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Operations Research

from Keio's Faculty of Science and Technology

Modeling and optimization of social systems

Ken-ichi Tanaka

Associate Professor
Department of Administration Engineering

Associate Professor Ken-ichi Tanaka is featured in this issue, whose field of research focuses on solving urban and regional problems via mathematical approaches.

Using mathematical models to derive optimal location of facilities and their operating hours

Modeling and optimizing social systems

Operations research (OR) is a discipline that uses mathematical methods to work out rational plans for or present optimal solutions for diverse social problems. Dr. Ken-ichi Tanaka is devoted to research that helps determine, via mathematical approaches peculiar to OR, optimal locations of public and commercial facilities and their optimal operating hours. By showing that convenience and profitability of facilities are largely affected by their locations and operating hours, OR allows facility administrators to make rational decisions. In this sense, OR is a highly practical discipline and is often referred to as a science for decision-making or a discipline for problem solving.

Introducing the time axis in facility location problems

The Department of Administration Engineering, to which Dr. Tanaka belongs, focuses on problems arising in such diverse areas as finance, information, and infrastructure, and seeks to provide solutions to the problems using mathematical approaches. Given the target research theme – the whole social system – being comprehensive in scope, it naturally concerns diverse fields and involves hard-to-handle aspects. OR is a highly practical discipline capable of presenting concrete solutions to problems related to society.

Of the diverse fields of OR, Dr. Tanaka specializes in "facility location problems" in the field of urban engineering. Dr. Tanaka explains the characteristics of his study as follows:

"More than a century has passed since the first facility location problem was proposed, which is now known as the Weber problem that seeks an optimal location of a facility such as a factory. Facility location problems have been extended in a variety of directions to deal with more realistic situations. Basically, however, most facility location problems have ignored the temporal dimension and have focused on static and deterministic problem formulations. What makes my research approach unique is incorporating the behavior of people into the model who wish to consume services at the facility within a limited period of time by considering the temporal dimension."

Dr. Tanaka proposed dynamic location problems that seeks to determine the optimal start time of services at facilities as well as their locations. As an example, the problem can be applied to determining how to provide after-work lectures to commuters who wish to study at graduate school. In addressing this problem, he assumed a case where employees of companies in the Tokyo metropolitan area drop in at the graduate school on their way home from their workplaces. Then he derived an optimal facility location and a desirable class-starting time that maximizes the number of users – an attempt to facilitate the decision-making process on the part of the service provider.

"Too early a starting time would result in less students who could attend classes in time after leaving their workplaces. But too late a starting time would make it difficult for them to return home by a desired time. By focusing on such trade-off on the time axis, the key point is to determine optimal service start times for facilities as well as locations," Dr. Tanaka mentions.

Mathematical methods often provide good solutions, which could not be easily found by intuition and experience

To proceed with the challenge, Dr. Tanaka decided to use the "Census data for commuter traffic in Tokyo metropolitan area" – large-scale data based on a questionnaire survey of trains and buses used for commuting in the Tokyo metropolitan area. Based on the data, Dr. Tanaka developed mathematical models to determine: where in the metropolitan area should the graduate school for after-work commuters be located and at what time should the classes be started. The aim is to maximize

