Y. Sadahiro
Editor

cSUR-UT: Library for Sustainable Urban Regeneration 5

Spatial Data Infrastructure for Urban Regeneration

Springer

cSUR-UT Series: Library for Sustainable Urban Regeneration
Volume 5

Series Editor: Shinichiro Ohgaki, Tokyo, Japan

cSUR-UT Series: Library for Sustainable Urban Regeneration

By the process of urban development in the 20th century, characterized by suburban expansion and urban redevelopment, many huge and sophisticated complexes of urban structures have been erected in developed countries. However, with conventional technologies focused on the construction of structures, it has become difficult to keep urban spaces adaptable to environmental constraints and economic, social and cultural changes. In other words, it has become difficult for conventional technologies to meet social demands for the upgrading of social capital in a sustainable manner and for the regeneration of attractive urban space that is not only safe and highly efficient but also conscious of historical, cultural and local identities to guarantee a high quality of life for all. Therefore, what is needed now is the creation of a new discipline that is able to reorganize the existing social capital and the technologies to implement it.

For this purpose, there is a need to go beyond the boundaries of conventional technologies of construction and structural design and to integrate the following technologies:

(1) Technology concerned with environmental and risk management
(2) Technology of conservation and regeneration with due consideration to the local characteristics of existing structures including historical and cultural resources
(3) Technologies of communication, consensus building, plan making and space management to coordinate and integrate the individual activities initiated by various actors of society

Up to now, architecture, civil engineering, and urban engineering in their respective fields have, while dealing with different time-space scales and structures, accumulated cutting-edge knowledge and contributed to the formation of favorable urban spaces. In the past, when emphasis was put on developing new residential areas and constructing new structures, development and advancement of such specialized disciplines were found to be the most effective.

However, current problems confronting urban development can be highlighted by the fact that a set of optimum solutions drawn from the best practices of each discipline is not necessarily the best solution. This is especially true where there are relationships of trade-offs among such issues as human risk and environmental load. In this way, the integration of the above three disciplines is strongly called for.

In order to create new integrated knowledge for sustainable urban regeneration, the Center for Sustainable Urban Regeneration (cSUR), The University of Tokyo, was established in 2003 as a core organization of one of the 21st Century Centers of Excellence Programs funded by the Ministry of Education and Science, Japan, and cSUR has coordinated international research alliances and collaboratively engages with common issues of sustainable urban regeneration.

The cSUR series are edited and published to present the achievements of our collaborative research and new integrated approaches toward sustainable urban regeneration.

Y. Sadahiro (Ed.)

Spatial Data Infrastructure for Urban Regeneration

Springer

Yukio Sadahiro, Ph.D.
Associate Professor
Department of Urban Engineering
The University of Tokyo
7-3-1 Hongo, Bunkyo-ku,
Tokyo 113-8656, Japan

ISSN 1865-8504
ISBN 978-4-431-74096-4 e-ISBN 978-4-431-74097-1

Library of Congress Control Number: 2008923059

Springer is a part of Springer Science+Business Media
springer.com
Printed in Japan

Typesetting: Camera-ready by the editors and authors
Printing and binding: Shinano Inc., Japan

Printed on acid-free paper

Preface

This book represents part of the result of a project undertaken by the Center for Sustainable Urban Regeneration (cSUR). The center was established in 2003 by a research fund titled the 21st Century Center of Excellence (COE) Program provided by the Ministry of Education, Culture, Sports, Science and Technology of Japan. The project leader was Shinichiro Ohgaki, a professor in the Department of Urban Engineering of the University of Tokyo.

cSUR integrates the four specific fields of urban planning, architecture, civil engineering, and environmental engineering with the participation of over a hundred researchers of the university. The objective of the center is to create an integrated approach to, and knowledge for, sustainable urban regeneration based on a global network of researchers and professionals; and to coordinate an international research alliance that consists of leading academic institutions worldwide.

The project was carried out by four research units:

A. Environment Management
B. Urban Stock Management
C. Social Information Management
D. Action Studies

Each unit consisted of smaller subunits. The third unit, which includes the contributors to this book, consisted of three smaller groups:

C-1) The Next Generation Geographic Information System Integrating Human and Social Information
C-2) Decoding and Analysis of Historical and Cultural Information Concerning Urban Space
C-3) Participatory Planning and Urban Space Management Support Systems

This book was primarily written by the members of Group C-1, whose objective was to develop the theory and application of information systems for urban regeneration. These provide a powerful basis for collecting and managing information on both the physical and the social environment, the promotion of public participation, preparation of plans for sustainable development, and assistance in final decision making. However, urban information systems are often developed for a specific purpose such as facility management, transportation planning, disaster management, and so forth. The application of such systems in urban regeneration is not straightforward, because the data and necessary functions for urban regeneration are not present. General urban information systems, on the other hand, are often too large and inefficient. The design of a system suitable for urban regeneration called for exclusive consideration.

To this end, Group C-1 studied information systems for urban regeneration from both the theoretical and empirical viewpoints, and the work has resulted in this publication. This book consequently includes a wide variety of discussions, from the theory to the applications of urban information systems.

Part I focuses on the theoretical aspect of information systems for urban regeneration.

Chapter 1 outlines the urban and regional information infrastructure currently available in Japan. Planning urban regeneration requires much analysis of the urban and regional situation with regard to population distribution, land-use patterns, urban activity, and so forth. Information on a situation is provided in a variety of forms, from paper maps and documents to spatial data and image files in digital format. These are integrated into an urban and regional information infrastructure that can create, manage, analyze, and visualize digital spatial data.

Chapter 2 proposes a new method for constructing three-dimensional spatial data. Such data are essential in urban analysis and simulation. Efficient—and, ideally, automated—data creation is indispensable for quick and on-demand spatial decision making. Two-dimensional maps, which are rather conventional, are used to improve the accuracy and resolution of three-dimensional data. Change detection in three-dimensional data is also discussed.

Part II consists of six chapters covering different aspects of information systems used for urban regeneration.

Chapter 3 discusses new technologies in remote sensing for monitoring the urban environment. Degradation of the physical and social environment is a serious problem in both developed and developing countries. To resolve this issue, the proper management of urban safety and sustainability is essential. New technologies in remote sensing are promising new tools for monitoring the urban environment that include high spatial resolution, hyper-spectral, microwave range, and three-dimensional observations. Chapter 3 describes the theoretical aspects of these technologies, followed by a section on their applications in urban assessment, the monitoring of urban expansion, and the heat island issue.

Chapter 4 proposes a system for visualizing Tokyo historical data. Vested interest in a place is a key to successful public participation in city planning, and this is indispensable in sustainable urban regeneration. One effective way of evoking such interest is to display the local history; people love to see old pictures and maps. In line with this, Chapter 4 proposes an efficient way of communicating history — through GIS-based methods of visualizing historical spatial data. Two systems have been developed, one for fast and smooth visualization of three-dimensional data, and the other for creating movies from historical data. The former is an extension of a commercial product called DragonFly, whereas the other is a fully original development of this COE project. They both have their own merits and are complementary to each other.

Chapter 5 discusses traffic control for a sustainable urban environment. Traffic congestion is obviously one of the major problems in both developed and developing countries. To help resolve this serious issue, new information technologies such as Advanced Vehicle Identification (AVI), Electronic Toll Collection (ETC), and the Vehicle Information and Communication System (VICS) have been developed. Each has already proved useful in relieving traffic congestion; however, they are most effective when working as an integrated system. To this end, Chapter 5 proposes a method of integrating the data obtained from individual systems. Case studies are used to evaluate the results. This chapter also proposes a new traffic management system that fully utilizes the integrated data.

Chapter 6 proposes a new urban planning and regeneration decision-making support system. The system simulates urban area micro-scale fire spread caused by earthquake, taking building conditions into account. The result is evaluated in terms of environmental vulnerability, especially in densely populated areas consisting of wooden houses and narrow access roads. Evaluation measures are presented to community members to enable them to deepen their understanding of their urban environment, and this leads to discussion on old-town reconstruction. The system works interactively toward an integrated plan for urban regeneration.

Chapter 7 discusses the utilization in urban regeneration of spatiotemporal data representing travel behavior. Transportation planning requires an accurate understanding of individual travel activity. Many options are available to capture human travel behavior, from traditional methods such as field surveys to more sophisticated ones using a global positioning system (GPS) and integrated circuit (IC) tags. Travel, however, is an activity undertaken by an individual. Consequently, it is necessary to identify the activity that motivates travel behavior. Chapter 7 describes human activity and travel behavior with respect to transportation management. The methods of data collection and analysis are discussed extensively, followed by a consideration of their applications to transportation management. Emphasis is placed on human activity in cyberspace, an issue that has recently emerged following growth in use of the Internet.

