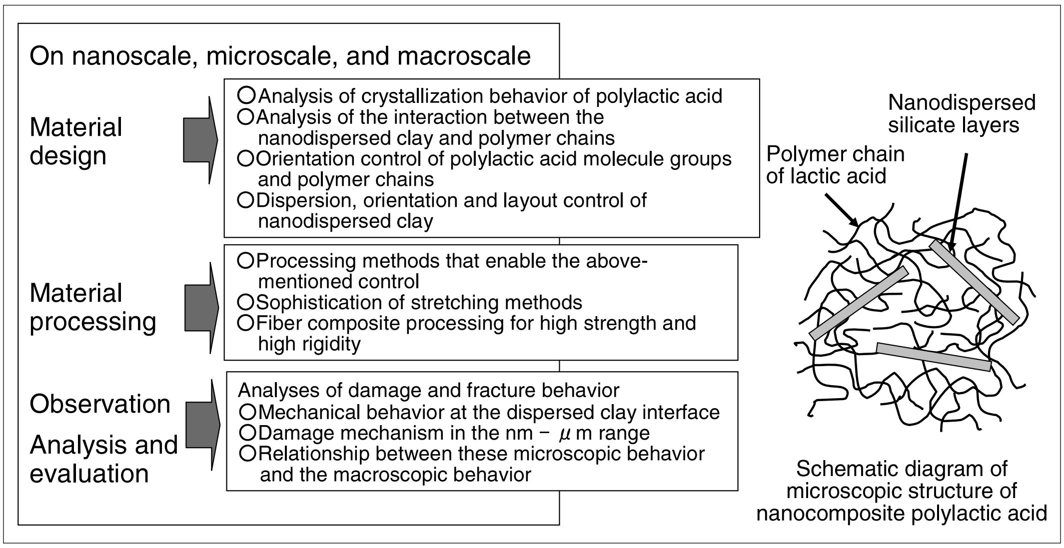


Figure 11 : Orientation for material design and strength evaluation of polylactic acid toward significant improvement in mechanical properties

Prepared by the STFC

macroscale are further controlled. Kenaf bast contains much cellulose and long, and strong fibers are obtained from the bast. However, to use kenaf as an industrial material, it is necessary to secure the quality and a stable supply[19].

For polylactic acid to be used as an injection molding material, it is further required to improve the crystallization speed, moldability, heat resistance, and shock resistance. Themes for material design and material processing from the nanoscale through microscale to macroscale include: analysis of crystallization behavior of polylactic acid, analysis of the interaction between the nanodispersed silicate layers and polylactic acid molecular chains, orientation control of polylactic acid molecular chains, dispersion, orientation, and layout control of nanodispersed silicate layers. Regarding the observation and analysis for strength design and evaluation, it is indispensable to analyze the damage and fracture process by understanding the mechanical behavior at the interface between the nanodispersed silicate layer and base material, damage evolution in the nanoscale through macroscale range, and the relationship with macroscopic mechanical behavior[20, 21].

In the composite technology on a nanoscale for inorganic nanomaterials and organic polymers, the viscosity of organic polymers drastically increases as the filler material is increased in the organizing treatment, and there is a limit to the improvement of physical properties. Therefore, in order to drastically improve the material properties, research and development of synthesis through material design at the atomic and molecular level is necessary. One of such synthetic methods is a process in which metal alcoxide is used as the raw material for the inorganic component. To uniformly disperse the filler finely in the organic polymer on a nanoscale, an electroviscous fluid is used as the solvent in the metal alcoxide method. Here, an electroviscous fluid refers to a fluid whose rheological characteristics vary in an electric field. Research and development related to the nanocomposite technology that applies an electroviscous fluid for polyamide plastics has been conducted[22-24]. It may be possible to further improve the material properties of polylactic acid by applying such conventional technologies for the plastics of petroleum origin.

5 Future themes other than material properties

5-1 Development of low-cost production process

One of the major causes that disturbs the application and diffusion of biomass plastics is its high cost. When polylactic acid is used as the raw material for plastics, the cost is two to five times higher than that of plastics of petroleum origin[25]. While the present price of plastics of petroleum origin is about 80 to 100 yen/kg, the "Biomass-Nippon Strategy" sets the target price of plastics of biomass origin to about 200 yen/kg in 2010, which is about twice as high as that of plastics of petroleum origin[3, 6, 28].

Figure 12 shows the production process of polylactic acid and the approximate cost ratio

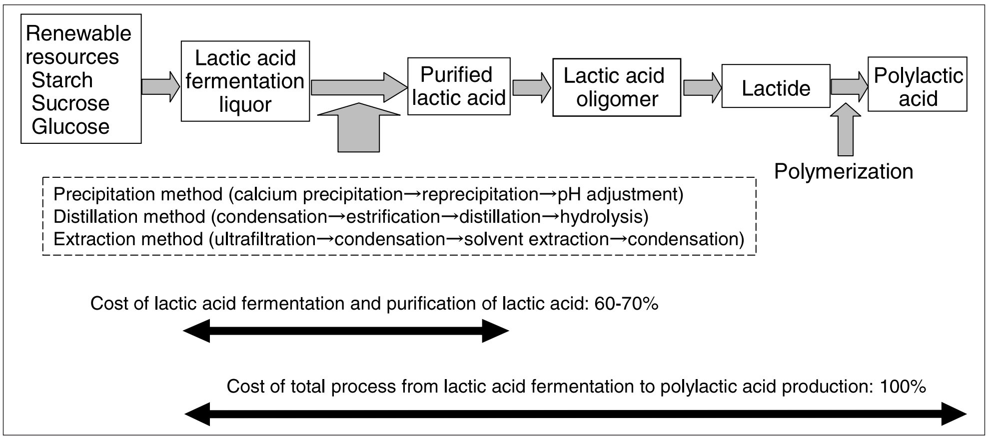


Figure 12 : Production process of polylactic acid and approximate cost ratio of purified lactic acid

Prepared by summarizing the contents of References[4, 6, 10, 26, 27]. References[6, 10] calculate the cost on a production scale of 37 thousand tons of polylactic acid using old rice as the raw material.

of purified lactic acid in the total cost[4, 6, 10, 26, 27]. In the production of polylactic acid, the cost required for purified lactic acid is the largest, which accounts for about 70% of the total cost. Therefore, it is indispensable to reduce the production cost of plastics made from polylactic acid to a level comparable to that of plastics of petroleum origin (one half to one fifth of the present level), by significantly reducing the cost of the purified lactic acid used for polymerization. To obtain high purity lactic acid from fermented liquor, precipitation, distillation, or the solvent extraction method is used, and all of these processes consume much energy. Therefore, it is essential to develop a technology that uses energy more efficiently[27].

In order to reduce the cost of lactic acid, technologies utilizing enzymes or lactic acid producing bacteria that reduce or eliminate processes causing high cost such as neutralization, distillation, and condensation in the purification process must be developed. Innovative processing that applies microorganisms or biotechnology is expected to contribute to the enhancement of price competitiveness for plastics of plant origin. It is also possible to reduce the cost by recycling the lactic acid recovered from used polylactic acid so that the costly process of producing lactic acid is eliminated. On the other hand, since the price of plastics of petroleum origin that use naphtha as the raw material is expected to significantly increase due to the plateaued level of petroleum production, the relative cost-effectiveness of polylactic acid will improve in the future as a result of the increased cost of petroleum.

The “Strategic Technology Roadmap for the Green-bio Field” of the “Environment and Energy Sector of Biotechnology Strategy Guidelines” lists the production of useful materials such as high-quality, high-value-added products and the efficient production of materials as technical themes, and defines a road map by classifying the necessary technologies into such categories as those used for “material production making use of microorganisms” and “material production making use of plants.”[29] The road map lists the development of microorganisms and enzymes that are resistant to organic solvents and the development of material production using bio-refineries and closed plant factories as important technologies to be developed. Japan is considered to be dominant in these technologies. According to the road map in the green-bio field, for example, the development of a technology that enables bioprocess making use of microorganisms under special conditions in an organic solvent is expected to realize a significant reduction of production costs by 2025. Among these chemical products that make use of biofunctions, plastics of plant origin are considered to be the core materials and polylactic acid will dominate among them. Therefore, further improvement of the mechanical properties of polylactic acid and the development of low cost production processes are dual issues for the diffusion of this material.

5-2 Effect on the international demand and supply of food

Destabilizing factors for the demand and supply of food, such as population growth, increase in food demand in Asia due to economic development, and the progress of global warming, are increasing worldwide[30, 31]. The expansion of food production and stable supply are limited by factors such as the decrease in cultivated acreage caused by the desertification and depletion of water resources, and the balance between population growth and food supply is being eroded. Therefore, taking the global trends in the demand and supply of food into consideration, the effect of the use of a large amount of polylactic acid for automobile components is estimated as follows.

Figure 13 shows the results of the estimation of the worldwide yield of biomass sugar[32] and the demand for sugar necessary to produce polylactic acid in the automobile industry. The chart shows the results of estimation assuming that all the plastics used for automobiles in the world are replaced with plastics of plant origin (polylactic acid). The estimated total consumption of plastics for automobiles worldwide is about 5.7 million tons at present. To replace all these plastics used for automobiles with polylactic acid, 8.4 million

Biomass	Worldwide yield (100 million tons/year)	Yield ratio of sugar (%)	Yield of sugar (100 million tons/year)
Wheat	5.6	60	3.36
Maize	5.3	60	3.18
Rice	5.3	60	3.18
Potato	2.7	15	0.14
Cassava	1.5	20	0.30
Sweet potato	1.3	25	0.33
Sugarcane	11.0	15	1.56
Beat	2.8	15	0.42
Total	35.5		12.8

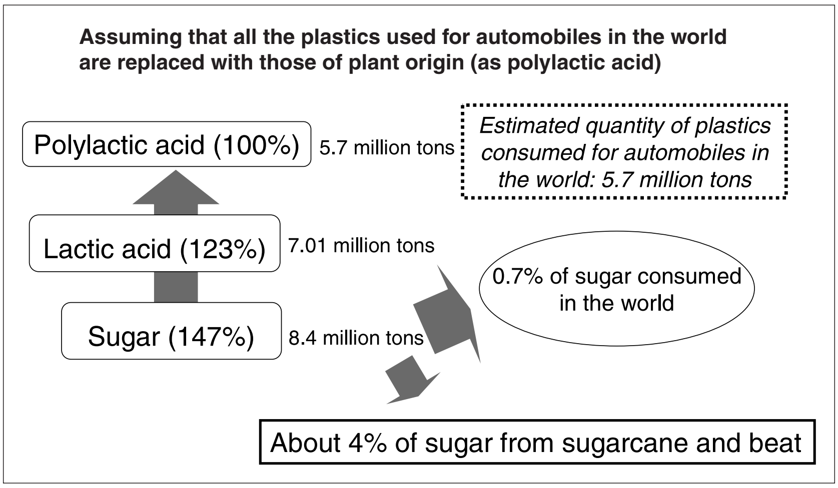


Figure 13 : Estimation of worldwide yield of biomass sugar and demand of sugar for polylactic acid used for automobiles

The yield of biomass sugar is calculated based on Reference[32]. Prepared by the STFC

tons of sugar is required taking the yield ratio into consideration. Since the total yield of sugar in the world is about 1.3 billion tons, about 0.7% of the total sugar produced in the world is consumed by automobiles. If all the sugar used for automobiles is taken from sugarcane and beat only, about 4% is consumed for automobiles. Although it is unlikely that the amount of sugar used for automobiles will immediately cause a food problem, it is desirable to obtain as much of this sugar as possible from surplus sugar of food or surplus biomass resources. Since biomass resources are unevenly distributed among countries and regions, and types and quantities are diversified, comprehensive utilization of biomass on a global level must be promoted.

Although the number of automobiles in the world is expected to exceed a billion in 2010[33], it is not a dream to provide all the interior components of automobiles only with plastics of plant origin, mainly based on polylactic acid, if the mechanical properties of polylactic acid are improved and the cost reduction is achieved as expected in the future. Furthermore, if the technologies developed for automobile components are expanded into other consumer durable goods, it will become necessary to reconsider the effect of the sugar demand for polylactic acid on the demand and supply balance of food.

6 Conclusion

Since the number of automobiles in the world is certain to increase, future technologies that reduce the environmental impact in the total life cycle of automobiles must be developed. In this sense, the role of environmentally-friendly material technology that does not waste natural resources is becoming more important than ever.

For the broad utilization of plastics of plant origin in the future, it is important to grow stable plant materials and develop components that make use of the advantages of natural raw materials. The material structures from microscale to macroscale must be matched to the use environment of automobiles. From the viewpoint of synthesizing technology, research and development for the sophistication of the production process regarding crystallization and molding properties, which are unique to the plastics of plant origin, and significant improvement of material properties such as heat resistance and shock resistance must be conducted. In such research and development, conventional technologies for the plastics of petroleum origin should be applied or taken as a model. To realize the full-scale application of plastics of plant origin to structural materials in the future, it is essential to analyze and evaluate the mechanical properties of materials under the environment where automobiles are used by clarifying the underlying mechanism.

To solve the present cost problem of plastics of plant origin, innovative processes using microorganisms and biotechnology are expected to be developed in the future. In addition, research and development to utilize the advantageous functions of plastics of plant origin, such as transparency and high water absorption, must be promoted to create added values. The research and development of effective production and collecting systems for biomass is also required to improve the economic efficiency by utilizing various types of biomass so that plastics of plant origin further penetrate into various social systems.

Glossary

*1 Carbon neutral material

a material that does not affect the amount of carbon dioxide in the atmosphere through its life cycle.

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5

China's Environmental and Energy Problems and the Possibility of Japan-China Technical Cooperation

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1 Introduction

In March 2006, China adopted its 11th Five-Year Plan at the National People's Congress. In the Plan, China made a significant shift away from its previous energy policies - which gave top priority to economic progress underpinned by the expansion of energy production - to a policy that focuses on building a resource conservation-oriented and sustainable society[1, 2]. Japan-China energy cooperation has focused on supply, through means such as the development of energy transport infrastructures and resources backed by official development assistance (ODA). As a result of the abovementioned policy change, there is rapidly increasing momentum toward developing a new cooperative relationship in the areas of energy and environmental conservation.