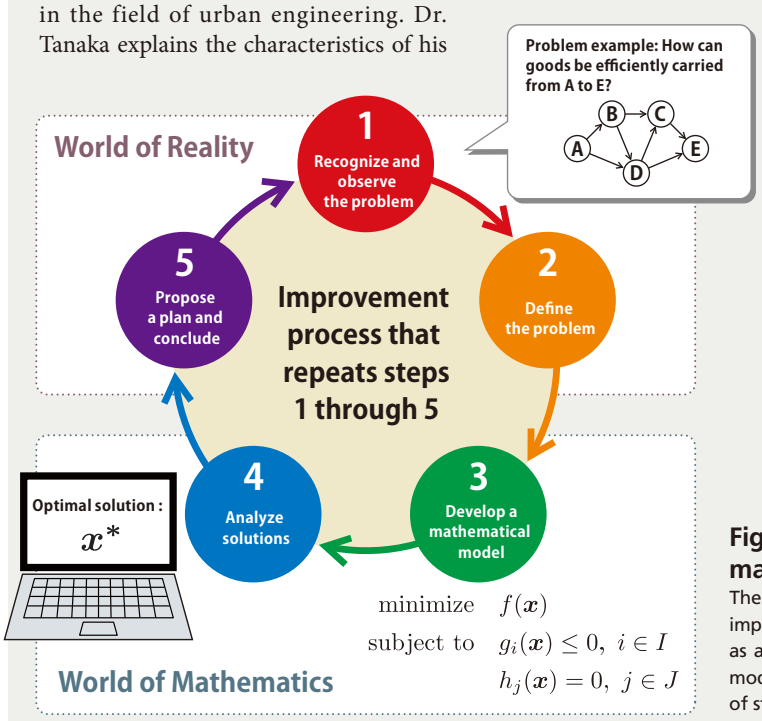

Fig. 1 Process of problem solving using mathematical models

The key point in developing a mathematical model is to focus only on important factors of the target under study, and formulate the situation as a mathematically easy-to-handle problem. The aim of mathematical modeling is to provide useful knowledge for decision-makers. The flow of steps 1 through 5 is repeated as long as time and cost permit.

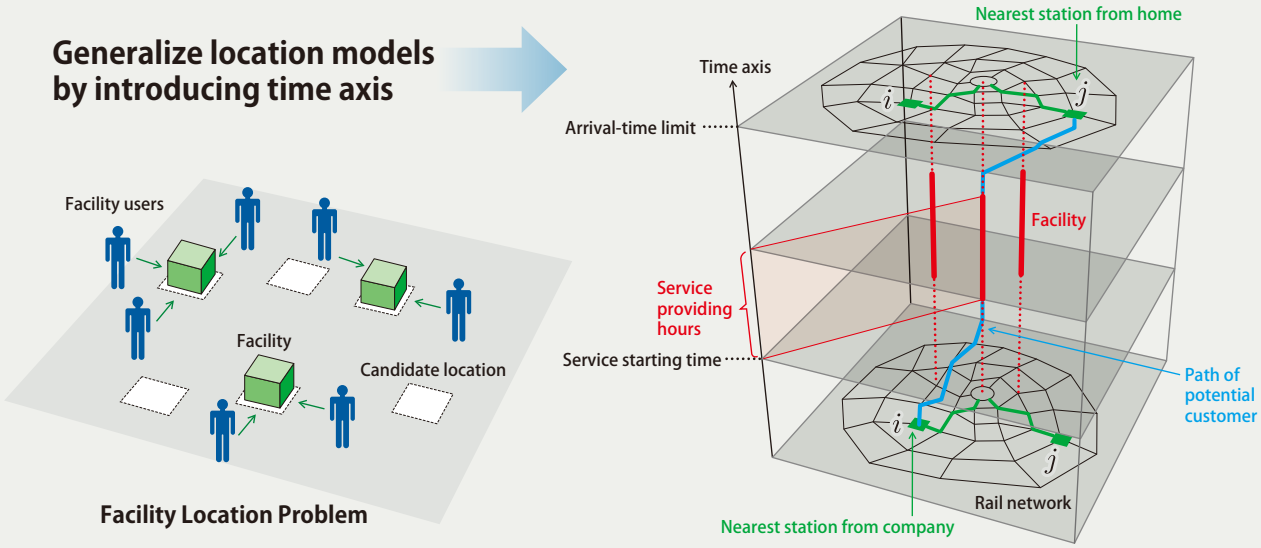

Fig. 2 Extending facility location problems by introducing time axis
Time axis is usually ignored when discussing facility location problems. However, temporal factors are important considerations when evaluating the accessibility of the facility. Fig. 2 generalizes the situation by introducing the temporal dimension into a physical network such as railway, road, and other networks. By describing the movement of people (commuters' behavior to access facilities) and the provision of services at facilities in the spatial-temporal dimension, various types of important location problems can be considered. This approach is aimed at building a general framework that can be applied to a wide variety of situations.

the number of commuters who can attend classes for three hours after leaving their workplaces and return home by 23:00

"But this attempt was not without a problem. Compared with merely locating the facility, inclusion of the time axis involves an incomparably larger amount of information to be handled. While a variety of solvers (software programs) are already available to solve mathematical optimization problems, even the latest solvers are unable to handle such large data volume due to inclusion of the time axis. To tackle this challenge, not only did I devise mathematically tractable models but also designed a special algorithm that exploits the structure of the proposed model," Dr. Tanaka adds.