Chapter 8 describes the environmental design for urban regeneration in relation to human behavior in space. The need for space is constantly changing. Unfortunately, people do not change according to the environment; they only adapt to it. Consequently, spaces designed for specific purposes and functions are not appropriate to urban regeneration. Spaces should accommodate the wide variety of human behavior inherent in the diversity of humanity and should permit coexistence. Chapter 8 discusses the relationship between spaces and human behavior in numerous situations. The desirable properties of space in urban regeneration are considered experimentally from the psychological point of view.

Yukio Sadahiro
Department of Urban Engineering
The University of Tokyo

1. Urban and Regional Information Infrastructure **1**
Yasushi Asami

1.1 Introduction.. 1
1.2 Development of Urban and Regional Information Infrastructure..... 2
1.3 Contents of Urban and Regional Information.................................. 4
1.3.1 Range of Urban and Regional Information 4
1.3.2 Integrated GIS 5
1.4 Application of Information Infrastructure to Assist Planning Urban Regeneration: Hedonic Approach.. 6
1.5 Application of Information Infrastructure to Assist Planning Urban Regeneration: Simulation Approach.. 10
1.6 Conclusion 13
References 13

2. New Urban Information Infrastructure: 3-D and Dynamic Information **15**
Ryosuke Shibasaki

2.1 Introduction.. 15
2.2 STARIMAGER / TLS (Three-Line Sensor): A New High-Resolution Sensor for Urban Mapping 16
2.3 Methodology for Automated Generation of 3-D Building Data..... 17
2.4 Generation of Approximated 3-D Building Data............................ 17
2.5 Modification of Horizontal Building Shapes.................................. 17

2.6 Modification of a Building in the Height Direction 20
2.7 Versatile Roof Modeling 21
2.8 Experiment with 3-D Spatial Data Development 21
2.8.1 Results 22
2.8.2 Discussion.. 23
2.8.3 Summary of 3-D Spatial Data Development 24
2.9 Monitoring Dynamic Changes of Urban Areas 24
2.10 Model-Based Change Detection 25
2.10.1 Model-Based Change Detection with Shadow Area Removal 28
2.11 Change Detection Experiment 30
2.11.1 Study Area 31
2.11.2 Data.. 31
2.11.3 Results 33
2.11.4 Discussion... 36
2.12 Summary: 3-D Spatial Urban Data and Their Dynamic Revision 37
References 37

3. Monitoring of Urban Infrastructure and Environment by Use of Remote Sensing **41**
Yoshifumi Yasuoka

3.1 Introduction.. 41
3.2 Principles of Remote Sensing 42
3.2.1 Spectral Characteristics 42
3.2.2 Remote Sensor.. 42
3.3 New Technical Developments in Remote Sensing 43
3.3.1 High-Spatial Resolution Observation 43
3.3.2 Hyper-Spectral Observation 44
3.3.3 Microwave Range Observation 44
3.3.4 Three-Dimensional Observation.. 45
3.4 Applications of Remote Sensing to Urban Assessment................. 45
3.4.1 Assessment of Urban 3-D Landscape.................................... 46
3.4.2 Monitoring of Urban Expansion with Satellite Images 47
3.4.3 Monitoring of Heat Island 49
3.5 Conclusions 51
References 51

4. Visualization of Historical Data in Tokyo **53**
Yukio Sadahiro, Eihan Shimizu and Takashi Fuse

4.1 Introduction.. 53

4.2 Data Creation 54
4.2.1 Topographic Data 55
4.2.2 Land use Data 57
4.2.3 Building Data (Micro Scale) 59
4.2.4 Demographic Data 62
4.3 System development 1: DragonFly 63
4.4 System development 2: Hongo History 67
4.5 Conclusion 72
References 72

5. Urban Transport Data Fusion and Advanced Traffic Management for Sustainable Mobility 75
Masao Kuwahara and Shinji Tanaka

5.1 Overview 75
5.2 Data Variety and Its Characteristics 76
5.2.1 Vehicle Detectors 76
5.2.2 Probe Vehicles 78
5.2.3 Automatic Vehicle Identification (AVI) 79
5.2.4 Electronic Toll Collection (ETC) 80
5.2.5 Image Sensors 81
5.2.6 Measurement Vehicle 82
5.3 Framework to Combine Various Data Sources for Urban Transport Management 83
5.3.1 Introduction 83
5.3.2 Data Storage Layer 84
5.3.3 Data Processing and Handling Layer 84
5.3.4 Application Layer 85
5.3.5 Usage for Urban Transport Management 85
5.4 Case Studies 87
5.4.1 Bus Travel Time Analysis Using Probe Data 87
5.4.2 Data Fusion 90
5.5 Advanced Urban Transport Management for Sustainable Mobility 94
5.5.1 Travel Time Prediction 94
5.5.2 Simulation 96
5.5.3 Demand Spread Over Time 98

6. New Technologies in Urban Regeneration – Community-Based Urban Planning Support System Enhanced by Urban Vulnerability Assessment Technologies 103
Takaaki Kato

6.1 Introduction 103
6.2 Urban Earthquake Disaster Simulations and Urban Vulnerability Assessment Technologies (UVAT) 105
6.2.1 History of Simulations and UVAT 105
6.2.2 The Present Situation Around Simulations and UVAT......... 107
6.3 Planning Support System for Urban Earthquake Disaster Mitigation: BOUSAI-PSS 111
6.3.1 Overview 111
6.3.2 Postulated Development of BOUSAI-PSS 112
6.3.3 Structure of BOUSAI-PSS 112
6.3.4 Expected Situations for Use and for Users 113
6.3.5 Significance of Introducing an Urban Improvement Planning Support System for Earthquake Disaster Mitigation 114
6.3.6 Subsystem of BOUSAI-PSS... 115
6.4 Community-Based Urban Planning with the PSS in Japan 121
6.4.1 Topics and Issues on Community-Based Design with BOUSAI-PSS 121
6.4.2 Perspective on the Application of BOUSAI-PSS to a Community-Based Planning Process.................................... 124
6.5 Conclusion 125
References 126

7. Application of Information on Human Activity-Travel Behavior in Urban Space and Time in the Information Age **127**
Nobuaki Ohmori

7.1 Introduction.. 127
7.2 Information on Human Activity-Travel Behavior to Evaluate Policy Measures for Sustainable Urban Regeneration............................ 129
7.2.1 Travel and Activities 130
7.2.2 Space-Time Constraints.. 131
7.2.3 Telecommunications.. 132
7.2.4 Positive Utility of Travel and Activities While Traveling..... 134
7.3 Survey Method for Collecting Information on Human Activity-Travel Behavior 134
7.3.1 Conventional Method 134
7.3.2 New Technology 135
7.4 Analysis and Application of Information on Human Activity-Travel Behavior 137
7.4.1 Demand Analysis... 137
7.4.2 Evaluation of Space-Time Accessibility 137
7.4.3 Simulation of Household Activity-Travel Patterns 138

7.5 Conclusions 140
References 141

8. The Behavioral Basis of Environmental Design for Human Beings **147**
Kazuhiko Nishide

8.1 Introduction 147
8.2 What is Human Environment? 148
8.3 How Do People Perceive This Environment? 148
8.4 What Is an Environment for Human Beings? 150
8.5 Human Dimension and Hidden Dimension 151
8.6 Personal Space 151
8.7 Meaning of Distance 152
8.8 The Distance and the Angle of Orientation Between People 154
8.9 Experiment on Personal Space 156
8.10 Interpersonal Distance 157
8.11 Space Formation of People 158
8.12 Reference Domains of Demonstrative Pronouns as an Aspect of Personal Space 160
8.13 Three-Dimensional Human Scale 163
8.14 Perception of Dimensions and Room Volume in the Room 165
References 166

1. Urban and Regional Information Infrastructure

Yasushi Asami

Department of Urban Engineering, The University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

1.1 Introduction

Planning for urban regeneration should involve many analyses and estimates with regard to the urban and regional situation. These should consider issues such as population, land use, urban activity, market tendency, physical environment, and so forth within possible regeneration strategies. Future population estimation is indispensable in developing a general master plan for a city. An understanding of the current land use pattern is essential in determining new zoning regulations. The rise and decline tendency of industrial activity is a key issue in deciding the direction of urban regeneration. Local as well as global market trends are further important factors. All these analyses require a variety of urban and regional databases, together with an efficient system that can handle such information properly. This whole system is the urban and regional information infrastructure.

The system can be classified into two parts: the database, and the handling system.

The database may consist of a variety of files. One kind of data is spatial, consisting of location and attribute information. Location can be the latitude and longitude of a reference point, or a set of such points indicating the boundary of a reference area. Another kind of data is nonspatial, consisting only of attribute information, and is not linked with spatial information. Attributes can be survey results such as population figures, land use ratios, total sales amounts, or land price lists. Moreover, spatial data can be classified into two groups: GIS-ready data and non-GIS-ready data.

