Title	Using mathematical models to derive optimal location of facilities and their operating hours : modeling and optimizing social systems
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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

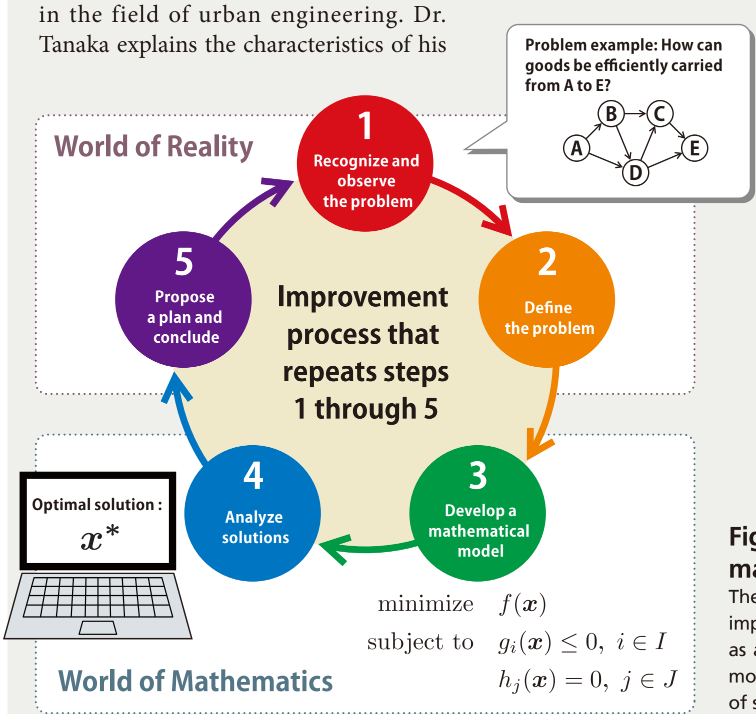

Fig. 1 Process of problem solving using mathematical models

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.

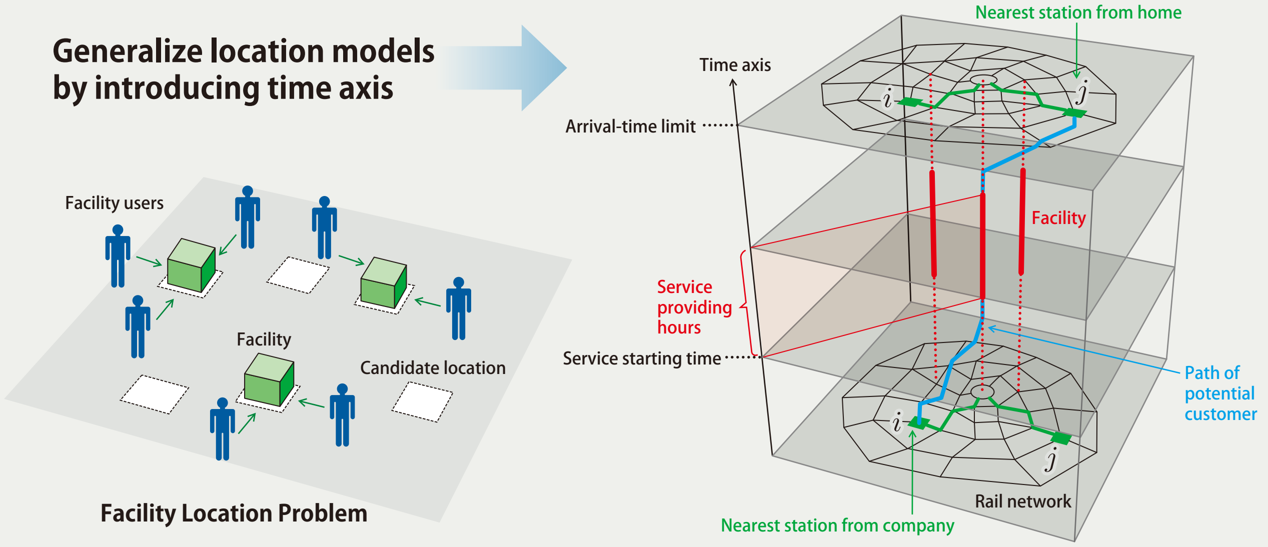

Fig. 2 Extending facility location problems by introducing time axis
Time axis is usually ignored when discussing facility location problems. However, temporal factors are important considerations when evaluating the accessibility of the facility. Fig. 2 generalizes the situation by introducing the temporal 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)