Assuming that class start times can be chosen from candidate set with every 10 min from 17:00 and 20:00 and only one location is selected in Tokyo metropolitan area, it was found optimal to locate the graduate school near Shinjuku station and start the classes at 7:10 p.m. The second and lower choices were Shibuya, Omotesando, Harajuku and Yoyogi in that order, which confirms our intuition. Interesting results were obtained when the number of facilities was increased to two or more. Let's look at a case of two facilities. If the class starting time can be set independently for each facility, it was found optimal to locate schools in Shinjuku and Aoyama-itchome and start at 7:30 and 7:00 p.m., respectively. In the case of starting classes at the same time, the optimal result was to locate schools in Jimbocho and Kikuna (Yokohama) and start at 7:10.

He continues, "If it's possible to set class starting times independently for each facility, it was found advantageous to locate several facilities simultaneously in Tokyo's city center and stagger starting times. On the other hand, if classes need to be started at the same time for all facilities, it was found better to locate facilities not only in the Tokyo city center but also in residential areas not far from service beneficiaries' homes. Optimal solutions thus vary widely according to the rules to operate facilities. As this example suggests, mathematical approaches can often provide rational, effective solutions, which cannot be easily found by intuition and experience. I think it's the fascination and power of mathematical modeling."

Wishing to present generic models useful for various situations in our lives

Dr. Tanaka mentions "the location and scheduling problem of the graduate school for after-work commuters is just one of the many instances with which the proposed dynamic location problem can be dealt." The true goal is to create generic models applicable to a variety of situations.

He continues "but this particular model alone can be applied to a wide range of subjects, such as sports clubs, movie theaters, concert and other event venues, by changing the way users drop in at facilities, the rules to operate facilities and other conditions. In addition, this model can also be used to wider situations where decision makers review and improve operating hours of services at existing facilities such as libraries and nursery schools. In short, my ultimate aim is to present frameworks for analysis by creating generic models," Dr. Tanaka stresses. This is why his research themes range widely.

For instance, Dr. Tanaka is recently engaged in a joint research theme on designing safe walking routes from school to home for elementary school children by making them walk together as a group. This study aims to minimize the sum of the distance each child has to walk alone while also trying to shorten all students' total distance of travels between school and home so that they are not involved in accidents or incidents on their way home. As a result, it became possible to reduce the sum of the distance that each student must walk alone to about 60% while keeping the total distance traveled by all the students to an increase of less than 1%. Recently, this research result was published online in an international journal of high reputation.

Some of Dr. Tanaka's projects underway are: energy-saving urban planning by considering users' transportation model choices; urban infrastructure maintenance and management models focused on aging facilities; and location problems for emergency evacuation facilities to prepare against volcanic eruptions. Inspired by needs from real-world situations such as mentioned above, he develops new mathematical models and attempt to present concrete solutions to each problem.

"The use of mathematical approaches can lead us to unexpected discoveries, which is useful for building a better society. I'm highly motivated to continue working hard so that I can develop and deliver impactful research results to society," Dr. Tanaka thus concludes with bright eyes.

(Reporter & text writer : Madoka Tainaka)

Encounter with administration engineering led me to follow a researcher's career.

Dr. Tanaka says as a child he liked playing amid nature and was extremely inquisitive. However, a dream of becoming a researcher never occurred to the boy. What drastically changed the course of his life was an encounter with administration engineering as a field of research. Approaching highly complex social phenomena, administration engineering aims to solve problems by developing mathematical models and offering concrete solutions for practical problems. Dr. Tanaka explains that this discipline is appealing partly because it has the powerfulness of making specific solutions to real-world problems, something which is common to engineering, and partly because it offers scientific excitement common to physics which describes natural phenomena by simple laws.