Typically, non-GIS-ready data include the area name information. For example, figures on the population of Tokyo are spatial data, but these are not GIS-ready. If the boundary line data of Tokyo are added, then they become GIS-ready data. Most survey data may fall into this category.

The handling system can be a personal computer (PC) with normal spreadsheet software such as MS Excel. The software can be a more sophisticated statistical package, or it can be a PC with GIS software. GIS software is a powerful tool for handling spatial relationships. When GIS software is used for integrating the urban and regional information, adding or linking the location information to non-GIS-ready spatial data and non-spatial data to make them GIS-ready is indispensable. For this purpose, the location information as the administrative boundary data is prepared by the Geographical Survey Institute in Japan. In the following section, it is implied that the urban and regional information infrastructure involves a system with at least GIS-like software installed so that spatial data can be appropriately handled.

In this chapter, the current development and content of urban and regional information infrastructure in Japan are described, together with the possible applications of such infrastructure in evaluating urban regeneration projects and policies.

1.2 Development of Urban and Regional Information Infrastructure

Urban and regional information infrastructure has been installed and operated in many municipalities in Japan since the end of the 20th century. One notable information infrastructure is that devised for urban planning. An epoch-making event started with a 1975–1981 Ministry of Construction project to develop an urban information system (UIS) in which urban digital databases were developed for the cities of Nishinomiya and Kita-Kyushu. This was a pioneering step to introduce GIS to municipalities.
A second phase of this project, UIS II, started in 1985 as an urban policy information system (Urban Information Study Group 1987). This system consists of:

1. a municipal administration information system that does not involve map information;
2. a zonal information system based on a 1:2,500 scale city planning map which includes systems for road network management, urban facilities planning, disaster prevention management, land use planning, taxation management, and other facets; and

3. a detailed urban area information system, i.e., a mapping system with large-scale map data.

After this move, several large municipalities attempted to introduce GIS to assist in their urban planning. The system typically consisted of a mainframe computer equipped with digitized data. The introduction of such a system involved much expense, and maintenance of the database was also very costly. Consequently, the cost-benefit of such a system was not sufficiently apparent to induce many municipalities to introduce it.

The development of information technology resulted in a cost reduction, and a movement towards digital data usage in administrative work contributed to a further lowering of the expense, accordingly there was less hesitation in introducing such a system. In the 1990s, the number of municipalities adopting a GIS with an urban information database increased dramatically. Nowadays, most major municipalities in Japan have already installed a GIS or are using a GIS in administrative affairs, although the system does not yet prevail in small municipalities.

The Tokyo Metropolitan Government, for example, is equipped with a GIS for urban planning based on a city planning database. This is derived from a survey conducted every five years or so corresponding to the renewal period of Tokyo city plans. The database contains information such as city planning regulations in the form of land use zones, designated floor area and building coverage ratios, setback regulations, minimum lot size, height limitations and fire prevention regulations. Also entered are details of the road network, parkland and green open space, current land use, and number of floors, together with the building structure and use. All these data are prepared in GIS-ready format. Digital maps, which include basic map data ready for GIS, are constructed by the Geographical Survey Institute. These two databases are fundamental spatial data for urban regeneration signifying the physical environment.

Quantitative analysis became very important for measuring the effects of urban policy in the years following 2000. From the 1990s, project and policy impact analysis has tended to be considered a necessity when implementing public works and making regulations and urban projects are no exception. Cost-benefit analyses became requirements prior to adopting publicly subsidized urban projects, and manuals for such procedures have been published in many fields.

One notable manual is the procedure of cost-benefit analysis for redevelopment projects (Committee for Estimation of Effects of Urban Redevelopment Projects 2003). In these guidelines, the total cost is calculated as the total present value of development, land acquisition, maintenance, and removal costs after the provision of facilities. Benefit is calculated as the total present value of increase in revenue and the benefit of improvement in facilities through hedonic analyses. To ease the comparison of many projects in different areas and times, parameters such as discount rate and hypothetical area of influence are determined in the manual.

A movement towards regulation reform accelerated the tendency to utilize cost-benefit analysis for regulations as well. It has been said that when introducing a new regulation, quantitative impact assessment is strongly recommended. The Council for Regulatory Reform in 2001–2004, and the Council for the Promotion of Regulatory Reform in 2004–2007 established in the Cabinet Office, are the major organizations to promote regulation reform.

The main aim of urban and regional policy is to ensure their objectivity. With this in mind, the council recommended that a quantitative validation be made for important policies. One notable example is related to central city invigoration. The Central City Invigoration Law and the City Planning Law were amended in 2006 to enhance the regulations for developing large facilities such as suburban shopping centers. The objective of intensifying the regulations is to ensure the erection of sound urban structures, but there was a concern about its abuse to protect the established interests of shopkeepers. The council recommended the introduction of an objective validation procedure to ensure the prevention of such abuse.

Another notable example is related to landscape conservation regulation. In 2004, a package of landscape laws was enacted to reinforce the development regulation to protect and improve the townscape. The council recommended introducing a procedure to ensure that the regulation reinforcement would yield a measurable social benefit. As these examples imply, quantitative validation will become more important in the future, and therefore all urban regeneration measures will become subject to such validation.

1.3 Contents of Urban and Regional Information

1.3.1 Range of Urban and Regional Information

Urban and regional information is not limited to data collected from the basic city planning survey. Another essential group of data is that related to economic aspects. Land price, rent level, earnings of businesses, and so on, are all important aspects to permit a grasp on urban activities in the area. They are also used to evaluate the residential environment and urban policies, as will be described later.

Social data are also an important component of urban and regional information. They includes the social status of residents, property rights situations, and so on. In particular, the property rights situation is crucial to understanding the degree of difficulty in achieving a consensus for land readjustment measures or redevelopment projects.

Environmental data regarding natural environment conditions, the nature of the underlying rock and the soil condition, pollution, and related factors are also essential factors in planning urban regeneration.

To facilitate the Center for Sustainable Urban Regeneration, which is a Center of Excellence (COE) activity, the Center for Spatial Information Science at the University of Tokyo provides GIS-ready spatial data for collaborative researchers. The data extends from national survey data (such as the Population Census, Housing and Land Survey, and Establishment and Enterprise Census) to digital maps made by the Geographical Survey Institute, private map companies, and residential maps. This collection covers only a limited scope when compared to the ideal coverage described above.

1.3.2 Integrated GIS

Urban and regional information infrastructure data should be easily handled on a unified base map in a GIS. Integrated GIS for municipalities is a major aim in this area that is still under development. There are several difficulties in attaining this integration.

Each administrative data item is collected for a specific purpose; consequently, the relevant specifications for data preparation are not readily met for an integrated system. Some data are prepared to a very fine degree of precision, yet other information is coarsely defined. The overlay of these data yields results with only limited precision. For example, spatial data for city planning is usually prepared with sufficient accuracy for a 1:2,500 scale map, while road management requires detail adequate to match a 1:500 scale map. However, spatial data for agricultural land use may be prepared to the precision required for a 1:25,000 scale map. Theoretically, all the data can be prepared with the finest precision, however in practice such survey detail may be difficult to acquire due to the tremendous cost in surveying, or unobtainable due to vagueness of the object itself. For example, a precise boundary may not be available for two adjacent lots in Japan.

The frequency of updating data varies depending upon its purpose. The population census is conducted every five years, while the official land price is updated every year and data for commencement of building construction is collected every month. Moreover, there are always time lags in updating databases. Typically, a basic city survey for planning is conducted every five years, but the timing of the update does not necessarily coincide with that of the census. In the case of the population census, the time lag is about two years.

When urban and regional information infrastructure is used, the accuracy of data in terms of time differs from layer to layer. One layer may signify data derived five years ago, while another represents that derived one month ago. Again, theoretically, all the data can be updated with the shortest time interval; however, in practice, this would be extremely expensive for some surveys. One can easily appreciate the impracticality of conducting a population census every month, for example.

Recently, it has become increasingly necessary to handle personal data with special caution. For example, data related to privacy cannot be used without the consent of the individual. Typically, data collected for one purpose cannot be used for other purposes without a respondent's consent. This implies that some data acquired in one department cannot be used in another due to a violation of the original statement of purpose in the data collection. A similar situation may occur due to limitations imposed by copyright covering the spatial data.