With this backdrop, Japan and China (Japan: Ministry of Economy, Trade and Industry and Japan-China Economic Association, China: National Development and Reform Commission, Ministry of Commerce and Embassy of the People's Republic of China) jointly held the Japan-China Energy Conservation Forum in Tokyo from May 29 to May 31, 2006[3].

This report describes the current status of China's environmental and energy problems, and discusses the possibility of future technical cooperation between Japan and China, taking into account discussions held at the forum.

2 The current status of environmental and energy problems in China and its environmental and energy policies

(1) The current status of environmental and energy problems in China[3]

As China's economic development makes rapid progress, its massive energy consumption is becoming a serious problem. Its total demand for primary energy reached nearly three times that of Japan in 2005. This demand will continue to increase consistently, and China is expected to surpass the United States as the world's largest consumer of oil in 2030. China's electricity demand is currently the second largest in the world, and is expected to continue to increase significantly for the next twenty years at an annual rate of as much as about 140 TWh, equivalent to the annual electricity demand of the whole Kyushu area, the third largest island in the Japanese Archipelago.

Massive consumption of fossil energy has caused serious environmental and energy problems. Li Xinmin, Deputy Director General of the State Environmental Protection Administration, says that energy related issues which occurred in advanced nations over a hundred years have concentrated over a period as short as twenty years in China.

Keenly aware that environmental protection, resource conservation and social harmony are essential to maintaining stable economic growth, the Chinese government has taken various policy measures (Table 1).

(2) Environmental and energy policies in the 11th Five-Year Plan[1-3, 5]

In China's previous energy policies, the top priority was to expand energy production to drive economic growth. However, in its 11th Five-Year Plan published in 2006, China made a significant change aimed at building a resource conservation-oriented society while maintaining a GDP growth rate of 7.5%. Table 2 summarizes the environmental and energy policies in the 11th Five-Year Plan. The Plan set specific numerical goals for building an energy conservation-oriented society, such as an energy consumption intensity reduction of 20%, which were not included in the previous 10th Five-Year Plan.

The priority environmental and energy policies are to

1. give priority to energy conservation;
2. rely on domestic energy supplies, mainly coal;
3. diversify energy sources;
4. optimize the supply-demand structure; and
5. proactively introduce nuclear and renewable energy sources.

The Energy Research Institute of National Development and Reform Commission, a major energy research organization in the Chinese government, has reported that the energy conservation goals set in the 11th Five-Year Plan can be achieved, according to concrete calculations[3]. A reduction in energy consumption equivalent to 195 million tons of standard coal during the period of the 11th Five-Year Plan is required to reduce energy consumption intensity by 20%. It is estimated

Table 1 : Current status of environmental and energy problems in China and policy measures

Issue	Status	Policy measures
Securing energy supply to meet rapidly growing energy demand	• Forecast total primary energy demand : 1,426 million tons of oil equivalent (2003) ⇒ 2,539 M toe (2030) [Reference : Japan - 517 M toe (2002), US - 2,281 M toe (2002)] • Forecast electricity demand : 1,907 TWh (2003) ⇒ 5,573 TWh (2030)	• **Enhancement of the policy-making structure** In May 2005, the National Energy Leading Group was established as the highest-level energy policy decision-making body in China and was led by Premier Wen Jiabao • **Enhancement of energy-conservation policies** 11th Five-Year Plan (2006 to 2010) A numerical reduction goal was set for reducing energy intensity The Renewable Energy Law became effective from January 1, 2006 The law mandates the purchase of renewable energy to cover 10% of total electricity generation in 2010 • **Prioritization of energy technology development** National Medium- and Long-term Plans for Science and Technology Development (2006 to 2020) Science and Technology and Education Development Program (2006 to 2010) National science and technology programs
Increasing imported oil dependency	• Peaking of domestic oil production • Imported oil: 2.4 M BD (2003) ⇒ > 5.23 M BD (2015)	
Surfacing domestic environmental problems	• 95% of coal-fired power plants do not have desulfurization systems ⇒ World's largest producer of sulfur dioxide emissions (25 Mt /y) One-third of land mass suffers from acid rain • Over-mining of coal ⇒ Caved-in land: 400,000ha. Untreated effluent: 3 B m^3 Gaseous waste: 9 to 12 B Nm^3	

Prepared by the STFC based on References[1, 3-5]

Table 2 : Summary of environmental and energy policies in the 11th Five-Year Plan

Viewpoint	Goal	Description (specific numerical goal)
Macro economy	Maintaining stable growth	Doubling the GDP of 2000 by the year 2010 at an annual GDP growth rate of 7.5% Unemployment rate of below 5%, new urban employment of 45 million jobs Three points improvement of the service sector
Energy	Building an energy conservation-oriented society	20% reduction in energy consumption intensity per GDP 30% reduction in water consumption intensity per added industrial value 60% increase in industrial waste recycling rate
Environment	Preventing the spread of pollution	10% reduction in major pollutant emissions 20% increase in forest cover rate Control of GHG emissions

Prepared by the STFC based on References[1, 3-5] that China as a whole has an energy conservation potential equivalent to 350 million tons of standard coal. However, a significant amount of investment, as much as more than 700 billion yuan, in energy-efficient equipment is required. In light of this and the time required from construction to operation of new installations, it has been questioned whether energy conservation can generate substantial energy savings within the time constraints of the five-year plan.

(3) Science and technology policies[2-4, 6]

National Medium- and Long-term Plans for Science and Technology Development announced by the Chinese government in February 2006 present a vision for energy development as per the "Three-Stage Strategy" shown in Table 3. Energy-related priority research topics and advanced technologies have been selected for the first stage which covers up to 2020, and these are presented in Table 4.

China has developed and implemented strategic priority research and development programs with specific purposes, based on National Medium- and Long-term Plans for Science and Technology Development (Table 5). The areas of energy and the environment had been included as priority research topics in the strategic priority research and development program. The budget for the areas of energy and the environment and its percentage of the total budget has continued to increase since 2000 (Table 6).

Table 3 : Three-Stage Strategy in the National Medium- and Long-term Plans for Science and Technology Development

	First stage	Second stage	Third stage
Year	2006 - 2020	2021 - 2035	2036 - 2050
Description	Build an energy conservation-oriented society through measures such as optimization of industrial structure, enhancement of energy conservation and energy efficiency improvement.	Diversification of energy sources Increase the nuclear share to the current global average of 16%; accelerate the introduction of renewable energy; and introduce hydrogen fuel-cell vehicles.	Achievement of a sustainable energy society Reduce the coal share in primary energy to less than 50%; and increase the combined renewable and nuclear share to more than 30%.

Prepared by the STFC based on Reference [3]

Table 4 : Energy-related priority research topics

Sector	Priority research topic	Description
Energy	Energy conservation in the industrial sector	Development of energy-efficiency technologies for high energy-intensity industries (steel manufacturing, chemical and transport industries); high-efficiency long-life LED lamps; technology for the cascading-use of energy
	Clean-coal technology	High-efficiency coal mining technology; technology to reduce coal pollutants; large gas turbines; integrated gasification combined cycle (IGCC); coal liquefaction technology; coal gasification technology
	Oil and gas exploration technology	Technology for large-scale low-grade oil and gas development; technology to increase the yield of old oil wells; technology to explore and develop deep oil and gas resources
	Renewable energy cost reduction, large scale introduction of renewable energy	Large-scale offshore wind farm technology; low-cost photovoltaic power generation technology; biomass; technology to develop and use geothermal energy
	Very large-scale electric power transmission technology	Large-capacity, long-distance DC power transmission technology; electricity quality monitoring and control technology; high-efficiency power distribution technology; technology to control information on electricity supply
Transport	High-fuel economy vehicles, new energy vehicles	Technology to design and manufacture hybrid, alternative fuel and fuel cell vehicles; high-efficiency, low-emission internal combustion engine technology
Urban development	Energy-efficient buildings	Development and introduction of technology to improve the efficiency of buildings; development of high-insulation building materials; standardization of high-efficiency buildings

Prepared by the STFC based on References [3, 4]

Table 5 : Strategic priority research and development programs

Program	Outline
Key Technologies R&D Program (1982-)	A research program aimed at addressing major science and technology issues closely related to national economic growth, such as energy and transportation
863 Program (1986-)	A program to advance high-technology research aimed at (1) increasing domestic technology levels to those of advanced nations, (2) contributing to economic growth through the industrialization of the results of research, (3) developing infrastructures for high-technology industries, and (4) developing leading personnel who have both strategic ideas and comprehensive interdisciplinary capabilities. The priority areas of research are information technology, biotechnology, new materials, automation technology, energy, laser technology and marine technology. Research topics in the area of energy include nuclear energy, renewable energy, hydrogen energy, fuel cell technology, clean coal technology, and lithium secondary battery technology.
Torch Program (1988-)	This plan aims to industrialize and internationalize the results of high-technology research. 30,000 high-tech corporations are situated in 53 high-tech industry development zones, supplying approximately three million jobs.
973 Program (1997-)	A priority basic research program used for basic research in the university sector; research topics in the area of energy include high-efficiency, clean burning of fossil fuels, coal gasification, liquefaction and alternative energy.

Prepared by the STFC based on References [3, 4, 7]

Table 6 : Year-to-year change in budget for strategic priority research and development programs

Unit: 100 million yuan

Year	Grand total		Basic research program*	863 Program	Key Technologies R&D Program	Torch Program
	Energy area total	Percentage				
	Environment area total	Percentage				
1994	126.58	100.0%	1.23	7.84	14.41	103.10
	12.56	9.9%	0.06	0.89	0.80	10.81
	1.38	1.1%	0.03	0.01	1.34	0.00
1995	195.19	100.0%	1.45	10.24	22.64	160.86
	21.07	10.8%	0.07	1.25	0.41	19.34
	1.86	1.0%	0.04	0.01	1.81	0.00
1996	127.90	100.0%	0.45	1.70	9.98	115.77
	21.89	17.1%	0.03	0.83	0.41	20.62
	0.42	0.3%	0.00	0.00	0.42	0.00
1997	166.54	100.0%	0.52	5.05	16.52	144.45
	10.34	6.2%	0.05	1.10	0.77	8.42
	6.40	3.8%	0.01	0.01	1.58	4.79
1998	207.19	100.0%	1.05	6.39	21.36	178.39
	13.23	6.4%	0.06	1.68	1.06	10.44
	5.65	2.7%	0.04	0.01	0.98	4.62
1999	330.55	100.0%	1.71	10.04	28.87	289.93
	19.68	6.0%	0.10	1.69	2.50	15.40
	8.13	2.5%	0.00	0.05	1.37	6.71
2000	419.43	100.0%	6.88	14.88	35.33	362.35
	26.06	6.2%	1.13	1.21	3.62	20.10
	13.54	3.2%	0.62	0.20	2.12	10.60
2001	No published data available for 2001					
2002	625.57	100.0%	11.01	25.33	125.31	463.92
	43.01	6.9%	1.42	8.97	5.62	27.00
	41.26	6.6%	0.63	1.11	1.69	37.83
2003	788.69	100.0%	10.72	95.04	146.07	536.86
	61.98	7.9%	1.50	14.55	9.96	35.97
	27.23	3.5%	0.70	4.50	5.56	16.47

* Include the Climb Program and the 973 Program

Prepared by the STFC based on Reference[8]

3 Chinese share of science and technology papers and international co-authoring relationships

The Chinese share of science and technology papers was compared with those of the US and Japan to investigate the results of Chinese science and technology policies in the area of energy. Figure 1 compares year-to-year changes in the share of papers in all areas of energy technology as well as in five typical areas for the periods before 1993, from 1994 to 1999 and after 2000.

The Chinese share of papers in all areas of energy was a few percent up to the early 1990s, which was very small compared with Japan and US. This, however, sharply increased in and after the 1990s, being close to Japan and the US. China is still behind the US but is almost comparable to Japan. This indicates that the aforementioned strategic priority research and development program has produced results, and that China is catching up with advanced nations including Japan and the US in terms of output of science and technology. Particularly in the areas of lithium secondary battery and coal gasification technologies, China's share of papers has almost become comparable to those of Japan and the US. In the areas of solar cells, nuclear energy and biomass, China's share has been low still. Until the mid 1990s, the US share of papers in all energy areas was the highest in the world. After the 1990s, Japan sharply increased its share of papers, narrowing the difference with the US and even surpassing it.