What was your childhood like?

I was born in Musashino City of Tokyo, where Nogawa Park, Koganei Park and Inokashira Park were found within several kilometers from my home. On holidays and during summer vacations, my father often drove a car to take me to nature-rich destinations like Yamanashi and Nagano prefectures, which also helped make me an outdoors-oriented boy. Insect hunting was my favorite pursuit, which I used to enjoy with my friends. I was particularly fond of stag beetles. I was also interested in stars and constellations. I remember I was too excited to sleep at night when thinking about the end of the universe (Laughter). All in all, I was a natural science freak throughout the elementary and junior high school days.

In the meantime, I had learned to play the piano in my childhood. During my junior high school days, I even learned under a music college teacher, wishing to advance to a music college. However, I quit piano lessons halfway after hesitating to decide which way to go.

Under such circumstances, I went to a local metropolitan high school. It was around that time that I was awakened to the fun and excitement of mathematics. It was really surprising for me to know that the area of a figure surrounded by a curve can be found by means of a manipulation called integration. Just at that moment, I found mathematics is a really fascinating subject – for the first time in my life. Looking back at myself, I seem to have had the inborn sensitivity to appreciate the fun of natural sciences and mathematics. But it doesn't necessarily mean I got good grades in these subjects (Laughter).

That's why you chose an engineering course rather than biology upon entering the university?

Well, at Keio University, I chose the Department of Administration Engineering simply because it appeared somewhat interesting due to the diversity of areas it covers, such as humans, urban planning and social problems. Once class studies actually began, I found the approach used in administration engineering very interesting as it expresses social problems, human behaviors and other complex and "soft" targets mathematically and sheds light on their underlying structures. In those days, I was still interested in physics due to its ability to describe phenomena in the world in terms of simple laws. But after receiving class lectures, I came to realize that administration engineering could also use the similar approach in dealing with real-world problems. I was lucky in that sense.

Did you make up your mind to choose a researcher's career when you joined the Department of Administration Engineering?

No. My future as a researcher never occurred to me in those days. What's more, I was not so serious about learning until the end of the third year. In fact, I was enjoying a student life, doing a side job as a lecturer for a cram school, engaging in basketball, badminton and outdoor circle activities.

I was awakened to the fun of learning only as a fourth-year student, when joining the lab of Professor Osamu Kurita (now professor at the Department of Administration Engineering). The way Prof. Kurita talked to us was impressive. Particularly, his powerful analysis of various social problems using his wealth of knowledge as well as mathematical models was overwhelming. I was compelled to study under this professor. Even now I am still under the great influence of Prof. Kurita's research style – mathematically approaching targets like urban and regional problems that have spatial structures.

But there were some tough aspects in my research life. It was because our lab had the policy of emphasizing the process in which students need to find their own research themes. As a student barely entering a research life, I had many difficulties. I had a hard time setting the theme through trial and error but somehow developed a model from zero. This hard-earned experience was the origin of my career as a researcher, which remains a fond memory even today.

In reality, what structures to focus on varies according to the

Modeling of social problems is truly exciting. I'd like to develop and deliver models of my own.

Ken-ichi Tanaka

Dr. Ken-ichi Tanaka was born in Tokyo, Japan. His specialties are operations research and social systems engineering. After graduating from Keio University Department of Administration Engineering, Faculty of Science and Technology in 2000, he completed the master's course at Keio University Graduate School of Science and Technology in 2002, then completed the doctoral course at the same graduate school in 2005 (Dr. Eng.). He became a research associate at Tokyo University of Science Department of Management Science, the Faculty of Engineering. Then he served as an assistant professor for the Department of Systems Engineering and then for the Department of Informatics at The University of Electro-Communications. In April 2014, he became an assistant professor at Keio University Department of Administration Engineering, Faculty of Science and Technology. In April 2016, he was promoted to the current position as an associate professor of the same department.

individual researcher. As such, the work of modeling inevitably involves the person's subjectivity. No wonder modeling is often referred to as "art & science." To put it another way, the fun of modeling lies in that each completed model contains some artistic elements that reflect the creator's view of the world. Given that human or social problems are not governed by strict laws as in the world of physics, coexistence of multiple, dissimilar models is acceptable. For me, this was another intriguing aspect of this discipline.