1.4 Application of Information Infrastructure to Assist Planning Urban Regeneration: Hedonic Approach

A number of papers have been published recently that have attempted to evaluate some factors of residential environment quantitatively in monetary terms, and which can be used to judge the effect of proposed urban regeneration projects. For example, research in evaluating monetary values of factors in residential environment includes work by Kanemoto, Nakamura and Yazawa (1989), Gao and Asami (2001), Geoghegan (2002), Yamaga, Nakagawa and Saito (2002), Morancho (2003), Gao and Asami (2007a, b), and Takuma (2007). In particular, Gao and Asami (2007a) analyze the influence of lot size and shape on the externalities of local environments and apply the results to examine in detail a situation involving the broadening of a road in a densely built-up residential block. Gao and Asami (2007b) propose a standardized landscape survey, extracting critical evaluation factors with a principal component analysis, and then identify the effect of these factors on land prices with hedonic pricing models.

The basic tool for these analyses is the hedonic approach. Typically, land price or its price per unit area is regressed with many variables signifying factors of potential influence. In the case of Gao and Asami (2007a), the variables include actual floor area ratio, travel time to the railway station and the time from the nearest railway station to the CBD by train, building age, width of road frontage and frontage of the lot, building quality in the neighborhood, sunshine duration, local abundance of trees, and so on. This approach is based on the capitalization hypothesis that the land price reflects the environmental effect upon a specific residential lot.

As is seen from the list of variables used in the analysis, urban and regional information infrastructure has to include lot land price and many indices measuring factors that influence the price, as well as factors of interest whose influence has to be analyzed to evaluate urban regeneration projects. In the study of Gao and Asami (2007a), data such as sunshine duration and ventilation (although the latter was not found to be significant) were calculated using three-dimensional CAD data for buildings. Recently, three-dimensional building data has been provided by private companies utilizing laser scanner technology. This may change the research base, and analyses of three-dimensional space for city planning may soon become much more popular in this field.

To illustrate the hedonic approach, a part of Gao and Asami (2007b) is summarized in the following text. The main purpose of their paper is to determine the economic value of landscape in residential areas. The analysis is done in three steps. The first step is the acquisition of appropriate data closely related to the urban and regional information infrastructure. The data are drawn from the Weekly Housing Information (Recruit, Co. Ltd.), which provides information on houses and land for sale. The sample sites are limited to transactions involving vacant lots in nine wards of Tokyo. The sample number is 272. The original data include the property prices at the sample sites. Since an actual transaction price is difficult to obtain, the final list prices are used in the analysis.

In addition to price, the original data include detailed information on the sample lots such as their size, shape, the width and direction of fronting roads (called 'front road'), accessibility to public transport, the environmental attributes of the neighborhood, and the indices of "chome" (the Japanese name for a city block, which usually constitutes the smallest unit of a census) including building density, gross floor-to-area ratio, population density, and the proportion of wooden structure buildings.

The original database did not contain any important indices of the landscape condition for the sample lots. To complement the data, an on-site landscape survey was conducted based on a qualitative evaluation system (Arai, 2001). To be more specific, an 11-factor evaluation system was used, as shown in Table.1.1 to evaluate the local sample site townscape and street setting. The “A” factors are indicators of neighborhoods, while “B” factors are those of streets. Every factor consists of several options, each representing a points rating of 1, 0, +1, +2, etc. These produce 11 factor ratings.

Table.1.1. Factors for evaluating urban landscapes

Factors	Items	Point
A1: Continuity of external walls (+1, 0, 1)		
	Walls are well-aligned along streets to a high degree	+1
	Walls are well-aligned along streets to an average degree	0
	Walls along streets are not continuous	1
A2: Conformity of colors and materials (+1, 0, 1)		
	Colors and materials of buildings are in harmony to a high degree	+1
	Colors and materials of buildings are in harmony to an average degree	0
	Colors and materials of buildings are not in harmony	1
A3: Compatibility of building styles (+1, 0, 1)		
	Building styles share common features to a high degree	+1
	Building styles share some kind of common features	0
	Building styles have little in common	1
A4: Beauty of skylines formed by buildings (+3, +2, +1, 0, 1)		
	Building heights are orderly and under control	+1
	Roof shapes are similar	+1
	Rhythms of skylines are beautiful	+1
	Silhouette of buildings distinctively lacks order	1
A5: Openness and scale of buildings (+1, 0, 1, 2)		
	Spaces formed by buildings are open and comfortable	+1
	Street spaces are narrow and compressed	1
	Open spaces are dull and without change	1
A6: Visually aesthetic and continuous greenery (+2, +1, 0)		
	Greenery in the district forms a network	+1
	Greenery is visually continuous	+1
B1: Greenery of walls and trees (+1, 0, 1)		
	Walls along roads are continuously greened	+1
	Walls along roads are greened to an average level	0
	Walls along roads are mostly concrete blocks	1
B2: Greenery of open pedestrian spaces (+2, +1, 0, 1)		
	There are well-greened parks and playgrounds	+1
	There are abundant trees along the streets	+1
	Land is deserted and garbage is scattered throughout it	1
B3: Favorable pedestrian space (+1, 0, 1, 2, 3)		
	Streetscape is rich and pleasant	+1
	Street scenes are chaotic with garbage bins, bicycles	1
	Advertisements are in disorder	1
	Illegal parking hinders pedestrian use	1
B4: Friendly outdoor space (+1, 0, 1)		
	Street spaces are friendly and sociable	+1
	Streets spaces are isolated, without living atmosphere	1
B5: Decorations and street furniture (+2, +1, 0)		
	There is street furniture, sculptures, waterscapes, etc.	+1
	There is well-designed lighting, etc.	+1

The second step is the principal component analysis to reduce variables by combining similar ones. As a result, three components are found for landscape-related variables. These are termed compatibility, greenery, and familiarity.

The third step is the hedonic analysis. Unit land price (i.e., the land price divided by the area of the sample site) is regressed with explanatory variables. The specification of the regression equation is tested, and the best model is selected. Table.1.2 summarizes the result.

Table.1.2. Regression model for unit land price in Tokyo

Variable (Definition)	Coefficient (thousand Yen/m^2)	t-value	P-value
Intercept	688.4	16.68	<0.0001
Line-Seibu (Along Seibu railway lines, 1; otherwise, 0)	129.4	8.45	<0.0001
Line-Keio (Along Keio railway lines, 1; otherwise, 0)	41.3	3.09	0.0022
Line-Tokyutoyoko (Along Tokyutoyoko railway lines, 1; otherwise, 0)	75.6	4.8	<0.0001
Multiple line (The nearest station connects at least two railway lines, 1; otherwise, 0)	35.7	2.95	0.0035
FAR1 (If effective FAR is below 100%, 1; inclusively between 110% and 270%, 1; otherwise, 0)	61.2	4.96	<0.0001
FAR2 (If effective FAR is below 210%, 1; beyond 220%, 1)	111.7	4.78	<0.0001
FAR3 (If effective FAR is inclusively between 110% and 160%, 1; inclusively between 170% and 210%, 1; otherwise, 0)	18.4	2.12	0.0353
T-Station (Time to the nearest train station [min])	9.8	7.45	<0.0001
Irregular shape (With an irregular shape and S 70, ln (S 70); otherwise, 0)	25.1	6.63	<0.0001
Frontage/S (Frontage facing main front road [m]/S)	590.2	2.82	0.0052
ln (w_1) (ln (width of main front road [m])	44.8	2.64	0.0088
ln (w_2 1) (If the width of the second front road w_2 2.0 m, ln (w_2 1); otherwise, 0)	49.7	3.62	0.0004
Cul-de-sac (Front road is of dead-end type, 1; otherwise, 0)	46.1	3.64	0.0003
Chome-elevation/S (Average elevation of chome [m])	108.4	3.09	0.0022
Chome-popden (Population density of chome [person/ha])	0.3	2.65	0.0087
Chome-BCR < 40%/S (If building coverage ratio of detached houses in chome is less than 40%, 1/S; otherwise, 0)	3892.4	2.74	0.0067
Obnoxious (With obnoxious facility in neighborhood, 1; otherwise, 0)	115.0	4.00	<0.0001
Compatibility (First principal component of landscape)	7.2	2.17	0.0310
Greenery (Second principal component of landscape)	8.0	1.99	0.0477

R^2, 0.687; Adj. R^2, 0.663; sample size, 272.
* Effective FAR was the maximum floor-to-area ratio under all planning controls on lots and onsite buildings, with less than 10% parts being dropped.

The first and second principal components of urban landscapes, signifying compatibility and greenery, are significant at 0.05 levels in the model. Specifically, land prices increased by 7,200 Yen/m^2 if the level of compatibility increased by one point, and by 8,000 Yen/m^2 if that of greenery increased by one point. The signs of compatibility and greenery indicate that the effects of landscape factors on land prices are positive because all of them are positively associated with compatibility and greenery.

The results with regard to compatibility and greenery provide useful implications for urban landscape management and planning policy. First, the significantly positive effect of urban landscape on land price is proven. The average land price of the Tokyo sample is 602,400 Yen/m^2. This means that compatibility or greenery marginally accounts for 1–1.5% of the total land price in Tokyo.