The percentage of internationally co-authored papers to all papers in the area of energy published by each country in each year range is shown in Figure 2. This shows the change in international co-authoring relationships. During and before the 1990s, China had the highest percentage of co-authoring relationships with the US in both all and specific areas of energy technology. Since the end of the 1990s, the percentage for the US has been decreasing. In contrast, the percentage of international co-authoring relationships with Japan has been

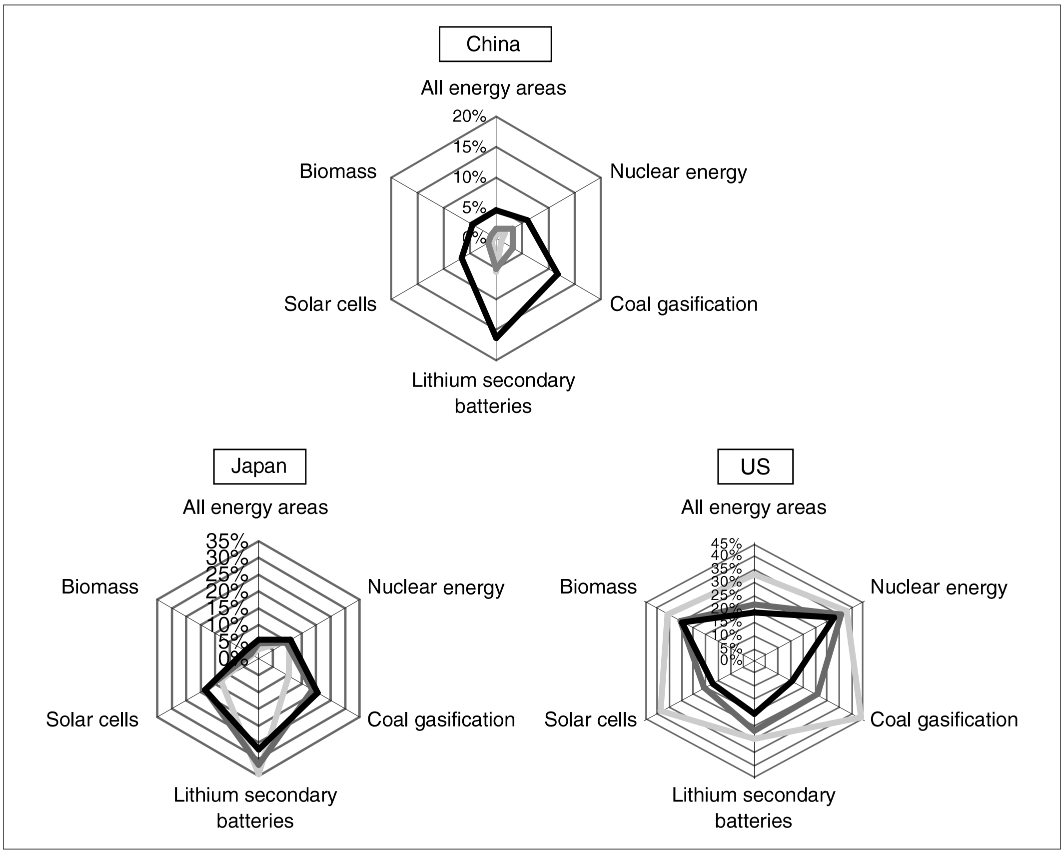

Figure 1 : Change in the share of science and technology papers in the area of energy in China, Japan and US
(— FY1980-1993, — FY1994-1999 and — FY2000-2006.06)

Prepared by the STFC based on data from Thomson's Web of Science database

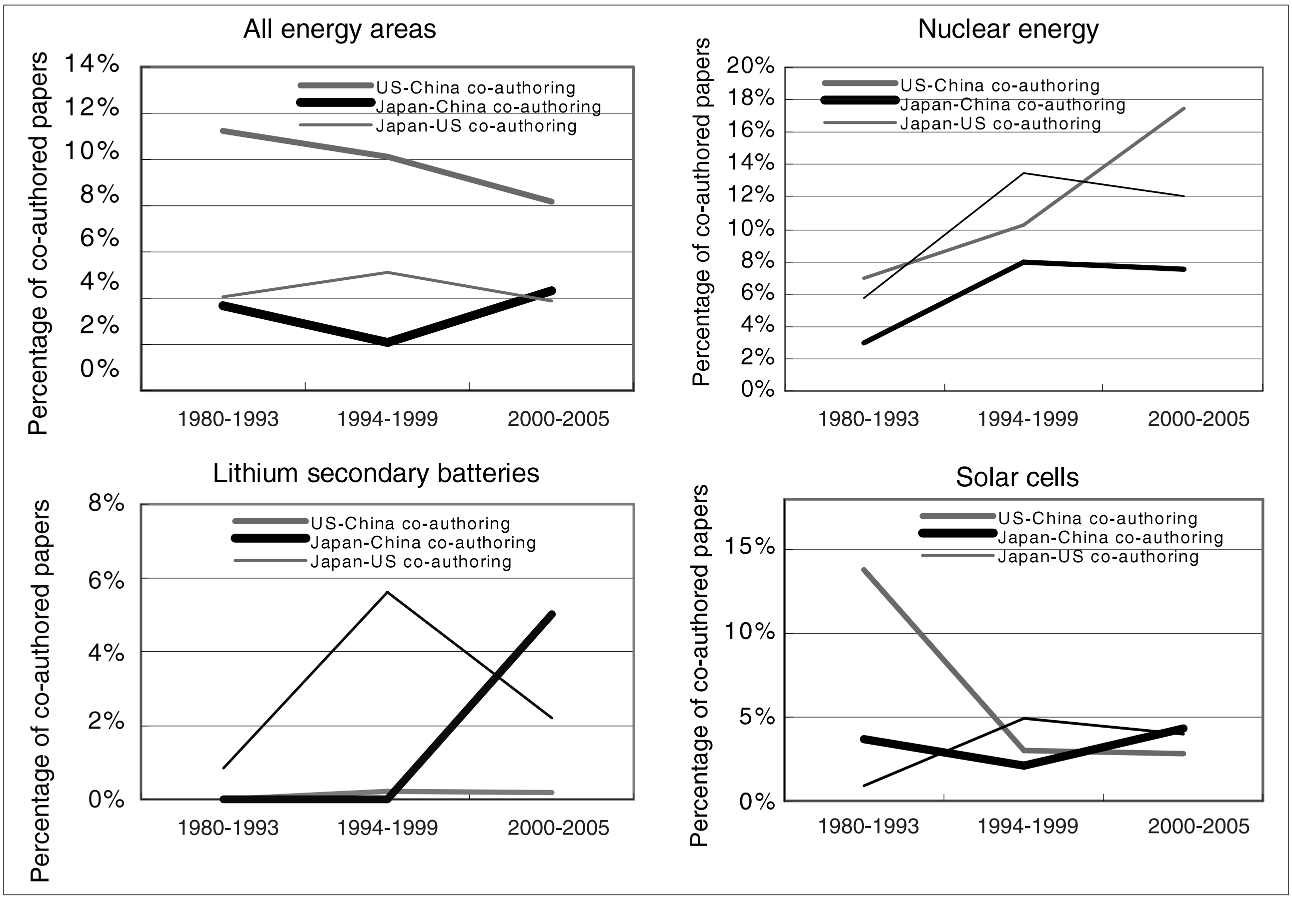

Figure 2 : Change in the percentage of internationally co-authored papers to all papers in the area of energy (FY1980-1993, FY1994-1999 and FY2000-2006.06)

Prepared by the STFC based on data from Thomson's Web of Science database

increasing. China has also become important to Japan as a co-authoring partner in the area of energy. Since the beginning of the 2000s, the Japan-China relationship in co-authoring has exceeded the Japan-US relationship. This trend has been observed in the area of the environment as well[9]. These facts indicate that the Japan-China relationship in basic research and development in the areas of the environment and energy has become closer than with the US. Particularly in the areas of alternative energy and renewable energy technologies, such as lithium secondary batteries and solar cells, the percentage of co-authoring relationships between Japan and China has significantly increased. Shown in Figure 1 are the areas in which Japan has the highest share of papers. In the area of nuclear energy, the US-China relationship is rapidly expanding, and this is the area in which the US has the highest share of papers.

4 Industrialization of basic research in China

The effect of the national high-tech industry development zones created in various locations in China can be seen as many new corporations are growing one after another, utilizing various scientific and technological innovations. About 50% of sales are attributable to new corporations in the areas of electronics and information technology. New corporations in the areas of alternative energy, renewable energy and energy-efficiency technologies, are also doing well, accounting for about 20% of sales (Figure 3). In certain areas, where Japanese technologies such as lithium secondary batteries have been overwhelmingly dominant, there are some Chinese products that are driving out Japanese competition. As previously shown in Figure 1, China has recently sharply increased its share of papers in the area of lithium secondary batteries.

It is characteristic of China that scientific and technological results have led to increased sales by new corporations in the high-tech industry development zones in a short period of time.

It has been pointed out that the innovation system of China, developed independently over the past twenty years, has contributed to the growth of high technology firms[10]. This system focuses on the construction of infrastructures, such as high-tech industry development zones, as well as on human resources, such as those represented by the "Haigui [Sea Turtle] Policy", aimed at promoting the return of high quality researchers from overseas. Due to this system, the results of advanced research at universities have led to the entrepreneuring and the growth of new corporations. It is very likely that the innovation system has become effective for alternative energy, renewable energy and energy-efficiency technologies.

In 2005, the National Energy Leading Group was established as the highest-level energy policy decision-making body in China and was led by Premier Wen Jiabao. This body did not exist previously, and it led to the improvement of administrative organizations. National Medium- and Long-term Plans for Science and Technology Development announced in February 2006, gives priority to establishing an innovation platform for energy science and technology aimed at achieving sustainable economic growth within five years[12]. Recently also in Japan, there has been a vigorous movement to fundamentally reform systems promoting innovation, such as the incorporation of national universities and research organizations. The Chinese case in this area is very compelling.

With the increasing globalization of research and development, governmental and private sectors in Europe have noticed the possibility of establishing a new innovation platform in China, and they continue to promote organizational exchanges with China[10]. For example, the Max Planck Institute of Germany has established the Shanghai Institute for Advanced Studies and Microsoft has developed the Great Wall Plan. It should be expected that Japan and China will develop a long-term knowledge network between the countries.

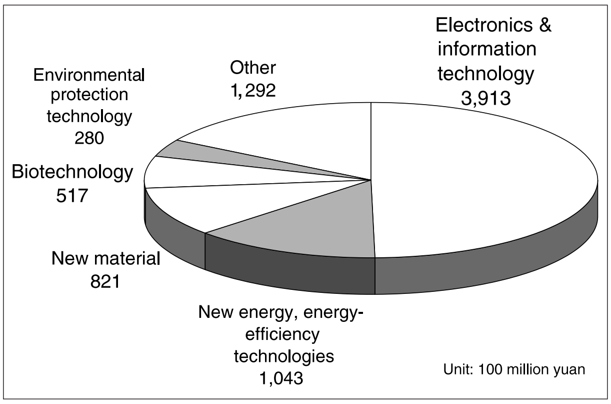

Figure 3 : Sales and product technology areas among corporations in high-tech industry development zones

Prepared by the STFC based on Reference[11]

5 Issues and possibilities of future Japan-China technical cooperation[3]

Given the abovementioned environmental and energy problems facing China, the Japan-China Energy Conservation Forum mentioned in Chapter 1 was held. About 850 concerned parties (China: approximately 200 people, Japan: approximately 500 corporations), including cabinet members, participated in the forum and exchanged opinions on a wide variety of issues including programs, policies, technologies and experiences concerning energy conservation and the environment. The participants actively discussed how future Japan-China technical cooperation should be developed. Table 7 summarizes, based on the keynote speeches, Japan's and China's recognition of the technical cooperation on energy conservation and environmental issues. Japan and China confirmed that the purpose of Japan-China technical cooperation is to help solve China's environmental and energy problems as well as to contribute to the sustainable economic growth of China and stabilization of the Asian region, leveraging the experience and technology of Japan, which has survived two global oil shocks. Both countries generally agreed on the content and areas of technical cooperation. Some concrete projects were also agreed upon in the forum (Table 8).

The Japanese government has commented that the promotion of corporate self-management and information disclosure to consumers are the keys

Table 7 : Various viewpoints for Japan-China technical cooperation

	Japanese viewpoints	Chinese viewpoints
Purpose	Solving China's environmental problems leveraging Japan's experience and technologies Operation of environment-related and energy conservation businesses by Japanese corporations in China	Providing attractive markets for Japanese corporations Contributing to the stabilization of East Asia through China's sustained and mutually complementary economic growth Enhancing the relationship between Japan, as a country implementing CDM projects, and China, as a country receiving such projects
Points of success	Building a cooperative relationship through businesses in the private sector Developing laws concerning producer responsibility and disclosure that helps consumers make judgments in China Prior preventive action Promoting corporate self-management; Corporate motivation for investment in energy-efficient equipment with cost awareness and subsidy programs	Developing a win-win relationship by promoting cooperation in business Establishing a mechanism for communication between the two countries (inter-government policy studies, platform for inter-corporate exchange)
Content	Designing programs for technology transfer, cooperation in human resource development, environmental regulation and accelerated energy conservation	Provision of technological capabilities, funding capabilities and know-how (stockpiling of imported resources, operation of environmental equipment), development of energy-efficiency technologies
Technical area	Clean coal technology, renewable energy technology, and solutions for yellow sand and acid rain problems	Afforestation, effluent treatment, clean production technology, prevention and monitoring of automobile exhaust emissions, clean fuels (alternative fuels), energy-efficient buildings
Proposed effective activity	(1) Providing model cases with support in the form of funds and tax incentives (2) Developing post-yen loan schemes (3) Holding technical meetings on energy conservation and environmental protection (4) Personnel exchange	(1) Establishing a model research laboratory, (2) holding technology shows and exchange meetings, (3) promoting inter-corporate joint research and business projects, (4) holding the Japan-China Energy Conservation Forum on a regular basis
Pending issues	Improving business conditions in China Protection of investors' benefits (investment agreements, protection of intellectual property rights)	Stabile political relationship between China and Japan Improving a sense of responsibility and ethics among Chinese corporations, increasing public awareness, non-disclosure of core technologies by Japanese corporations

Prepared by the STFC based on Reference[3] and comments and opinions from the forum

Table 8 : Concrete projects agreed upon in the Japan-China Forum on Energy Conservation and the Environment[14]

Implementing body	Content and name of agreement	Description
Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry (Japan) National Development and Reform Commission (China)	Implementation of inter-governmental communication concerning energy-conservation policies	Developing schemes to promote energy conservation and a framework for inter-governmental communication aimed at promoting the exchange of opinions on policy issues
Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry (Japan) National Development and Reform Commission (China)	Cooperation in human resource development in the area of energy conservation	Providing training in Japan to help develop human resources for developing and operating energy conservation schemes in China (a few hundred trainees over five years)
Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry (Japan) Department of International Cooperation, State Administration of Work Safety (China)	Training programs in the areas of coal production and coal mining safety	Continuing the training of Chinese engineers in the areas of coal production and coal mining safety beyond 2007
Yazaki Corporation (Japan) TEDA Investment Co. (China)	Establishment of a joint venture "Tianjin Binhai Energy & Development Co., Ltd."	Establishing joint ventures providing energy-conservation diagnosis services, technical services and management consultation services
International Center for Environmental Technology Transfer (Japan) Tianjin Economic-Technological Development Area Administrative Commission (China)	Consignment agreement between the International Center for Environmental Technology Transfer (ICETT) and the Tianjin Economic-Technological Development Area Administrative Commission	Conducting surveys and research on the Tianjin Economic-Technological Development Area; providing training on effluent treatment technology and seminars on environmental technologies
Hitachi Appliances, Inc. (Japan) Shenzhen Coolead Industry Co., Ltd.(China)	Product purchase agreement	Installing 8,400 air-conditioning systems for energy-efficient buildings

to success in solving environmental and energy problems. However, the Chinese government has pointed out that currently there are impediments typical of the period of transition to a market economy, such as problems in improving a sense of responsibility and ethics among Chinese corporations and increasing public awareness.