For a while during my master course years, I was at a loss whether I should find employment in the real world or not. But I finally decided to continue research work and enrolled in the doctoral course, remaining under the guidance of Prof. Kurita.

After graduation from Keio, what experiences did you acquire?

After completing the doctoral course in March 2005, I became a research associate at Tokyo University of Science (TUS) in April. Then, in October 2008, I moved to The University of Electro-Communications (UEC). The years with UEC were when I tackled research themes that constitute the cores of my current work. Indeed, new ideas for research I conceived then turned to be a great asset for what I am doing now.

After five and a half years of teaching and research activities at UEC, I returned to Keio in 2014.

What is the current organization of your lab?

Established only three years ago, my lab has a modest number of member students: two master-course first year and five undergraduate students. Our policy here is to allow the students to proactively address themes they have found interesting. Naturally, their research themes range very widely, from a problem for ranking sports teams to mathematical analysis of cityscapes. When it comes to themes brought in by students, it is often the case that I also need to join them and rack our brains together, which in turn is another opportunity for me to learn anew and can lead to new discoveries.

How do you spend your days off?

My family consists of four members – a son who is an elementary school second grader, a daughter turning two years of age soon, my wife and myself. Going to aquariums and museums together and making trips are pleasant refreshers. My family is a source of my power.

Especially, my wife is a good adviser for me. She often offers useful advice on my new research themes. If I fail to make my wife understand my points, my research work is bound to go nowhere (Laughter). Don't you think so?

What do you think are the merits of Keio University?

I'd like to point out the fact that both the teaching staff and students maintain a strong attachment to the Keio organization. It's wonderful to find everyone always aware of and practicing the calls: "Keio should deliver impactful research results to the world" and "What should be done to make Keio an even better organization?"

Speaking of the Faculty of Science and Technology overall, it has an atmosphere of supporting young people. The whole faculty is willing to support young researchers in terms of research funds and opportunities for studying overseas. The strong feeling of unity and identity is the source of strength for Keio.

◎ Some words from students . . . ◎

● Whatever questions we ask, Dr. Tanaka always responds sincerely and kindly with easy-to-understand answers. He is a really good teacher. Dr. Tanaka's scope of knowledge is extremely wide, meaning he has many topics to talk about. What we can learn from Dr. Tanaka seems endless.

(Reporter & text writer : Madoka Tainaka)

For the full text of this interview
http://www.st.keio.ac.jp/kyurizukai

Ken-ichi Tanaka's ON and OFF time

Here are some of the shots showing my ON and OFF times from my student years through the period as a teacher, as well as my private life with family.

Presentation at international conference

This photo was taken in 2003 at an international conference, when I made a presentation for the first time in English. Although I can prepare for my presentations, it's unpredictable to know what questions the audience may raise until I finish the presentation. So this keeps me tense until everything is over. Making presentations in English is now common for me, but I still clearly remember that first experience, when I was nervous until my presentation came to an end.

Awarding ceremony of OR Society of Japan

This photo shows me being honored with the Best Paper of the year by the Operations Research Society of Japan in 2012. By lucky coincidence, the person who bestowed the award was Prof. Takeshi Koshizuka who was the mentor for my PhD supervisor Prof. Osamu Kurita during his undergraduate/graduate school days. The contents of the theme of the award-winning paper are as outlined in this web magazine. This award encouraged me because this theme is fundamental part of my subsequent research work.

As a graduate student, I often stayed in the lab until late at night to carry on research. Looking back at those days, work seemed to progress at night much better than in the daytime. My lifestyle shifted to a daytime working pattern, but even now I hit upon a new idea for research during the night.