Second, the results of the hedonic pricing analysis indicate effective strategies for improving urban landscapes in built-up areas. Because principal components are linear combinations of the product of eigenvectors and standardized landscape factors, the estimates for compatibility and greenery in the 11 dimensions can be broken down. Thereby, the marginal effects of the 11 landscape factors on land price can be computed.

Third, the analysis suggests the importance of collaboration at neighborhood level for the improvement of landscape quality. This point is of critical importance in the management and planning of urban landscape, yielding a hint for urban regeneration. In built-up areas, compatibility and greenery depend on the qualities of building groups and neighborhoods rather than on those of individual buildings. Therefore, to improve landscape quality, the joint efforts of neighbors are necessary. In this sense, regulations that merely focus on individual sites or on the land use of larger districts are insufficient. Policies that encourage and induce cooperation at the neighborhood level are more effective. This recognition necessitates an adequate involvement of residents in local environmental affairs, as well as effective support from local authorities or nonprofit organizations. Nowadays, the importance of this point is increasingly acknowledged. In some wards of Tokyo, for example, municipal governments have enacted policies to encourage residents to green the walls and fences along streets by providing subsidies or reducing property taxes, and by lending personnel to help residents make covenants concerning the features of buildings and greenery. Meanwhile, there have been successful examples of neighbors initiating and making agreements amongst themselves.

1.5 Application of Information Infrastructure to Assist Planning Urban Regeneration: Simulation Approach

Another promising approach to comparing several alternatives for urban regeneration policy is to run urban and regional simulations in order to determine some target indicators such as total land price, population residing in or visiting the area, general domestic product, and so on. Many papers have been published estimating such key indicators. Among them, a study by Okada and Asami (2007) is introduced briefly here. In their paper, the increased number of visitors as a result of improvement in urban structure is estimated. A ranking of proposed projects then becomes possible based on the results.

The study considers the Galata area in Istanbul, which is one of the busiest commercial cores in a modern setting. However, the area is not well-endowed with visitor attractions arranged in a network manner, and so attracting more pedestrians is a key aim of urban regeneration.

Pedestrian counts for several road nodes are gathered from the survey by a research team headed by Professor Ayse Sema Kubat of the Istanbul Technical University. Initially, the simulation of pedestrian movement, an aggregate logit model is devised. Pedestrians are assumed to walk around the area whilst seeking the maximum utility from walking. This type of pedestrian behavior can be predicted by a route choice behavior whereby at each node (i.e., intersection of roads) a pedestrian will select a direction following a probabilistic function based on the expected utility determined by the attraction of the route. The attractiveness of routes can be characterized by landmarks such as historical heritage, shops along the way, width of the road, and so on.

Expected utility attained at node i, U_i, is given by the sum of the expected utility V_{ij}, by going to a possible neighboring node j, multiplied by the probability of going to node j from node i. The expected utility V_{ij}, from node i to node j is given by a function of the factors (shown in Table.1.3) attracting visitors and expected utility level attained at the next node j. The probability of choosing one edge was assumed to follow the aggregate logit model. As is seen in this model framework, unknown variables are intertwined, hence an iterative approach is taken to estimate parameters. The details concerning the iteration are shown in Okada and Asami (2007).

Table.1.3. Variable list for expected utility

Variables	Definition	Unit
Shop areas	Area of shops per 10m	m^2 per 10m
Width ped.	Width of pedestrian way	m
#Driven cars	Number of driven cars	Number
#Parked cars	Number of parked cars per 10m	Number per 10m
Pavement	Condition of pavement	5 classes
Walkway d.	1: There is walkway along road, 0: Otherwise	-
Crossing d.	1: Cross a street, 0: Otherwise	-
Energy cons.	Energy consumption to walk each road	kcal
U. destinatn	Utility of destination node $U_i = \Sigma_{j \text{ in Node } (i)} P_{ij} V_{ij}$	-

Table.1.4. Result for weekdays

Variables	Parameter	*t*-value
Shop areas	0.049	3.14***
Width ped.	0.046	2.67***
#driven cars	0.033	2.00**
#parked cars	0.014	0.81
Pavement	0.102	5.97***
Walk dummy	0.059	3.40***
Cross dummy	0.001	0.001
Energy cons.	0.034	-2.02**
U. destinatn	0.059	3.80***

Reg. R^2: 92.3%, Adj. R^2: 92.1%, F-value: 525, Sample size: 362
*** 1% sig., ** 5% sig., * 10% sig.

Table.1.5. Result for holidays

Variables	Parameter	*t*-value
Shop areas	0.024	1.39
Width ped.	0.051	2.60***
#driven cars	-0.009	-0.47
#parked card	-0.027	-1.38
Pavement	0.026	1.33
Walk dummy	0.047	2.42**
Cross dummy	0.015	0.87
Energy cons.	-0.000	-0.01
U. destinatn	0.056	3.07***

Reg. R^2: 90.4%, Adj. R^2: 90.3%, F-value: 486, Sample size: 362
*** 1% sig., ** 5% sig., * 10% sig.

Tables.1.4 and 1.5 show the results of the estimated pedestrian route choice model. As is seen in the tables, all variables except energy consumption that are chosen as significant values have positive effects.

Given the estimated model, one can conduct a simulation with respect to some factors appearing in the model by changing the variables to reflect on proposed urban regeneration projects. For example, urban regeneration projects attracting shops along streets and those improving the pavement of a pedestrian route can be evaluated with the estimation model above. The indicator for the evaluation of a proposed project can be measured by a predicted increase in the volume of pedestrians into the area. However, urban regeneration projects may differ in cost depending on the project type. To take this issue into account, an efficiency measure given by effect-cost ratio is used. The effect is measured by the increase in the volume of pedestrians, and the cost is measured as project cost.

The model can order hypothetical projects for urban regeneration in a manner which conforms fairly closely to professional proposals. Some additional projects are also ranked highly and are worth considering as practical projects.

1.6 Conclusion

Two different approaches intended for use in the evaluation of alternative proposals for urban and regional regeneration are outlined in the previous two sections. As is seen, the basic information used for explanatory variables for both cases is essential in order to permit a comparison of alternatives. Urban and regional information infrastructure should provide such a framework. In many cases, the basic data are not sufficient to fulfill the needs of a specific evaluation, and some additional data has to be collected separately. To ease the input of such data as spatial data for the infrastructure is also an important task. In this regard, the infrastructure should be user-friendly, and it should allow database enrichment and update with the least effort.

References

Arai Y (2001) Evaluation indices of residential environments, Asami Y (ed) Residential Environment: Evaluation Method and Theory, University of Tokyo Press, Tokyo, pp A1–A80

Committee for Estimation of Effects of Urban Redevelopment Projects (2003) Scheme of manual of cost-benefit analysis for urban redevelopment projects (revised edition), Urban Renewal Association of Japan, Tokyo

Gao X, Asami Y (2001) The external effects of local attributes on living environment in detached residential blocks, Urban Studies 38: 487–505

Gao X, Asami Y (2007a) Influence of lot size and shape on redevelopment projects, Land Use Policy 24: 212–222

Gao X, Asami Y (2007b) Effect of urban landscapes on land prices in two Japanese cities, Landscape and Urban Planning 81: 155-166

Geoghegan J (2002) The value of open spaces in residential land use, Land Use Policy 19: 91–98

Kanemoto Y, Nakamura R, Yazawa N (1989) Hedonic estimation of the value of environmental quality, Environmental Science 2: 251–266

Morancho A B (2003) A hedonic valuation of urban green areas, Landscape and Urban Planning 66: 35–41

Okada E, Asami Y (2007) A pedestrian route choice model to evaluate alternative plans for regeneration of Galata region, ARI Journal, Istanbul Technical University, in press.

Takuma F (2007) Fundamental research on measuring negative externality of densely built urban areas, Quarterly Journal of Housing and Land Economics 64: 30–37

Urban Information Study Group (1987) Urban information database: Manual for constructing urban policy information system (UISII), Kibun Publishing Co, Tokyo

Yamaga H, Nakagawa M, Saito M (2002) Earthquake risks and land pricing: The case of the Tokyo Metropolitan Area, Journal of Applied Regional Science 7: 51–62

2. New Urban Information Infrastructure: 3-D and Dynamic Information

Ryosuke Shibasaki

Center for Spatial Information Science, The University of Tokyo, 5-1-5, Kashiwanoha, Kashiwa-shi, Chiba 277-8568, Japan

2.1 Introduction

Detailed computer simulations, especially for urban areas, are becoming indispensable tools for the propagation analysis of electrical waves for wireless communication, flood analysis, wind analysis for high-rise buildings, landscape simulation and so forth. Three-dimensional (3-D) spatial data faithful to the real world can serve as a common information infrastructure to support a variety of simulations needed for decision-making. Photogrammetry using aerial photographs is effective for the manual reconstruction of 3-D spatial data. High-resolution images in particular provide sufficient detailed information, although the automation of 3-D data reconstruction is still limited in terms of reliability.