Both countries have agreed on the importance of building a cooperative relationship based on the private-sector. The Chinese participants have pointed out that when transferring technologies, Japanese corporations excessively disclose their core technologies and thus that a constructive cooperative relationship has not been developed. On the other hand, the Japanese participants have expressed concern over the protection of investors and intellectual property rights, and thus differences in views have been identified. These issues cannot be avoided in establishing cooperation focusing on industrial technologies in the private sector.

As explained in Chapter 3, cooperation between Japan and China is already extensive in basic research and development in the areas of environment and energy. However, there is still much room for cooperation between the two countries in solving common problems. Japan and China have essentially agreed on the priority of research topics concerning science and technology policies in the areas of environment and energy. At the Japan-China Energy Conservation Forum, discussions focused on the cooperative relationship in the area of industrial technology. Participants from China proposed establishing a model research laboratory and conducting inter-governmental policy studies. Therefore, strategic concurrent discussions in the areas of basic research and development and innovation will give a more concrete form to the desired complementary relationship between the two countries and will help to build a smoothly functioning cooperative relationship.

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6

R&D of CAD Systems Suitable for Japanese Design Organization Structure

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1 Introduction

Manufacturing technology was one of the priority fields defined in the government's Second Science and Technology Basic Plan. This field was renamed "MONODZUKURI (Value-creating manufacturing, technologies that increase the value of manufactured products) technology" in the Third Science and Technology Basic Plan, which was approved by the Cabinet on March 28, 2006. For the MONODZUKURI technology field, as one of the eight fields identified as requiring national effort, a promotional strategy has been formulated by the Council for Science and Technology Policy. This renaming represents the government's determination to enhance Japan's capacity for value creation-oriented manufacturing, which goes beyond traditional manufacturing technology, for the purpose of developing science and technology that can raise the value of products[1]. For Japan to maintain its international competitiveness and to further develop its economy under the constraints of resources, the environment and population, questions of how to form a value chain around 'MONODZUKURI' to encompass even service and information industries, and how to maximize the added value created in such a chain represent major policy challenges.

The value produced by the manufacturing sector accounts for around 20% of Japan's GDP. However, the fact that this added value represents as much as 90% of exports from Japan suggests that the manufacturing sector is more competitive than any other industry in Japan[1, 2]. The strength of Japanese-style MONODZUKURI is said to lie in the team-oriented approach combined with integration (known as 'suriawase' in Japanese), which allows talented engineers and technicians involved in a project to work together toward fine-tuning parameters in a cooperative work environment[1]. If we focus for a moment on manufacturing processes, products can be divided into two types: Modular Architecture products*1, as typified by desktop computers, and Integral Architecture products*2, as typified by automobiles. Research shows that Japan's manufacturing sector is more competitive in Integral Architecture products[3]. In a questionnaire given to publicly listed manufacturing corporations, as many as 70% of the respondents answered that their core business comprises of Integral Architecture products[3], suggesting that many listed manufacturers are internationally competitive in their core business segments.

The Third Science and Technology Basic Plan outlines a promotional strategy for each priority field, and in the case of the MONODZUKURI technology field[1] the significance of design and manufacturing systems is emphasized in its basic policy, entitled "Science-Based Japanese-style MONODZUKURI": "To remain internationally competitive in MONODZUKURI, the Japanese-style MONODZUKURI should not depend only upon the high management capabilities and skills of individuals, but should rather be further encouraged by promoting science and technologies adapted to the needs which exist in this field, such as constructing design and manufacturing support systems customized for specific manufacturing processes"[1].

One of the key strategic science and technology areas chosen to be promoted in the field of MONODZUKURI technology is "science-based KASHIKA technology that further advances Japanese-style MONOZDUKURI technology." In other words, the government has set out a policy for the dissemination and accessibility of MONODZUKURI by using information technologies and measuring/analysis technologies, in an effort to develop a scientific infrastructure for MONODZUKURI that can enhance Japan's strength in this area[1]. Information technologies that can create a database of products, storing design results, will play the central role in the building of support systems for design and manufacturing. Among such technologies are the computer-aided design (CAD) systems, the importance of which is currently under discussion by the MONODZUKURI technology Promotion Project Team on the Expert Panel on Basic Policy, part of the Council for Science and Technology Policy[4]. The team recognizes "promoting fundamental technologies for MONODZUKURI with the utilization of IT" as a primary issue in developing common fundamental technologies[1]. Another critical R&D issue identified is "new measuring/analysis technologies and appliances, and precision processing technology that meet MONODZUKURI-related needs," which the team suggests should be considered in connection with the previous issue of "promoting fundamental technologies for MONODZUKURI with the utilization of IT"[1]. In other words, they point out the need to address measurement issues in relation to CAD systems as processors of design information, if "the dissemination and accessibility of MONODZUKURI" is to be achieved through the specification of certain points of measurement and the verification of actual measurement data against design information[4]. In this way, CAD assumes a critical role in science-based MONODZUKURI in Japan[1, 4].

With these perspectives in view, this report clarifies the future direction of CAD technologies suitable for Integral Architecture design organization and structure, which represents the greatest strength of the manufacturing sector in Japan, and identifies those major issues which require national policy support to ensure that the manufacturing sector in Japan maintains and improves its international competitiveness.

2 Current usage of CAD systems

Figure 1 shows the position of the design process in the workflow of a manufacturer and the elements that make up the entire process. Manufacturers began utilizing CAD technologies in their design process around 1980, with the aim of increasing the competitiveness of their products. Since then many measures have been implemented to improve the designers' performance through the utilization of the information processing power of CAD systems.

The rate at which CAD technology has been utilized in the design process is cited in the White Paper on MONODZUKURI 2006[2] from "Research and Survey on Small and Medium Manufacturers' Deployment and Utilization of IT"[7], a report published by the Japan Industrial Policy Research Institute in March 2006. This source document divides CAD systems into three distinct categories, and reports that utilization rates among small and medium-sized manufacturers for these categories are 82% for two-dimensional (2D) CAD systems*3, 58% for three-dimensional (3D) CAD systems*4, and 33% for CAE systems*5. Another research paper on CAD utilization[8], which is based on a survey conducted in the autumn of 2002 and was presented by Fujita et al. to the Japan Society of Mechanical Engineers in January 2006, estimated that over 90% of manufacturers use CAD systems across the automobile, industrial equipment and general electric machinery industries. This implies that the adoption of 2D and 3D CAD systems and CAE tools among large companies is as least as common as among small and medium-sized companies, if not more frequent.

As Figure 1 shows, 2D/3D CAD and CAE systems play a core role in the detailed design and testing & trial production phases, although they make no contribution to the planning and concept design stages. The use of CAD/CAE systems for planning and concept design is limited to their utilization as peripheral work

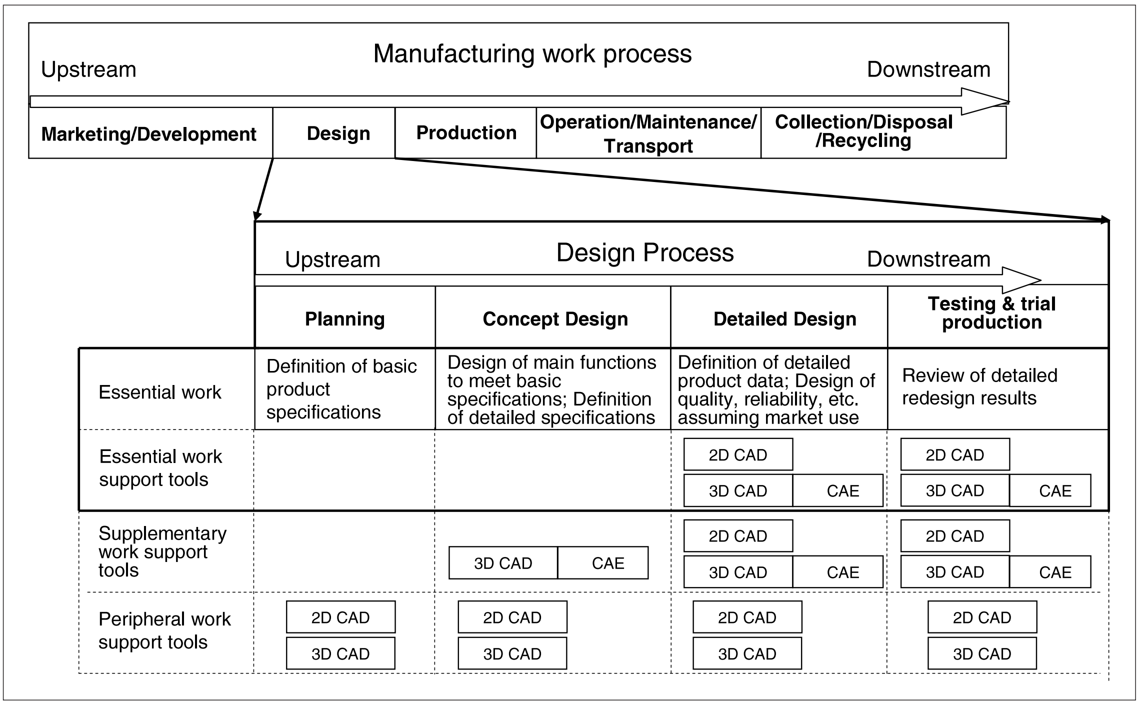

Figure 1 : Elements of the manufacturing work process and the design process

The above manufacturing process names are prepared by the STFC, based on the discussion frame for "10. Manufacturing field" in "The 8th Science and Technology Foresight Survey: Delphi Analysis"[5].The above design process names are prepared by the STFC, based on the report on standardization activities concerning the Design Process Assessment Indices[6], published by the Technical Standardization Center of the Technical Standards and Engineering Department, the Japan Electronics and Information Technology Industries Association (JEITA).

tools, helping designers to organize ideas and note the results of designs, or to their utilization as supplementary work support tools to assist in rendering the geometry of the main parts in three dimensions and estimating configuration spaces. The reason for such limited usage is that 2D/3D CAD and CAE systems are not designed to of handle the data necessary for product modeling, which is used the core work domain of planning and concept design.

The product model determines the structure of the database to be constructed for the product. In Figure 2, CAD applicability is defined from two perspectives: the type of data necessary for the product model and the stages constituting the design process. In other words, the chart illustrates four CAD applicability areas (S1 to S4) in terms of what kinds of data are essential for each design phase and how those data are used for design. The 2D/3D CAD and CAE tools available in today's market would all be placed in the S4 category, which spans from the last part of concept design to detailed design and the testing & trial production stage. These systems can handle geometry*6 as well as certain kinds of attributes*7. Meanwhile, current technologies have not succeeded in developing any practical CAD systems that can be used in the S1 or S2 areas. This explains why there were some blank areas for support tools in Figure 1. Although a CAD system may be used in the planning or concept design phase, its use is limited to supplementary or peripheral work, and does not extend to essential work.

Figure 3 shows how geometry, attributes and design intent*8 are related to CAD capabilities. The 2D CAD system primarily handles geometric data, and its geometry creation function draws objects one-by-one that combine a triangle and a rectangle. The 3D CAD system works in the same way, and in principle the operator needs to create objects one-by-one. CAD systems that can automatically reshape an object when the dimensions are changed, using relations such as those shown as examples of attributes, are slowly becoming available. Systems that can also handle design intent are however still at the development stage[9]. To summarize, then, current CAD systems, which are designed mainly for geometric modeling and are therefore suitable for precisely modeling a component according to its geometric definitions, can accurately communicate

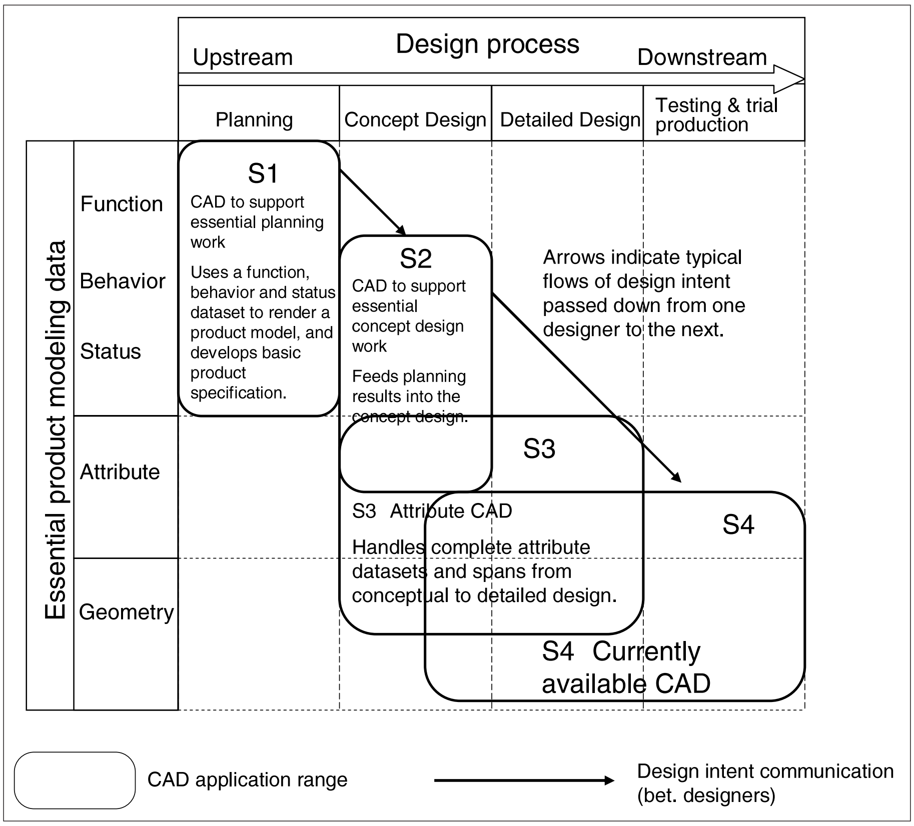

Figure 2 : Design process and CAD

Prepared by the author based on the results of joint research with Prof. Arai and his assistants Tsumaya and Wakamatsu, the Graduate School of Engineering, Osaka University, and Prof. Sugimura, the Graduate School of Engineering, Osaka Prefecture University.