Student days

This is a view I saw from the window of my lab when I was a student. Taken on a fine day, this shot looks toward the inland direction. Mt. Fuji can be seen in the distance. As my lab faced the south, the Landmark Tower could be seen in the direction of downtown Yokohama. For my break time, I used to looking out the window and eating something sweet. My current lab faces the north and I can see a good view of downtown Tokyo.

Photo taken after my students' graduation ceremony

This photo was taken together with five of the first students of my lab after their graduation ceremony. In the first year of my lab, I had a hard time managing it, repeating trial and error. But I'm sure I will remember it later as a fond memory. I'm looking forward to seeing my students to be successful in various fields of society by using the knowledge of OR.

Snapshots of my family

I took this photo when our family visited Kurohime Heights in Nagano Prefecture. My son is checking the insect net to find a grasshopper he caught. In the evening we went out to hunt kuwagata (stag beetles) and successfully caught a few suji-kuwagata and miyama-kuwagata – kinds of stag beetles that are rare to see in downtown areas. Suji-kuwagata is a very beautiful small beetle. It looks like ko-kuwagata but the shape of its mandibles is slightly different from that of ko-kuwagata. The suji-kuwagata is still alive in our home even after more than a year.

These shots were taken when our family visited Tateshina in Nagano Prefecture. The photo in the center shows my son and myself strolling together in the woods with an insect net. In the right photo, a gomadara-kamikiri, a variety of longhorn beetle, is seen moving on the palm of my son. Gomadara-kamikiri is another beautiful insect, which has white dots on its black wings. There are many varieties of longhorn beetles, many of which are unique and handsome. Areas surrounding our Yagami Campus are rich in greenery, where I've found several different varieties of longhorn beetles.

私の本棚
My favorite books

Urban Operations Research

I came across this book during my graduate school days. It is a textbook written by two authors who produced outstanding achievements in wide-ranging fields of OR. It allows the reader to appreciate the excitement of boldly approaching urban and regional problems using mathematical models. Especially noteworthy is the section about stochastic models, which is highly original and tremendously powerful. Here, the authors developed queueing models and various other stochastic models in a spatial context. Though first published in 1981, the appeal and impact of this book remain unchanged even after 35 years.

Introduction to Linear Algebra

First published more than 50 years ago, this book is a masterpiece for learning linear algebra. I became a university teacher in April 2005 and the first subject I became responsible for was "Exercises in Mathematics". Designated as a recommended reference book, this book was the first one I read to prepare for the class. Logical development is very clear – the way a beautiful theorem is proved after several preparatory steps is impressive. Although some part contains advanced topics, I recommend this book to students in all fields of science and technology.

The Structure of Scientific Revolutions; Physics and God (in Japanese)

How have we humans perceived the world around us since the earliest times to this day? And how have incidents, which could urge revolutionary changes to our view of the world, occurred? These themes are very intriguing topics. The first book uses numerous examples to illustrate that the development of science has not been a linear path and that "scientific revolutions" urging drastic paradigm shift have played major roles instead. The second book, "Physics and God," is unique and easy to read. It interprets the development of physics as changes in the image of God. Since I try to describe the world around us using mathematical models, thinking about these problems may not only enjoyable but also part of my research activity.

Network and Discrete Location

Looking overseas, quite a few technical books and textbooks concerning facility location problems have been published to date. Of these, this is my most favorite one. Being a world-renowned researcher leading this field of study, the author has demonstrated an outstanding sense for writing a textbook as well. He emphasizes the process of mathematical modeling, which is a great feature of this book. As it is written in easy-to-understand English, I recommend this book as the first book for students who wish to learn facility location models.

When Least Is Best (Japanese Edition)

After moving to Keio University, I read this book with my lab students as a textbook. This book introduces how optimization problems have been used in the fields of mathematics, physics and engineering to this day since thousands of years ago. It also describes how historically important problems have been addressed by great physicists and mathematicians, such as Fermat, Descartes, Newton, Euler and Lagrange. This book on my shelf is the Japanese translated version. After reading it, I became a fan of the author, who wrote many other wonderful books.