We are making efforts to improve existing automation methods by integrating high-resolution images with complementary data such as a low-resolution digital surface model (DSM) and two-dimensional (2-D) existing maps. We have demonstrated that the accuracy and speed of stereo matching can be improved by using both high-resolution stereo images and DSM, although image segmentation to extract buildings may cause errors in high-density urban areas (*Nakagawa et al., 2003)*. Although larger buildings can be relatively easily extracted by segmenting DSM, rather than from stereo images, the extraction of smaller buildings is still difficult (*Nakagawa et al., 2002)*. In this chapter, we demonstrate the following.

1. How to use existing 2-D maps to solve such problems.
2. How data revision (i.e., change detection) can be automated for detailed 3-D spatial information with texture data.

The resolution of existing 2-D maps is coarser than that of fine aerial images. The positions and shapes of buildings on the map cannot be exactly matched with those extracted from an aerial image. The position and shape of a building polygon from a 2-D map needs to be adjusted to the image by using a SNAKE or an active contour model and a line-edge matching algorithm.

After the compilation of 3-D spatial data for urban areas, another important issue is data revision, because urban features such as buildings change very dynamically. The revision process consists of two steps: detection of changes; and data generation or modification based on the detected changes such as the addition of 3-D data for a newly built building. Change detection in particular is very labor intensive because all the urban areas must be examined by visual inspection. We demonstrate that 3-D detailed data with texture helps greatly in improving the automation level of change detection.

2.2 STARIMAGER / TLS (Three-Line Sensor): A New High-Resolution Sensor for Urban Mapping

STARIMAGER / TLS (three-line scanner) is an optical sensor for aerial survey. TLS is composed of three linear CCD(Charge Coupled Device) imaging sensors arranged in parallel, and can acquire triple stereo images for each direction (forward, nadir, and backward) at the same time (Figure 1). As a result, the occlusion area can be considerably reduced. Using two of the three images it is also possible to obtain 3-D coordinates by using a stereo matching algorithm.

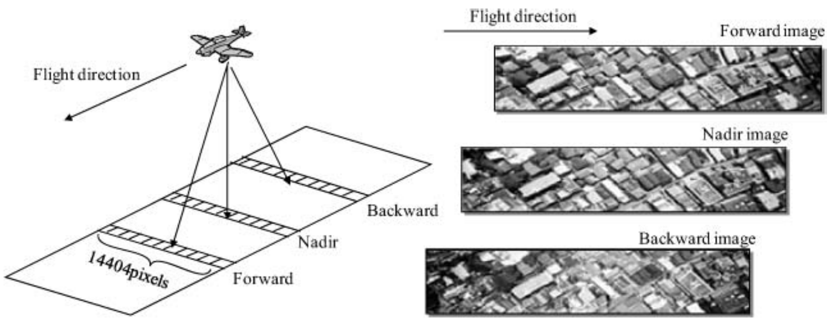


Fig. 2.1. Image data acquisition with TLS

An advantage of a linear CCD sensor is that more pixels can be arranged in a single scene as compared with a 2-D frame CCD sensor. A linear CCD sensor can therefore achieve a resolution similar to that of an aerial photograph, although a linear CCD sensor can acquire data only one line at a time. The ground resolution of TLS data in this research is approximately 3 cm. However, the position and attitude of the sensor when acquiring each line image varies with time and its orientation. In addition, an estimation of position/attitude cannot be made by directly applying existing methods of photogrammetrical analysis.

2.3 Methodology for Automated Generation of 3-D Building Data

The data integration method for automated 3-D data, used mainly for building reconstruction, requires TLS images, DSMs, and 2-D polygon data. Each data set is assumed to have been acquired during the same period of time. The data integration is made by way of the following processing steps.

1. Generation of approximated 3-D building data.
2. Modification of horizontal building shapes.
3. Modification of building height.
4. Versatile roof modeling.

2.4 Generation of Approximated 3-D Building Data

The first stage of processing is the generation of approximated 3-D building data. The generation step requires “horizontal shape”, “height” of buildings, and “ground height”. Horizontal building shapes are taken from 2-D maps, whereas building heights are given by DSMs, and ground height or digital elevation model (DEM) data are estimated through filtering DSM data. The approximated 3-D buildings are used as initial values for the next stage.

2.5 Modification of Horizontal Building Shapes

The approximate building 3-D polygons, which are back-projected onto the images or image spaces are not exactly matched with the building shapes on the images. A polygon is modified to exactly match with building edges on the nadir image. First, the roof of a 3-D building polygon is back-projected assuming that it is a horizontal plane. The SNAKE model defined in the following eq.1 is used to modify a polygon to exactly match corresponding building edges on the nadir image, which has less occlusion than the other images.

$$E_{smake} = \omega_1 E_{internal} + \omega_2 E_{external} \rightarrow Optimize \qquad (2.1)$$

where

$E_{internal}$; Internal energy

$E_{external}$; External energy

ω_1 ; Relative Weight of Internal energy

ω_2 ; Relative Weight of External energy

The initial projected polygon on the nadir image, is modified to minimize the total energy. The energy is the sum of internal energy defined as “closeness” to a rectangle (i.e., if the polygon is a rectangle, the energy is minimal), and external energy is defined as the “closeness” of a polygon to the building edges in the nadir image (i.e., if the polygon is exactly matched with the building edges in the image, the energy is minimal).

The modified polygon on the image is reprojected onto the object space or the original building, and the original building polygon is replaced. As a result, the horizontal position and shape of the 3-D polygon are modified as shown in the upper part of Fig.2.2.

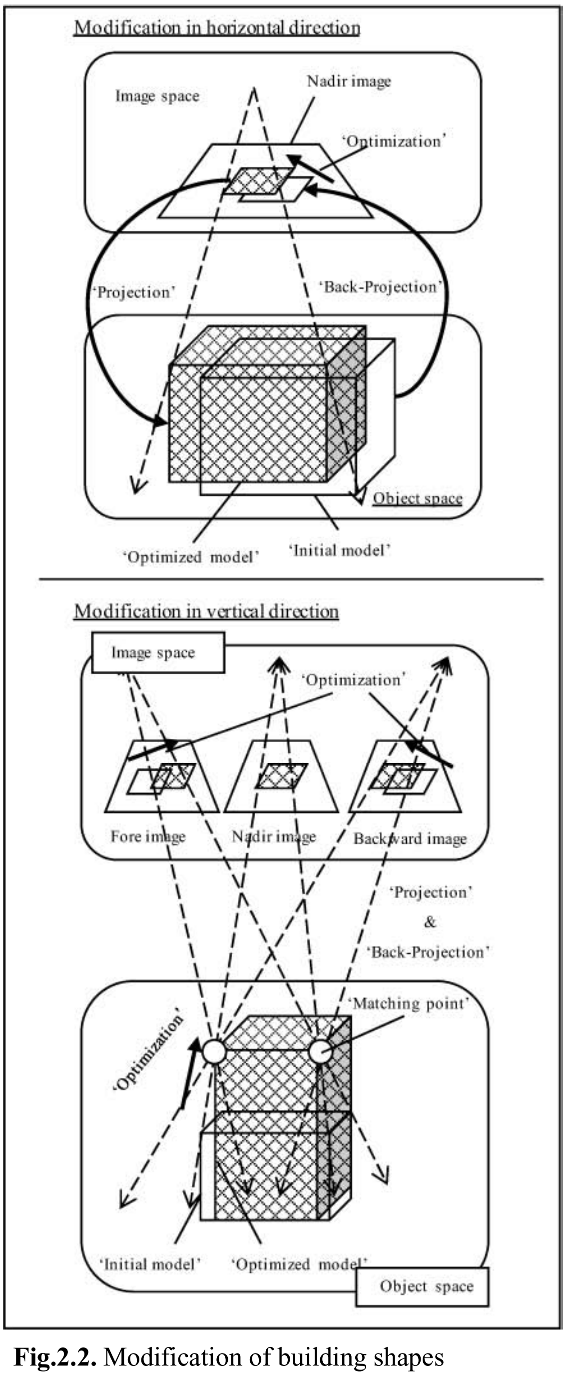


Fig.2.2. Modification of building shapes

2.6 Modification of a Building in the Height Direction

The height of the 3-D polygon on the object space is adjusted by an automatic modification based on triplet line-edge matching using the SNAKE algorithm shown in the lower part of Figure 2. The triplet line-edge matching is also based on the energy concept defined for the SNAKE. Two more parameters are evaluated as shown in Equation 2. One of the parameters is an overlapping ratio between the polygon boundary and edge pixels in Forward / Backward images. Another is the similarity of intensity values between the inside and outside of polygons in the Nadir and Forward / Backward images. These parameters are assigned to the external energy. Values for the weight parameters are based on the direction of lines in the TLS images (Fig.2.3).