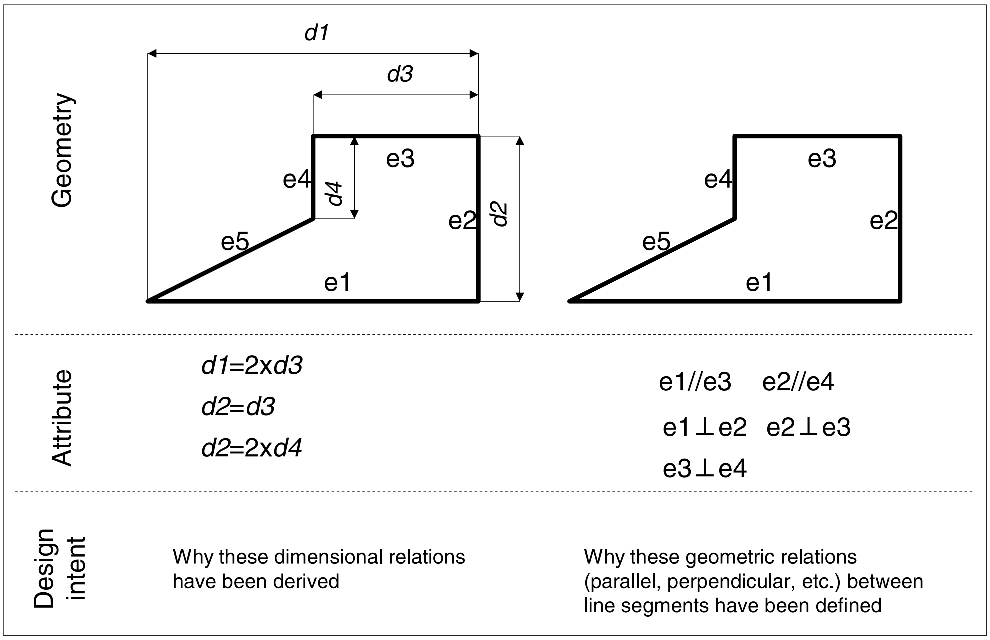

Figure 3 : CAD system function and processable data

geometric data to later processes[9-11].

Figure 4 demonstrates an example of the application of CAD to an electrical equipment unit, in an attempt to make CAD applicability to design easier to understand. The chart shows the application of both 3D CAD and CAE systems, described as essential work support tools in the detailed design phase in Figure 1. Figure 4 shows how a unit of electrical equipment (H15cm × W60cm × D40cm) is modeled by a computer and displayed on the screen. When the designer plans the layout of parts, there are a number of design

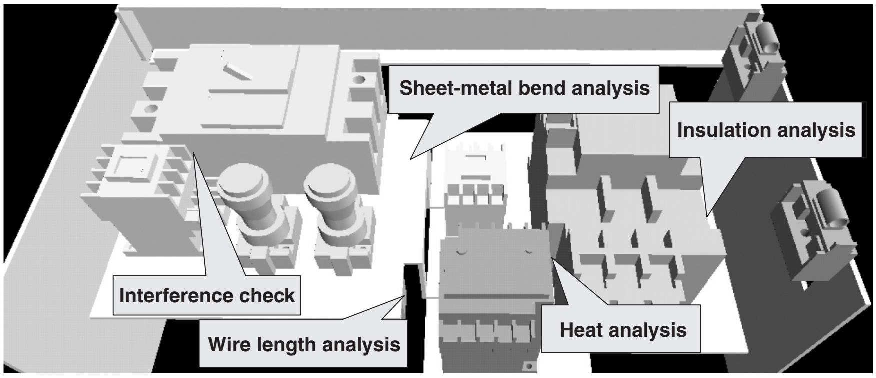

Figure 4 : Example of CAD application to electrical equipment unit

elements that must be taken into consideration, including interference checking, which refers to the spatial feasibility of the layout, as well as insulation, heat, and the required distance between parts. CAE and 3D CAD systems check these design requirements and suggest layout modification options to support the design process.

CAD systems are useful not only as individual design tools for designers, but are also often used at design review meetings held by review teams consisting of some 10 people. For example, together with the representation shown in Figure 4, a CAD system can make accessible information on the electrical fields and heat distribution which cannot normally be seen, and can display them on a large screen, helping the team to examine the design more closely.

3 CAD systems that can enhance the strength of Japanese-style MONODZUKURI

This chapter specifically describes the challenges faced in the development of IT systems that can further advance Japanese-style MONODZUKURI technology in the future.

3-1 Utilizing CAD systems in planning and concept design for making more competitive products

Many designers believe that CAD systems would bring substantial benefits if they could be utilized in the planning and concept design phases of the design process, because it is in these phases that decisions are made about the inclusion of certain characteristic features and functions into the product (those elements that give a product a unique competitive advantage). Eliminating as many problems as possible in the early stages of design is known as "front loading,"[2, 7, 12] and this approach plays a critical role in the management strategy of some companies. In particular, Japanese organizations often address inter-departmental design issues, such as ease of installation, serviceability, quality requirements, and the creation of a structure that facilitates easy assembly and thus higher productivity, in their planning or concept design phases[4, 7].

The range of applicability for the most popular CAD systems used currently (S4 in Figure 2) is not a result of strategic decisions by individual companies. CAD application is confined to the S4 area only because the mathematical product models that these CAD systems can handle are able to express geometry and attributes only partially. This is why current CAD systems are only applicable to design issues that can be reduced to purely geometric or spatial problems in mathematics. Figure 4 is a typical example of this. In other words, CAD application is limited to the production of drawings, simulation-based strength evaluations, and structure validation by displaying a 3D computer graphic model of a 3D geometric design. At the same time, CAD systems which would fall under the S3 category in Figure 2 are being developed by CAD manufacturers who have developed S4 CAD packages, largely by extending the current S4 applications. Once these become available, S3 CAD systems are expected to serve as useful transitional tools until S1 and S2 systems are developed.

S1 and S2 CAD systems that can be applied to planning and concept design must be enabled to express the product's "function, behavior and status"*9 by mathematical models. If S1 and S2 CAD systems were commercially available, a designer would start planning using an S1 CAD system. Then the data set by the S1 CAD system on the product's function, behavior and status would be passed to the S2 process. The designer would then conduct concept design using an S2 CAD system and successfully generate major attributes. These attributes would be transferred from the S2 to the S4 system. Finally, the designer would proceed to the detailed design stage with the help of an S4 CAD system, and use this to define detailed attributes and geometry. The design process would be completed by performing experiments and prototyping, using an S4 CAD tool.

To make such a workflow a reality, future R&D activities should be focused strategically on CAD systems applicable to the S1 and S2 areas.

3-2 Complete separation of the CAD system's data from the software used to analyze this data, and the need for small custom CAD software components

There is a concern that newly industrializing countries may quickly catch up with Japanese industry if CAD systems in the S1 and S2 categories as shown in Figure 2 are developed and distributed worldwide as powerful support tools in the planning and concept design phases, the critical phases in defining the product's unique and therefore most competitive features. In one case, Japan was actually outperformed by a less developed country which had strategically utilized special CAD systems in standard mold production. There are also other examples in which the widespread use of CAD systems enabled certain countries to imitate Japanese design technologies[10].

One possible solution to this concern, that the availability of CAD systems applicable to planning and concept design may inhibit Japanese companies from maintaining their strength, is to completely separate the CAD system's data from the software which carries out the necessary calculations. Some researchers have even suggested that there is a need to split the structure of IT systems into the following three categories, in an attempt to create IT tools most suitable for Japanese-style MONODZUKURI: (1) existing tools such as CAD systems, (2) common middleware that provides fundamental functions in Japanese-style MONODZUKURI, and (3) customized technological know-how unique to each company[7].

In the case of Figure 3, 'data' here refers to dimensional relations and geometric constraints (parallel, perpendicular, etc.). When these data are input, the software, which generates a draft object, is functioning like an 'engine.' The software then does not contain within it critical design results like dimensional relations. If the architecture of a CAD system could be clearly divided into part consisting of the 'engine' or software, and the part consisting of the data, then even if widely distributed only the software would be treated as a shared module among users and incorporated into a general-purpose CAD product, without the need for relevant data to be released outside the original organization.

In reality however, it is generally believed that complete separation between the software and data would not be possible in the majority of cases. This raises the need to develop small CAD software components that are customized for each type of object to be designed and that may be added to general-purpose CAD systems. Although enabled to deal with company-specific design technologies, these small CAD software components would be much smaller than the whole CAD system. Further, they would of course be used only within the organization. Engineers skilled in applied mathematics would be necessary for the development of these small CAD software components, in order to mathematically define the product modeling which constitutes the very core of every CAD system. This is because development would most likely make use of CAD development tools designed by CAD manufacturers. In other words, despite dealing with only one component, the level of technical capacity required for development is equal to that necessary in developing an entire system. However, Japan has seen a gradual decline in the number of engineers with sufficient expertise in applied mathematics to develop CAD software. Steps should be taken to increase the number of engineers specialized in applied mathematics needed for product modeling.

3-3 CAD systems to support design processes that require frequent communication across organizational boundaries

It is said that CAD systems developed in Western countries are inherently not suited to Japanese organizations. One reason given is that the standards to which Western CAD manufacturers design their products have been formulated on the assumption that it is Western organizations that will be using these products. Western organizations tend to divide work among sections very clearly, define areas of responsibility much more specifically, and their members are not required or expected to communicate across organizational boundaries. As such, they can differ somewhat from Japanese design organizations. Such differences were discussed by the MONODZUKURI technology Promotion Project Team on the Expert Panel on Basic Policy, the Council for Science and Technology Policy, as an issue to be considered in the field of IT for MONODZUKURI[4]. In the same context, survey reports published early in 2006 concluded that CAD systems developed in Europe and North America are not suitable for Japanese organizations, based on the opinions of CAD advocators in several companies[7, 9].

The CAD systems developed in the West that have been indicated as being unsuitable for Japanese organizations[4, 7, 9, 10] are CAD packages that are in use in the S4 category in Figure 2. It is possible that this lack of suitability is true for not only S4, but also for the S1 to S3 categories.

In both Japanese design organizations and in their activities, designers usually look at the entire design process, including its downstream phases. Meanwhile, downstream process designers send important feedback on quality improvement and other issues to upstream process designers. The design activities are consistent throughout the organization because of frequent communication across organizational boundaries. The result is the creation of values, such as improving product quality, which is regarded as the strength of the Japanese manufacturing sector[1, 3].

Any design, whether it represents product shape or other elements, is a result of selection from multiple choices. It is essential to let the engineers in downstream processes know why that particular shape has been chosen by the designer. Similarly, an engineering change in an upstream process requires the downstream process teams to be notified, without fail, of the content of and the reason for the change. This information is “design intent,” and it is of a different nature to function/behavior/status, attributes and geometry (Figure 3). The arrows in Figure 2 indicate typical flows of design intent being passed down from one designer to the next. CAD systems should be equipped with a mechanism for these flows. This kind of communication between designers, which is very common in Japanese organizations, is the strength of Japanese-style MONODZUKURI, and should be incorporated into CAD systems.

For example, let us assume that a chain-driven machine that will assist a person to travel is to be designed. Let us also assumer that the designer chooses as thin a chain as possible within the permissible range for safety, only from the perspective of rationalizing the design. However, in terms of maintenance of the machine, using the thinnest chain in the design may result in a tight tolerance for chain tension and thus longer time for adjustment. The consequence of this is an increase in total cost. In a case such as this, a Japanese designer would communicate with the maintenance section in the early stages of design and would be able to choose a chain that is a little thicker than the absolute thinnest, and thus a little more robust, thereby reducing the total cost.

Even Western CAD manufacturers have developed various related applications for CAD systems that are meant to support cross-departmental design teams. Typical examples are product data management (PDM) systems and networked design review systems[7]. These systems are effective design data management tools aimed at supporting any design process which comprises of multiple separate sections by allowing them to access synchronized design data or by creating electronic databases that can still be used in 10 years time. Although these are both effective within Japanese organizations, design data management and inter-departmental communication are still two different functions.

In short, CAD systems to support inter-departmental communication should ideally consist of an integrated software package that allows engineers in the design process to handle problems in production, maintenance and other downstream processes. The passing down of design intent as represented by the arrows in Figure 2 is an important means of communication and should therefore be incorporated into CAD systems.

It also must be noted that an integrated CAD package would require a large-scale development project (and consequently a system of an equally large scale).