The Museum of Stag Beetles; Brilliant Beetles

Among the insects, beetles having armor-like bodies are particularly numerous in variety and very attractive. Using beautiful and impactful pictures, these two books introduce beetles' uniquely attractive forms that they have acquired over an overwhelmingly long period of time. My son, an elementary school second-grader, is looking forward to meeting these insects on a summer vacation trip.

The appeal of modeling

Ken-ichi Tanaka

Operations research (OR) is a multidisciplinary research area with a wide range of applications. In particular, OR is distinctive in that it aims to solve real-world problems by developing mathematical models. We call this process "modeling."

In modeling, we "extract the problem's intrinsic part only, whereas ignoring other parts." This is because we won't be able to see anything if we leave the complex reality as it is. Then how do you consider a certain part of the reality to be intrinsic? This depends on each person's view of the world. Therefore, it's no exaggeration to say there are as many models as the number of analyzers. Especially, problems concerning people and their society are so complex that they cannot be described with the same strictness as laws of physics. When dealing with complex and "soft" targets, the same problem can be approached from diverse view point. Thus, there are infinite possibilities for modeling each problem. I believe this is the very appeal of disciplines covered by OR and administration engineering.

Recent development in computers, highly efficient algorithms and digital geographic data are collectively paving the way for an environment that will allow us to come up with more concrete solutions to large-scale problems in the real world. Such a situation will demand us to be armed with a sense for modeling problems in mathematically easy-to-handle ways. The importance of modeling is bound to increase in the field of OR.

Importance of this approach is not limited to research alone. "Extracting the intrinsic part of target problems", "Grasping the structural nature of problems", "Finding a common structure among different target problems" … These attitudes will be useful in various ways when solving everyday problems and performing creative works in society. "Emphasis on basic theories" is a tradition our Keio Faculty of Science and Technology has cherished since its establishment. I think "Emphasis on basic theories" mean what I mentioned above. College life is the luxury you can afford only now. This makes it all the more valuable for you to acquire such abilities.

I took the opportunity of this interview to review the path I followed and think about my future. Researchers are often asked, "What themes are you studying?" I usually explain, "I'm studying urban and social problems using mathematics." In a word, my answer would be, "Modeling." I'd like to continue education and research activity in order to develop and deliver attractive models.

Science and Technology **Information**

Science and Technology Information
The 17th KEIO TECHNO-MALL 2016
"Develop Industry-Academia Collaboration and Nurture Dreams"

The KEIO TECHNO-MALL is an annual event to widely disseminate research results from the Keio Faculty and Graduate School of Science and Technology while also serving as a vital venue of encounters for industry-academia collaborations such as joint research and technological transfer. More than 100 demonstration-oriented booths, the largest scale of its kind for Japanese universities, will be featured along with technical seminars and roundtables by researchers. Every year, this event attracts a large number of visitors – from businesses, government/public organizations, other universities, etc.

Date: December 16 (Fri.), 2016 10:00 ~ 18:00
Venue: Tokyo International Forum (Exhibition Hall E2, Basement 2)
Contents: Exhibits of real objects and demonstration-oriented exhibits along with other attractive events
Admission free Prior registration is not required for any event.
For details: www.kll.keio.ac.jp.ktm/

<Talk session events>

"Human brains deceived by the computer – As seen in computer visions and robots"
Guest: Mr. Kenichiro Mogi
Structural features and Japaneseness, beauty and comfort of town planning as seen in the Tokyo Olympic Stadium design
Guest: Mr. Kengo Kuma

Editor's postscript

The Department of Administration Engineering is one of the traditional departments of Keio's Faculty of Science and Technology. But it appeared in this web magazine for the first time in six years. In this issue, we introduced Associate Professor Tanaka's social engineering study. How did you enjoy it? Research endeavors, which approach our human society scientifically, will increase in importance more and more in the future. Through the interview with Dr. Tanaka, I could feel his good personality as well as the favorable atmosphere of his lab, which reflects the tradition of the Keio Faculty of Science and Technology.

(Kenji Kobayashi)

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