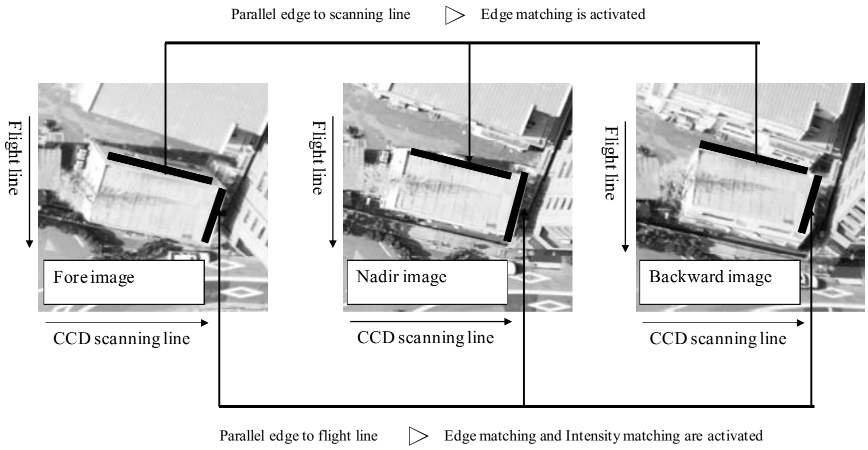


Fig.2.3. Parameter decision in TLS images

$$E_{external} = \omega_{ext1} E_{edge} + \omega_{ext2} \left(E_{outside} + E_{inside} \right) \tag{2.2}$$

where

E_{edge}; Energy derived from edge matching

$E_{outside}$; Energy derived from intensity matching on outside of polygons

$E_{external}$; Energy derived from intensity matching on inside of polygons

ω_1; Relative weight of energy derived from the edge mathing (E_{edge})

ω_2; Relative weight of energy derived from the intensity matching $\left(E_{outside} + E_{inside} \right)$

This line-edge process uses not only the nadir edge image, but also the forward edge and the backward edge images. Finally, the modified polygon is projected from the image space to the model space, and the 3-D polygon is updated. As a result, the boundary of the 3-D polygon is corrected in terms of elevation.

2.7 Versatile Roof Modeling

To faithfully represent the complex shape of a building, a “versatile roof modeling” step is applied. This step is an option to generate 3-D complex building models through a 2-D interface. Adjusted horizontal 3-D data are first projected into image space. Next, line-edge matching is conducted, and ridgelines of building roofs are shifted at the same time. Finally, modified models are back-projected into object space. Based on this processing, 3-D data are adjusted to true values.

The versatile roof model consists of various parameters, i.e., the ridge line direction, horizontal shift, shrinkage, and height (Fig.2.4). The authors found this model applicable to 99% of the differing roof types found in urban areas, but with particular reference to Tokyo.

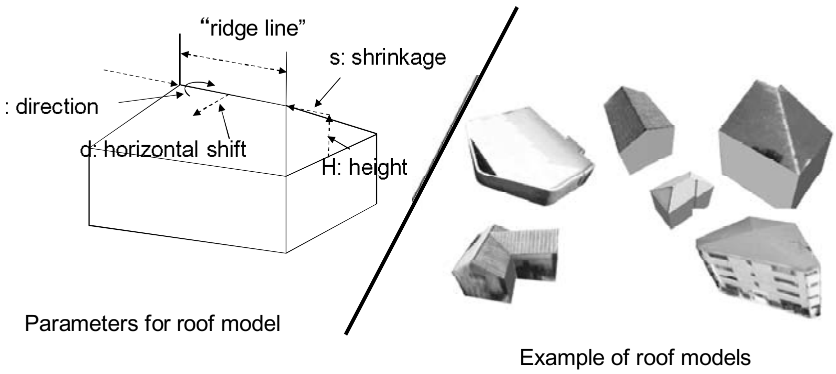


Fig.2.4. Parameters and examples of versatile roof modeling

2.8 Experiment with 3-D Spatial Data Development

The study area is Tokyo. Roofs of variable shape such as horizontal or gable are crowded into this area. The following data are used in this research.

1. TLS images: The original spatial resolution is approximately 3 cm. Image resolution is reduced to one half of the original to increase processing speed for this research.
2. DSM: The spatial resolution is 50 cm. These data are generated from air-borne LIDAR (Laser Imaging Detection and Ranging) data. With LIDAR, the height of terrrain surfaces are measured with 50cm to several meter interval and, finally, DSM or gridded elevation data of terrain surfaces are generated by interpolating the height data from the LIDAR.
3. 2-D polygon data: The digital level is 1:1000. One hundred and sixteen building polygons are used in this experiment.

2.8.1 Results

Three-dimensional building models are refined by using this approach. Additionally, all textures of this 3-D model are taken from TLS images. Furthermore, the 3-D model is texture-mapped by automatic selection from several TLS images. The result is shown in Fig.2.5, which shows that very faithful building models are developed.

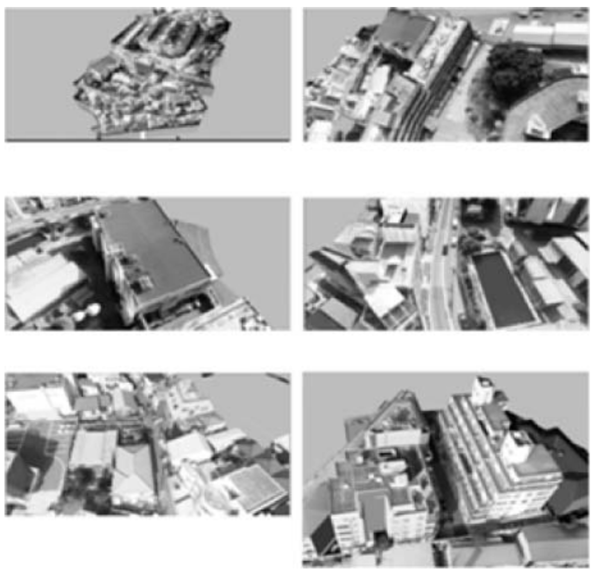


Fig.2.5. Refined 3-D models

2.8.2 Discussion

The evaluation of each method is described in this section. The reference data are generated by manually inputting polygons in TLS images.

SNAKE Model

The accuracy of automated modification of horizontal building shapes depends on the performance of the SNAKE model. In our study the distances between the vertex points of modified polygons and those of the reference data in the nadir image are evaluated.

Since the automated modification is better than the initial data, the result is called "improved" in this paper. The resultant "improved" ratio is 64.7% (75/116). One factor for successful improvement is the marked contrast between buildings and their surroundings in an image (left side, Figure 6). However, when an image has a poor contrast and there is a similarity of features between a building and its surroundings, the processing may fail. For example, some parts of the SNAKE polygon fit to building edges, but others fit to road features in the right side of Fig.2.6.

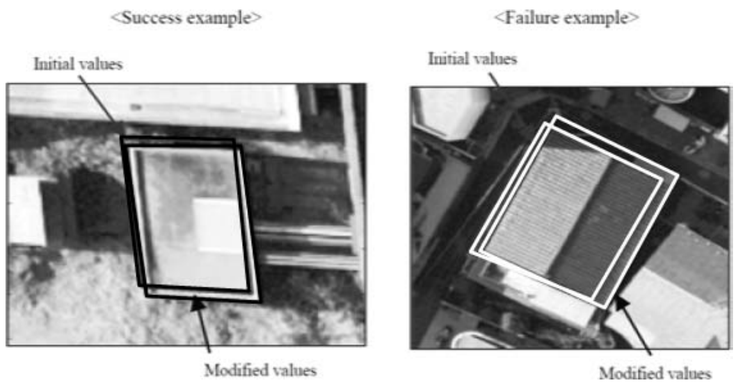


Fig.2.6. Results of automated shape modification with the SNAKE model

Line Matching

The accuracy of modification for building height value depends on the accuracy of line matching. The error in this study is defined as the distance between the modified height value and the true value measured manually. The average height error is 0.55 m.

The following are regarded as the causes of mismatching.

1. Some building edges do not exist in the forward image due to poor contrast.
2. Not all edges can be captured in the image in some building cases (e.g., occlusions).
3. "Noise edges" on a roof (e.g., stripes of slate, parabolic antennas, roof fences) can cause mismatching.

2.8.3 Summary of 3-D Spatial Data Development

Three-dimensional building data can be generated by integrating DSM, existing maps, and high-resolution airborne images. The automation level of this 3-D data generation is very high when compared with that of existing photogrammetric methods using only digital images because DSM and the existing maps can provide relatively good initial values. If the features of buildings in images are clear enough, the success ratio of the automated data development is high.