4 Current CAD research in Japan

Most of the research papers published on CAD before 1990 fall within the S4 category in Figure 5. Many of them addressed equations that can serve as complete mathematical representations of the three-dimensional shapes of objects or equations for curved surfaces (e.g., of cars and aircrafts) that cannot be represented by a single polynomial. These research fields are known as the solid modeling theory and the free-form curved surface representation theory respectively. There was also active research in numeric analysis to convert these theories into formats that could be processed by computers. Although basic equations for these two theories had almost been completed by around 1970, application to complex real-world products had to wait for further advances in research. Many papers on advanced versions of the basic equations were published around 1990. They were aimed at mathematically defining product shapes. Theoretical problems in the basic equations were outlined in a number of articles[13-15] released around 1982, which were later cited by many papers. Since 1990, the focus of research among CAD system developers shifted to the question of how to improve basic equations to achieve higher

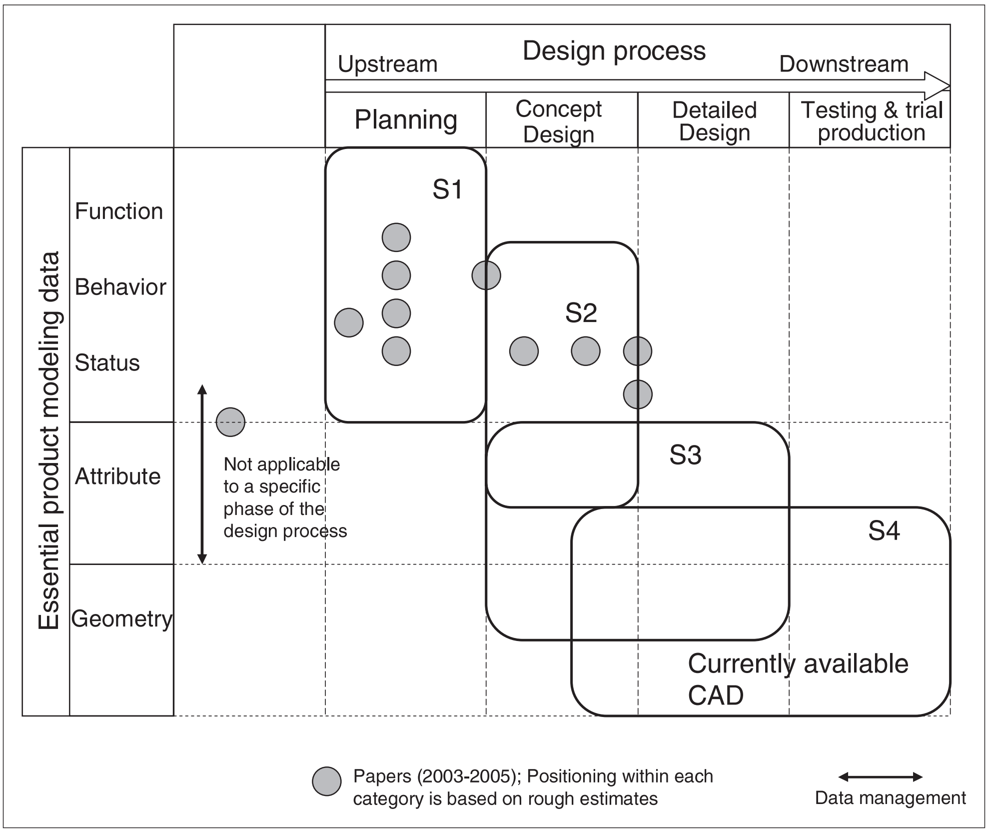

Figure 5 : Design engineering research trends as demonstrated by papers

Recent papers are plotted on Chart 2 by topic.
Prepared by the author based on the results of joint research with Prof. Arai and his assistants Tsumaya and Wakamatsu, the Graduate School of Engineering, Osaka University, and Prof. Sugimura, the Graduate School of Engineering, Osaka Prefecture University.

processing speed and thereby higher system performance. By 2000, the subjects of papers were distributed among all the categories from S1 to S4.

A typical paper on S1 and S2 is Reference[11], which attempts to develop a theory to represent a product model on a computer, using data related to function/behavior/status and intent. This kind of research requires an approach that is unlike the one taken in S4 research, or research that aims to mathematically express 3D geometric data, since function/behavior/status and intent are non-geometric data. The titles of papers in the S1 and S2 domains often include terms such as “the designer’s thinking process,” “design process with intent,” and “knowledge base.”

Recent Japanese papers focusing on the design process, like the one mentioned above, are plotted in Figure 5. Although there are many papers dealing with this topic, analysis was based on discussions held with Professor Arai and members of his laboratory at the Graduate School of Engineering, Osaka University, and with Professor Sugimura, at the Graduate School of Engineering, Osaka Prefecture University. The keyword used for the analysis was not “CAD” but “design engineering.” The following criteria were adopted for the analysis.

1. The analysis shall cover the papers published in and after 2003.
2. Papers focusing on specific design areas, such as shipbuilding and construction, shall be excluded. For this reason, the main targets of the analysis shall be those papers submitted to the Japan Society of Mechanical Engineers, the Japan Society for Precision Engineering, and the Japanese Society for Artificial Intelligence.
3. The authors shall be persons continuously engaged in design system research.

Only 11 papers were found to satisfy the above criteria. The results clearly show that recent papers concentrate on the S1 to S3 categories rather than on S4.

The analysis has also revealed that Japan is the center of research for formulating product modeling theory applicable to planning or concept design. However, the number of researchers, including university professors, who are continuously engaged in such research is small, at a little over 10. The number of researchers in firms and other private-sector organizations, which is difficult to calculate because many of these researchers address this topic only temporarily, probably stands at less than 10, if only those who specialize in theoretical research are counted. This number is very small considering the size of Japan’s industry. Some of the authors of the papers analyzed and the professors who lead this field assume that the establishment of a theory applicable not only to specific design cases, but also to a wide variety of practical design projects, depends largely on future theoretical research.

Although no statistics are available on the number of researchers engaged with CAD, the number is far smaller in Japan than in Western countries, and it is further said that the numbers of such researchers has sharply grown in recent years in South Korea, China and Taiwan. This is demonstrated by the fact that the authors from these Asian countries have come to account for 70-80% of the papers submitted to CAD-related journals.

Traditionally, most R&D funding for CAD systems has been spent on software development. However, future funding programs should focus more on nurturing researchers who can contribute to establishing product modeling theory. There are only a few universities in Japan that offer courses in applied mathematics as a fundamental theory for product modeling. Strategic assistance should be provided in this area, in view of the issue identified out in Section 3-2-the need to increase the number of engineers with expertise in applied mathematics.

5 Conclusion

In summary, this article highlights four issues to be addressed in relation to computer-aided design (CAD), which is an element of the “technology for science-based dissemination and accessibility of MONODZUKURI that further advances Japanese-style MONODZUKURI technology,” a key strategic science and technology area as chosen in the MONODZUKURI technology field in the Third Science and Technology Basic Plan.

(1) The design process consists of, in descending order, workflow of planning, concept design, detailed design, and testing & trial production phases. CAD systems applicable to the planning and concept design phases, in which functions which will give products their competitive edge are defined, need to be strategically developed.
(2) Uniform design activities enabled by frequent communication across organizational boundaries, which are said to be a strength of the Japanese manufacturing sector, will remain the driving force of value creation, such as the further improvement of product quality. R&D focused on the creation of an integrated CAD system that enables the designer to consider issues concerning production, maintenance and other downstream processes, and that can handle data that allows engineers working on downstream processes to embrace the concepts behind the product structure as envisaged by the designer.
(3) There is a concern that the availability of CAD systems that support planning and concept design may prevent individual companies from being able to maintain their strength. One possible solution is to completely separate the CAD system's data from the software. This would suggest the need for R&D on CAD system architecture to prevent that data which represents the basis of a product from being released outside the organization.
(4) In Japan there are currently very few researchers specializing in the applied mathematics needed to establish product modeling theory, or engineers with expertise in such applied mathematics. Furthermore, there are only a small number of universities in Japan that offer courses in applied mathematics as fundamental theory for product modeling. Strategic support must be provided to these areas in the future.

Each of the issues identified above requires further detailed examination by experts.

Acknowledgements

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Glossary

*1 Modular Architecture products
Products that are completed by carefully assembling existing pre-designed parts.

*2 Integral Architecture products
Products that can deliver expected functionality as a whole only when parts specifically designed and customized for them are fine-tuned to achieve harmonization.

*3 Two-dimensional (2D) CAD system
A system designed mainly to handle drawing data and produce drawings.

*4 Three-dimensional (3D) CAD system
A system designed to create three-dimensional geometric data so that designers can review design details, including geometric and layout interference problems, without the need to build prototypes.

*5 CAE (Computer-Aided Engineering) system
A system designed to support simulations in the design process.

- 2D CAD, 3D CAD and CAE are terms often used to classify those CAD systems currently available. In the broadest sense, 'CAD system' refers to a software tool that supports any part of the general design process, and the term is therefore often used as a collective term to represent both 2D and 3D CAD systems as well as CAE systems.

*6 Geometry
Data concerning vertices, line segments, areas and spaces. In Figure 3, geometry

refers to an object consisting of square and triangle line segments.

*7 Attribute

Examples of attributes are material, surface roughness, physical properties, and tolerance. Attributes of a cable refer to what it is intended to transmit, such as signals or 200-volt electricity. In Figure 3, attributes are data on dimensional relations, and geometric relations (known as geometric constraints) between line segments, as expressed as parallel, perpendicular and so on.

*8 Design intent

This refers to product structure definitions and engineering changes which are made on the basis of the designer's concepts and the data on the process through which the designer has reached the specific conclusion. They are collectively called design intent.

9* Function, behavior and status

Their definitions are the same as in a non-technical context. Take the automatic revolving door as an example. Although the automatic revolving door offers many functions, one of them is "safe revolution." The behavior associated with this is "stopping instantly if something is caught, to ensure safety," and the status is either "revolving or motionless." This produces a dataset: "automatic revolving door; safety; stops if something is caught; revolving or motionless." The idea of expressing a product by a combination of its function, behavior and status was proposed in a report by Umeda et al[11].

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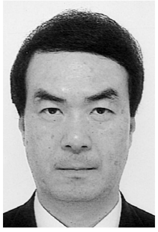

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7

Trends in Research on Turbulence Control Aiming at Reducing Friction Drag

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1 Introduction

When a gas such as air or a fluid such as water flows along a surface of an object, a well-ordered laminar flow takes place at low velocity. However, when the volume or velocity of the flow exceeds a certain limit, minute eddy motion develops and grows into diversified shapes of large vortices, one after another, which are collectively referred to as turbulent flow. Turbulent flows have common characteristics such as irregular motion, three-dimensional eddy movement, and dissipation. It is said that a turbulent flow occurs at a Reynolds number[*1] of around 2000, but it depends on the state and conditions of the flow. Figure 1 shows the state at the moment when the flow changes from a laminar to a turbulent flow.

While a turbulent flow has adverse effects on the progress of aircraft and ships by generating friction drag due to air or water and increasing fluid noise, it also brings about beneficial effects by accelerating mixing, heat transfer, and combustion. Turbulence control is a technology used to suppress the adverse effects and promote beneficial effects by adequately controlling the flow. Turbulence control not only contributes to energy saving, high-quality products, and prevention of environmental deterioration, but also be capable of bringing about breakthroughs in the transportation field.

Although research on turbulence has long been conducted, it remains both an old and new theme, due to the relatively slow progress made. Recently, however, basic data on turbulent structures are being accumulated thanks to the increased capability of supercomputers and the development of direct numerical simulation (DNS)[*2]. In addition, microelectricalmechanical systems (MEMS) [*3] technology to realize turbulent control is being rapidly developed. Studies attempting to actively control turbulent flows are also being conducted extensively because turbulence control is expected to contribute significantly to energy saving and measures resolve environmental problems.

This report describes the trends in research on turbulent flows, especially those concerning studies attempting to reduce the friction drag of wall turbulence by constructing a control system and applying MEMS technology, consisting of sensors used to detect microstructures of turbulence and actuators for controlling the fine structure.

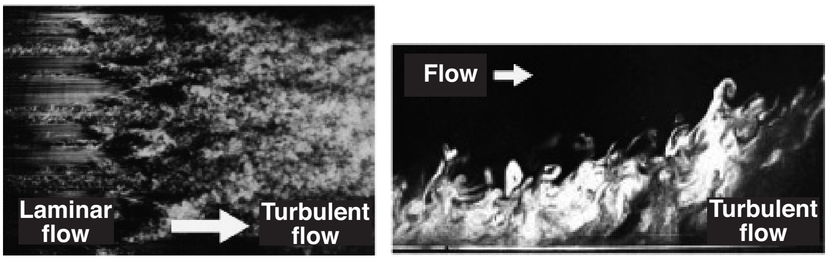

Figure 1 : Change from a laminar flow to a turbulent flow

Reprinted from the website of the Center for Smart Control of Turbulence:
(http://www.nmri.go.jp/turbulence/term_i/index.html)

2 Trends in research on turbulent flow

2-1 Trends in research on elemental technologies

Studies on turbulent flows in the modern age were started by Osborne Reynolds (1842-1912), who discovered the transition from a laminar flow to a turbulent flow by observing the phenomenon whereby the trajectories of dye in a pipe suddenly becomes irregular at a certain velocity; over 110 years have since passed.

In the United States, the living organism of a shark, which could swim very fast, was studied in the 1970's. The surface conditions of sharks' scales differ depending on the type of shark, and those that can swim fast have fine longitudinal grooves (riblets) on the surface of each scale. The intervals between the grooves are very short, within the range 35 and 100μm, depending on the position of the body. Experiments confirmed that these riblets reduced the turbulence friction drag by up to 8%[1]. In 1983, 3M Company developed a riblet film (Figure 2), which had fine longitudinal grooves on the surface of a vinyl sheet and used it in the Olympic Games and America's Cup (yacht racing).

The National Aeronautics and Space Administration (NASA), military organizations and aeronautics industry in the United States are also widely conducting research targeted at the practical use of devices applying riblets using the control theory and numerical simulation, and a demonstration test conducted by the airline industry proved that 2% of the total resistance could be reduced. If the surface of the fuselage were covered with riblet films that could reduce resistance by 2%, the fuel cost of Airbus A320 could be saved by 50 thousand l/year with a standard flight frequency[3], which would lead to estimated savings of $200 million in the airline industry of the United States[4]. However, the results of this research were not practically implemented, because the economic effect is reduced when the maintenance cost is considered.

Presently in the United States, research on the elucidation of the basic mechanism of turbulent flows and the active control of turbulence is mainly carried out at universities. For example, research attempting to reduce the friction resistance of ships using polymers and micro bubbles has been carried out since 2000 as part of a project of the Defense Advanced Research Projects Agency (DARPA(1)) of the U.S. Department of Defense.

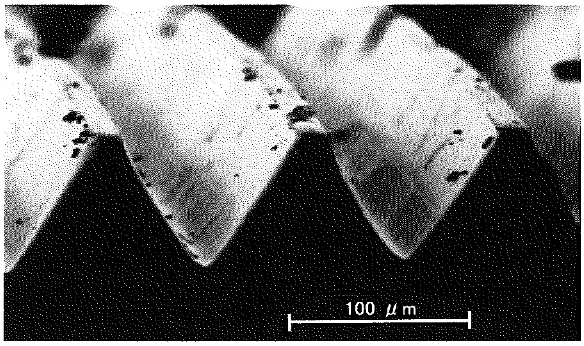

Figure 2 : Photo showing the surface of riblet films made by the 3M Company

Reprinted from Reference[2]

More practical studies are also underway in Europe at present. Holland, a maritime nation, has a history of research on reducing the friction drag of ships. Also, research on turbulence control is being extensively conducted by a Special Interest Group from the European Research Community On Flow, Turbulence And Combustion (ERCOFTAC(2)), which is an organization made up of research institutes studying turbulent combustion in the European Union (EU) and neighboring countries.

"Study on Rapidly-developing Research Area"[5], conducted by the National Institute of Science and Technology Policy in FY 2004, points out that "Smart Control of Turbulence" is one of the rapidly developing global fields in recent years. The analysis showed that this field includes wall turbulence, turbulent combustion, and numerical simulation. Unfortunately, Japan is not playing an important role in this field. Although basic studies on turbulence have been conducted in Japanese universities since the latter half of the 1950's, one of the reasons for the negative impression is that papers written in Japanese are not globally recognized.

The Japanese level of individual elemental technologies, such as MEMS technology including sensors and actuators, DNS technology necessary to elucidate and predict phenomena, and turbulence monitoring technology using optical sensors, that are required for turbulence control is quite high. However, since cooperation of diversified fields is required to conduct research on turbulence control, it is difficult for a single organization to implement. Therefore, the Center for Smart Control of Turbulence was established in the National Maritime Research Institute based on the Organized Research Combination Systems sponsored by the Ministry of Education, Culture, Sports, Science and Technology. At this center, the "Smart Control of Turbulence: A Millennium Challenge for Innovative Thermal and Fluid Systems" project was carried out for five years from FY 2000, to collectively harness the capabilities of independent administrative agencies and universities (Table 1).

In this project, the mechanisms for the development of turbulence and control theory were studied utilizing various sensors and actuators as the control measures, and a prototype control system was built up. In the study on "active turbulence control" of "Smart Control of Turbulence: A Millennium Challenge for Innovative Thermal and Fluid Systems" project for FY 2005[7], for example, the friction drag of turbulence was found to be reduced by about 6±3% in laboratory tests. In the study on "wall turbulence control" using micro bubbles, the mechanism via which turbulence is suppressed by the existence of bubbles larger than the vortex scale was elucidated, and it was demonstrated that local friction drag could be reduced by up to 60% in experiments using actual ships. In the study on "turbulent combustion control," combustion behavior in the gas turbine combustor was analyzed using LES*5 and flamelet model*6, and combustion control experiments were conducted using a small combustor, which resulted in the elucidation of oscillating combustion using secondary fuel injection. Now the research is in the practical application stage.

2-2 Progress of supercomputers and simulation

The turbulent flow includes characteristics of irregular motion, three-dimensional eddy movement, and irregularity which cause chaotic fluid phenomena*7 accompanied by extremely nonlinear behavior, meaning it has been difficult to control turbulent flows to date. In the latter half of the 1980's, however, it became practicable to implement DNS due to the improvement of computing capability of supercomputers, which made it possible to visualize the entire three-dimensional picture by simulating turbulence on computers.

In the 1990's, studies on constructing turbulence models and predicting thermal hydraulic phenomena were conducted utilizing many empirical data and numerical simulations

Table 1 : Status of research related to "Smart Control of Turbulence: A Millennium Challenge for Innovative Thermal and Fluid Systems"

Sub theme	Objectives of research	Description	Responsible organizations
Research on active turbulence control	(1) Development of fundamental technologies, such as micro machine technology consisting of sensors and actuators (2) Constructing a system that controls friction resistance, exfoliation, and heat transfer by active turbulence control	Development of devices for active turbulence control	AIST, JAXA, NMRI, universities
		Construction of active turbulence control theory	AIST, JAXA, universities
		Numerical simulation of turbulence control	JAXA, AIST, NMRI, universities
		Demonstration by model systems	AIST, JAXA, NMRI, universities
Research on turbulent combustion control	(1) Elucidation of turbulent combustion phenomena and the development of sensing technology (2) To promote the control of diffusion and mixing of combustion gas and air in turbulent jets to expand the application of lean premixed combustion*4 by stabilizing it to improve combustion efficiency and reduce hazardous gas	Development of turbulent jet control	JAXA, AIST, NMRI, universities
		Development of measuring technologies for turbulent combustion	JAXA, AIST
		Elucidation of the micro mechanism of turbulent combustion	JAXA, universities
		Assessment by model systems	JAXA, AIST, NMRI, universities

* AIST : National Institute of Advanced Industrial Science and Technology; JAXA: Japan Aerospace Exploration Agency; NMRI: National Maritime Research Institute

Prepared by the STFC based on Reference[6]

using supercomputers (CFD: Computational Fluid Dynamics(3)). In the early 1990's, modern control theory for fluid dynamics was mathematically established, and algorithms for turbulence control were extensively developed and verified. Since the latter half of the 1990's, active control of turbulent flows has also been attempted for artifacts based on these data. Table 2 shows the correlation between theory and empirical data in relation to the increased capability of supercomputers.

Table 2 : Correlation between theory and empirical data in relation to the capability of supercomputers

Age	Typical supercomputer	Correlation between theory and empirical data	Implementing institute
Latter half of 1980's	• CrayXMP/2 (U.S.A.) • SX2/SX3 (Japan) • Capacity of DNS memory : 10MB	• The results of detailed calculation of turbulent flows between parallel plates using DNS were reported for the first time. Reynolds number Re τ =180 (close to the minimum value which exhibits characteristics of a turbulent flow along wall surface). Approximately consistent with statistical values obtained by experiments.	Kim et al.,1987, NASA Ames Research Center /Stanford University (U.S.A.)
		• The particle tracking velocimeter was developed, and the results of detailed experiments, including data in areas close to the wall surface, agreed quantitatively with the DNS results.	Kasagi, Nishino, 1991, University of Tokyo.
1990's	• CrayYMP/C90 (U.S.A.) • IBMSP1/SP2 (U.S.A.) • SX-4/SX-5 (Japan) • SR-22000 (Japan) • VPP-500/NWT (Japan) • Capacity of DNS memory : 10MB-10GB	• DNS for turbulent channel flows with Reynolds numbers up to about Re τ =600 was attempted to discover which of the logarithm and power laws were followed for the velocity distribution. However, no conclusion was obtained because the Reynolds numbers were too low.	Moser et al., 1999, NASA Ames Research Center /Stanford University (U.S.A.)
		• Application of the modern control theory to flow control problems was formulated. - Numerical experiments on the reduction of friction resistance of turbulent flows using DNS have since been boosted. • A reduction of friction resistance by about 20% was achieved both by suboptimal control*8 that requires a relatively low calculation load and by more intuitive control based on the quasi-ordered structure of turbulent flows.	Abergel & Temam, 1990, University of Paris 11 Choi et al., 1993; Lee et al., 1998, Stanford University (U.S.A.), Choi et al., 1994, Stanford University (U.S.A.)
		• Numerical experiments using DNS under conditions with more consideration given to hardware systems, considering the physical values measured at the wall surface and the deformation of actuators, confirmed that certain resistance reduction effects could be obtained, even when the sensors and actuators are located discretely.	Endo et al., 2000, University of Tokyo
First half of 2000's	• SX-6/SX-7/ Earth Simulator (Japan) • SR8000/11000 (Japan) • ASCIWhite (U.S.A.) • Linux cluster grid based on Intel architecture (worldwide) • Capacity of DNS memory : 10GB-1TB	• DNS for turbulent channel flows with Reynolds numbers of Re τ =1000 – 2000 was carried out.	Del Alamo et al., 2004, Polytechnic University of Madrid (Spain), Iwamoto et al., 2005, University of Tokyo
		• Reduction of friction resistance by 6% was demonstrated by a wind tunnel experiment using a feedback control system (Yoshino et al., 2005, University of Tokyo)	
		• Although corroborative evidence for the reduction of friction resistance by the mechanism based on the suboptimal control theory (Fukagata, Kasagi, 2004, University of Tokyo) has been obtained (Yoshino, et al., 2006, University of Tokyo), it has not been sufficiently verified.	
		• DNS for controlling turbulent flows between parallel plates with a low Reynolds number of Re τ =100 using an optimal control theory, which requires laborious calculation load, was reported. It was shown that the feedback control could change a turbulent flow into a laminar flow (Bewley et al., 2001, UC San Diego (U.S.A.)).	

Prepared by the STFC based onRreference[8]

3 Recent research results in Japan

3-1 Development of wall turbulence and control mechanism

The limitless number of longitudinal vortices that occur in the direction of flow generate Reynolds shear stress causing turbulent friction drag. Figure 3 shows a near-wall longitudinal vortex in the cross section perpendicular to the flow direction and the relationship of spatial positions of the instantaneous production, destruction, and diffusion processes of Reynolds shear stress[9].

At the center of the longitudinal vortex is a core portion (L) where the pressure is locally low, and in the right side region (sweep side) is a portion where the pressure is locally high because the fluid impinges upon the wall surface. On the left side (injection side), the fluid of low pressure is elevated and forms a high-pressure stagnant region (high-pressure potato) bumping against the high-speed fluid supplied from upstream due to convection. The Reynolds shear stress is actively generated on both sides of the vortex and the generated shear stress is subsequently transferred to neighboring regions via turbulent diffusion and pressure diffusion, which disappears in the low and high pressure regions with strong correlation between the pressure and strain. The turbulent flow is maintained by such a ceaseless process of production , diffusion, and dissipation.

As mentioned above, factors that generate friction drag fluctuate intermittently in space and time, and the temporal and spatial scales of the actual object govern the dimension and response time[10] required for the sensors and actuators used. As shown in Figure 4, the required dimension is within the range 0.001mm and 10mm, and the response time is approximately between 0.01ms and 100ms. This indicates that the temporal and spatial scales handled in wall turbulence are small compared with those handled in conventional mechanical systems. The MEMS technology that has been rapidly developing in recent years has the potential to reduce friction drag at the wall surface by effectively suppressing the generation of Reynolds shear stress and turbulent kinetic energy, by selectively controlling the vortices.

3-2 Wall turbulence control using sensors and actuators

The motion of longitudinal vortices is suppressed by external force to annihilate the revolving movement exerted by actuators in response to the positional information on the longitudinal vortices on the wall surface detected by sensors. This results in the reduction of friction drag and noise. Figure 5 shows a

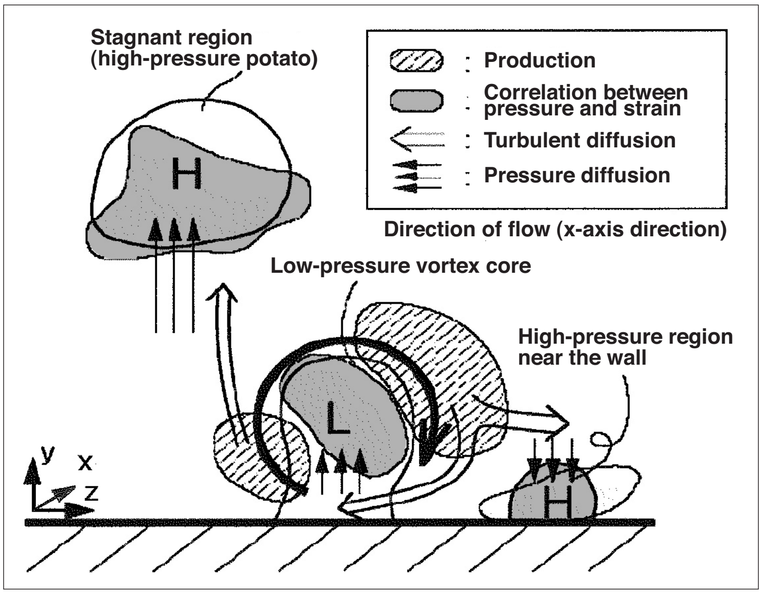

Figure 3 : Near-wall longitudinal vortex and the relationship of spatial positions of the instantaneous production, destruction, and diffusion processes of Reynolds shear stress

Prepared by the STFC based on Reference[9] with partial modification

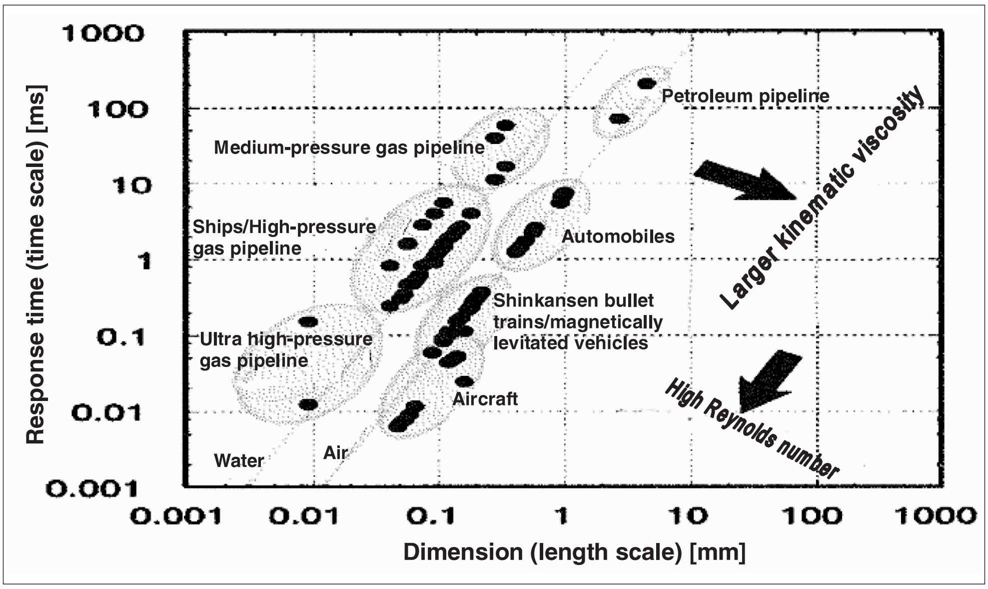

Figure 4 : Specifications for sensors and actuators used for longitudinal vortex control

Prepared by the STFC based on Reference[10] with partial modification

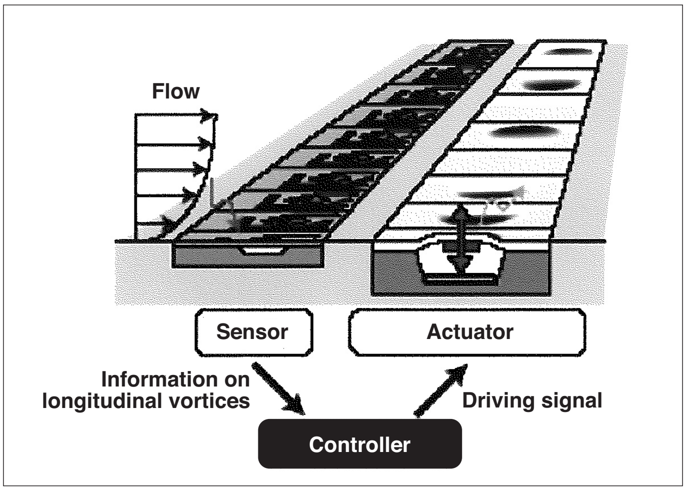

Figure 5 : Schematic diagram of a feedback control system for wall turbulence

Prepared by the STFC based on Reference[2] with partial modification

schematic diagram of a feedback control system combined with a controller.

Although many studies have been made on elemental technologies such as the algorithm, sensors, and actuator used for turbulence control, those aiming at constructing a total system are few. A group from Brown University (U.S.A.) constructed a system combining three sets of hot-film shear stress sensors, a cantilever actuator using piezoelectric elements, and a controller[11]. Meanwhile, Tsao et al. of the United States attempted to reduce friction drag by producing a prototype of a sophisticated control chip consisting of hot-film shear stress sensors, flap type electromagnetic actuators and a drive circuit[12]. However, these endeavors did not come into practical use.

Professor Nobuhide Kasagi et al. of the University of Tokyo developed a prototype of a turbulence control system, as shown in Figure 6, consisting of 192 micro shear stress sensors, 48 electromagnetic actuators, and a controller. Sensors are arrayed in four rows, each containing 48 sensors at 1 mm intervals, and actuators are arrayed in three rows, each containing 16 actuators at 3 mm intervals. The sizes of sensors and actuators are as small as 1 mm and 2.4 mm respectively; and the response time is about 0.1ms for both sensors and actuators. The displacement of the actuator film is about 50μm.

The DNS of this system applying turbulent-structure-based control*10 that controls the low-velocity streak fluctuation*9 showed that a reduction of about 12% was possible due to the stabilization of streak[13]. In the wind tunnel experiments to verify the drag reduction effect using the optimal control by Genetic Algorithm (GA)*11, drag was reduced by up to 11%. Taking the uncertainty of the shear stress measurement into consideration, this value corresponds to a drag reduction of 6%[14]. It was the first time in the world that the effects of friction drag reduction had been confirmed using such a large-scale feedback control system, which is considered to be a significant step toward the practical application.

Comparing the dimensions of the sensors and actuators with those shown in Figure 4, it is clear that the above-mentioned system can be applied to the control of longitudinal vortices in petroleum pipelines. To control the vortices of bullet trains, aircraft, and high-pressure gas pipelines, however, further miniaturization and sophistication of the system are necessary because dimensions within the range 0.001 to 0.1 mm and a response time of about 0.01 ms are required.

Turbulence control remains in the basic research stage in the laboratories, and to migrate to the stage of practical use, sensors and actuators must be miniaturized from the viewpoint of hardware so that they match the length scale of longitudinal vortices to be controlled. In addition, high accuracy, energy saving, low cost, durability, and long-term stability against staining are also required. It is also necessary to improve the micro fabrication technology and establish a mass production technology such as printing and embossing, based on a low cost production process. From the viewpoint of software, a highly efficient control algorithm that significantly reduces the volume of data processing must be developed. Such technical development is highly dependent upon the progress of technology in the industrial sector. To promote the application to practical use, therefore, information must be actively transmitted to the industrial sector so that combined research and development are accelerated among industrial fields that possess individual technologies.

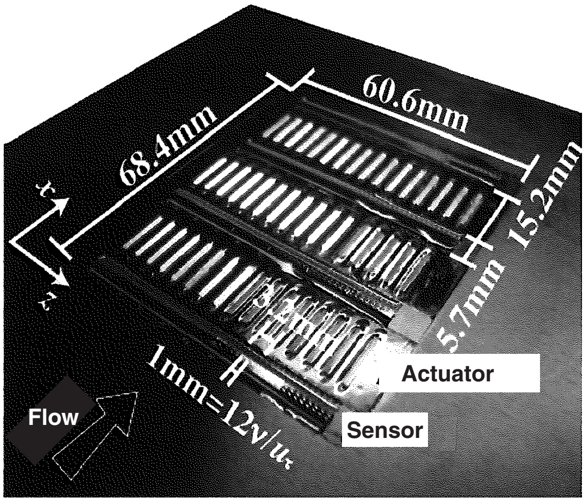

Figure 6 : Feedback control system for wall turbulence

Prepared by the STFC based on Reference[14] with partial modification

By solving problems of both hardware and software and developing necessary technologies, turbulence control is expected to play an important role, particularly in fields where high speed is pursued, such as magnetically levitated vehicles, bullet trains, and aircraft. Since studies similar to those conducted in Japan are underway in the United States and Europe, Japan must take measures to keep ahead of foreign countries in applications for practical use.

4 Conclusion

Turbulence control is one of the key points to reduce the resistance of fluids, improve combustion and heat and mass transfer, and to solve energy and environmental problems. It also has the potential to bring about breakthroughs in the transportation and other fields.

At present, as a result of the development of supercomputers, modern control theory, hardware for control, and CFD, research on the feedback control of turbulence phenomenon in response to momentary changes of flow conditions is being extensively carried out. Although turbulence control had previously been considered impossible due to the lack of analytical solutions, it is now one of the highly promising emerging technologies. In this field, Japan has produced appreciable results in the miniaturization of sensors and actuators that compose the control systems for wall turbulence. These subjects further require systematic studies on higher accuracy, energy saving, lower cost, and the establishment of long-term stability, as well as MEMS technology and micro fabrication technology to back up the research and development of control algorithms that elicit significant effects.

Since the research on turbulence control includes diversified fields of technologies, it is difficult for a single organization to solve all the problems. Therefore, top-class researchers in Japan must cooperate from a long-term standpoint. It is also necessary to cooperate with the industrial sector that has mass production technologies. To this end, information on turbulence control must be actively transmitted to the industrial sector.

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Glossary

*1 Reynolds number
A dimensionless number that characterizes a flow; defined as LU/v where L is a length scale, U is velocity, and v is the coefficient of kinematic viscosity. The value expresses the ratio of inertia force to viscous force.

*2 Direct numerical simulation (DNS)
a numerical simulation using a computer to solve a primitive equation without using additional mathematical models. When solving a turbulent field by DNS, tremendous computing power is required because the computational grids must be divided so finely that the minimum unit of eddies is distinguished.

*3 Microelectricalmechanical systems (MEMS)
A generic term for small machines that perform functions in the order of several μm to several mm.

*4 Lean premixed combustion
a combustion system in which a lean fuel gas-air mixture is combusted.

*5 LES (Large Eddy Simulation)
A simulation method in which larger eddies are solved similarly to DNS whilst smaller eddies are modeled.

*6 Flamelet model
a model that postulates that a laminar flame is deformed wrinkly in a turbulent flow when the value of the Reynolds number is large.

*7 Chaotic fluid phenomenon
a nonlinear that is too complex and irregular to predict.

*8 Suboptimal control
a control method in which the optimal control distribution is theoretically calculated by momentarily minimizing the evaluation function defined by the sum of friction drag and control energy.

*9 Low-velocity streak fluctuation
in turbulent flows along a wall, low-velocity portions (low-velocity streaks) appear in streaks near the wall. These streaks are destabilized due to the interaction with vortices and shear stress and fluctuate.

*10 Turbulent-structure-based control
a control method based on knowledge concerning the mechanism of turbulence generation.

*11 Genetic Algorithm (GA)
an optimum solution search algorithm using an evolutionary method.

Abbreviations

(1) DARPA	Defense Advanced Research Projects Agency
(2)ERCOFTAC	European Research Community On Flow, Turbulence And Combustion
(3) CFD	Computational Fluid Dynamics

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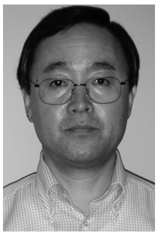

Kazuju IKEDA
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Took charge in the investigation and design of the Tokyo Outer Ring Road, and the maintenance and management of national roads in the Ministry of Land, Infrastructure and Transport. Now in charge of investigation and research on the "social infrastructure fields" of the Third Science and Technology Basic Plan. Professional Engineer (general technical management sector and construction sector).

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About SCIENCE AND TECHNOLOGY FORESIGHT CENTER

It is essential to enhance survey functions that underpin policy formulation in order for the science and technology administrative organizations, with MEXT and other ministries under the general supervision of the Council for Science and Technology Policy, Cabinet Office (CSTP), to develop strategic science and technology policy.

NISTEP has established the Science and Technology Foresight Center (STFC) with the aim to strengthen survey functions about trends of important science and technology field. The mission is to provide timely and detailed information about the latest science and technology trends both in Japan and overseas, comprehensive analysis of these trends, and reliable predictions of future science and technology directions to policy makers.

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— Targeting the vital subjects for science and technology progress, STFC analyzes its trends deeply, and helps administrative departments formulate science and technology policies.

— The research results are published as articles for “Science Technology Trends” (monthly report).

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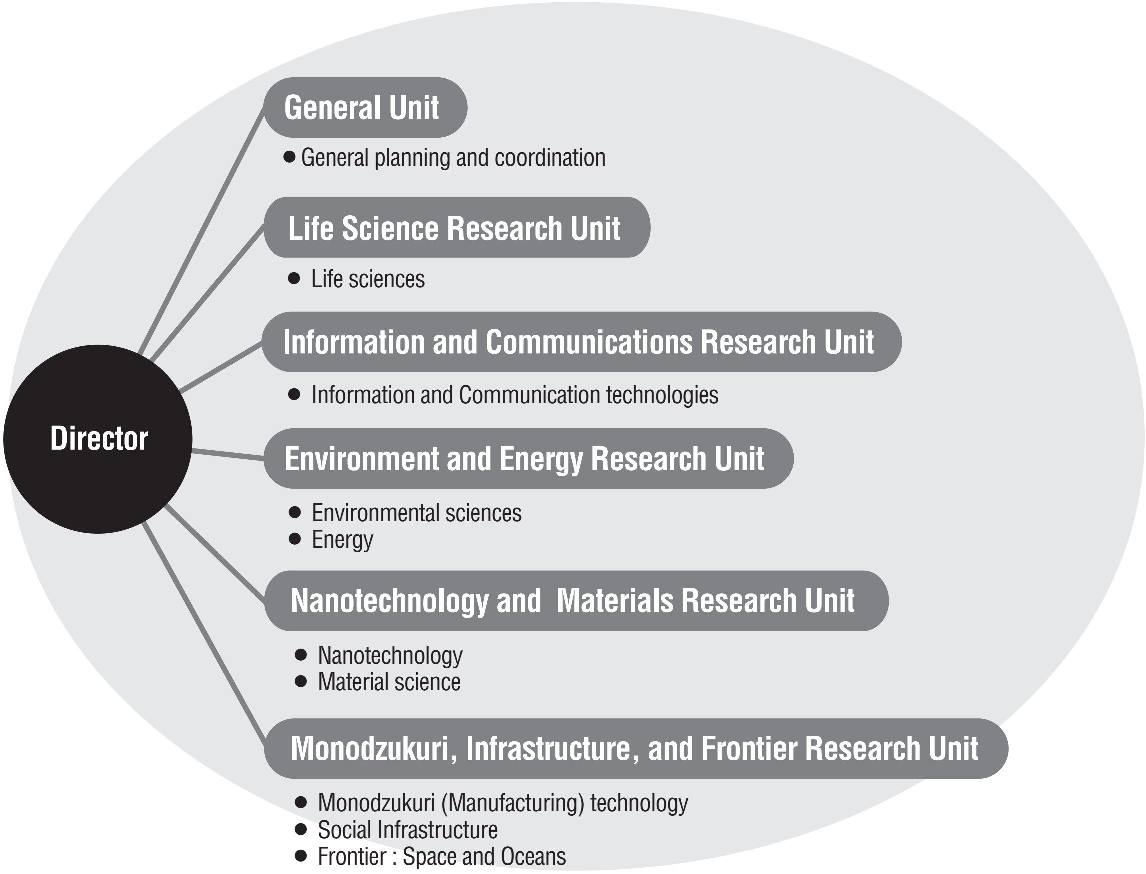
Organization of the Science and Technology Foresight Center



＊Units comprise permanent staff and affliated fellows
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