2.9 Monitoring Dynamic Changes of Urban Areas

One of the most serious problems in providing digital map data to a variety of users is the maintenance cost, because urban features such as buildings change very dynamically. Data revision consists of two steps: change detection and data addition/modification. Once the changes are detected, data addition and modification to reflect the changes can be made in the same manner as data development. To detect change, entire areas and all features must be examined, which may be very costly. Automation or the cost reduction of change detection is a key in keeping 3-D data up-to-date with lower cost. Since buildings are dominant urban features in number, we focus on how to detect building changes automatically, such as "newly built", "demolished", "replaced", and "extended and remodeled". In the fields of computer vision and photogrammetry, the following three methodologies have been developed to recognize these changes.

1. Raster-based change detection of features or segments in temporal images *(Sirinyildiz, 2004; Vosselman et al., 2004; Zhang and Fraser, 2005).*
2. Vector-based change detection of horizontal shapes in temporal GIS maps *(Nakagawa et al., 2000).*

3. Height-based change detection of temporal object volumes *(Matikainen et al., 2004); Murakami et al., 2004; Tuong Thuy Vu et al., 2004; Vogtle Steinle et al., 2004.*

However, especially in dense urban areas, each approach alone fails to provide flawless and reliable results. A limiting factor is the spatial resolution of input data such as general digital maps and aerial images; this is insufficient to allow recognition of detail for individual buildings and for small building changes with limited data points.

Moreover, methods 1 and 3 are based on the change detection of a cluster of pixels that can be caused by any object changes. Therefore, even if a changed area or a cluster of pixels is detected, it is uncertain whether it is caused by the change of a building or for another reason.

To detect changes more reliably in a dense urban area, clues such as color, horizontal shape, and building height have to be integrated. Here, precise 3-D building data described in the previous sections, which have very high texture resolution as shown in Figure 5, are used as baseline data. An aim of this section is to develop a building change detection algorithm that identifies “demolition”, “replacement”, and “extension and remodeling” of buildings in a dense urban area.

2.10 Model-Based Change Detection

When the 3-D surface of a building from the baseline data is projected onto a new image, a portion of the image corresponding to the 3-D surface can be delineated. A texture image of that surface is defined as a “reference image” and a portion delineated from the new image is defined as a “comparison image”. The change in buildings as “newly built”, “demolished” and so forth is expected to lead to some difference in the texture of the reference image to that of the comparison image. This is a basic concept to detect building changes, assuming that there is accurate orientation of the images (Fig.2.7 and 2.8). The procedure of change detection, called a “model-based change detection method”, is described in Fig.2.9.

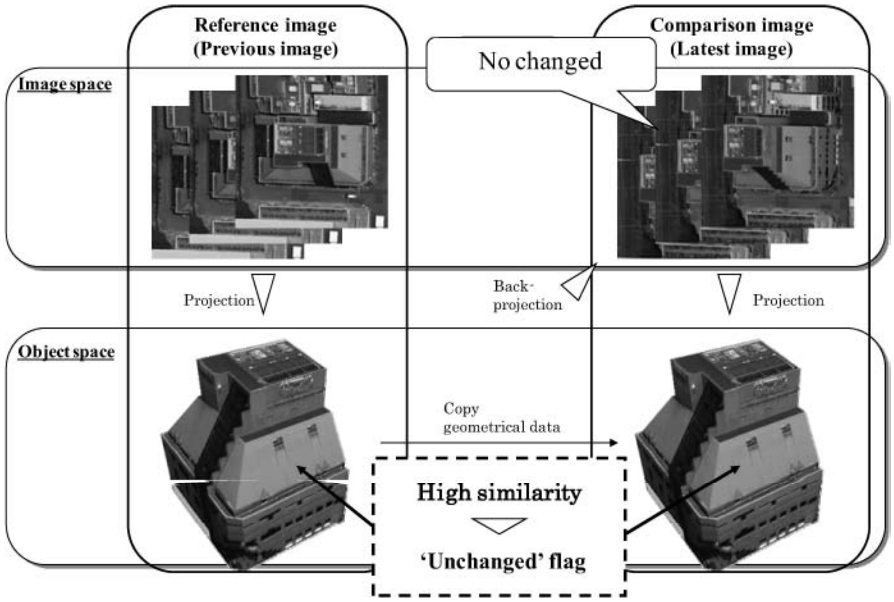


Fig.2.7. Example of mode-based change detection (no change case)

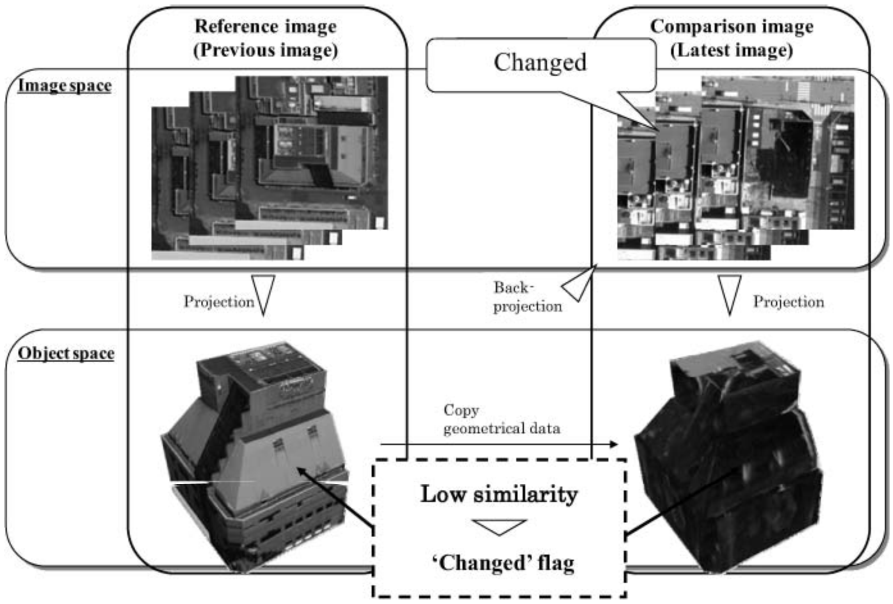


Fig.2.8. Example of mode-based change detection (change case)

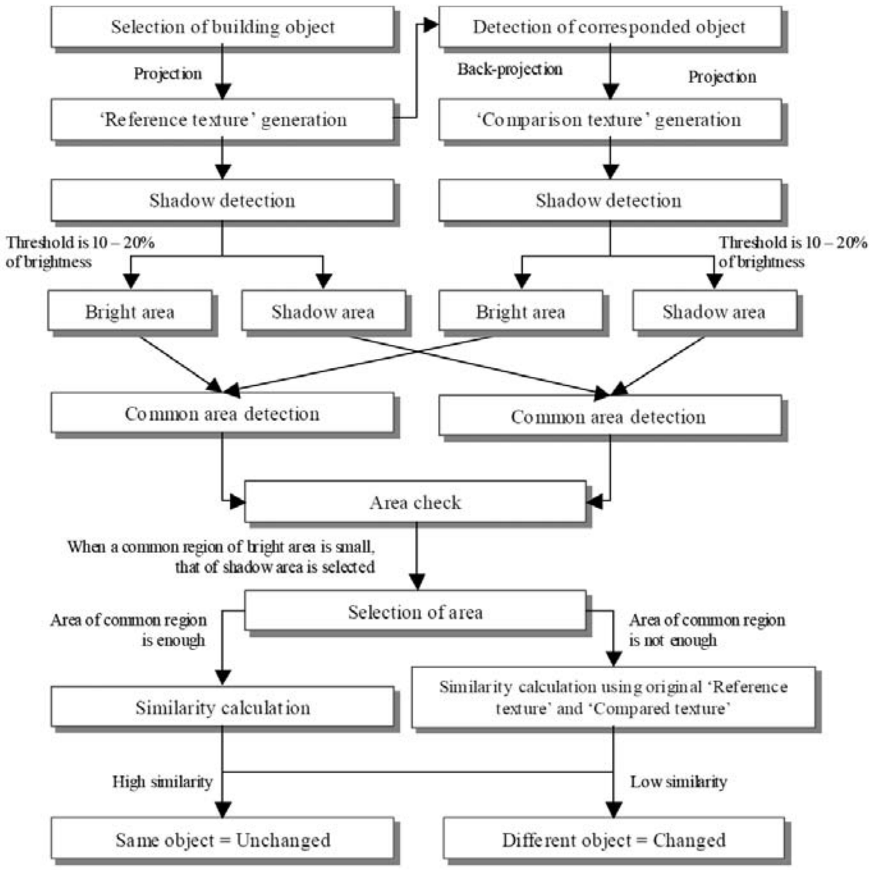


Fig.2.9. Processing flow of the model-based change detection

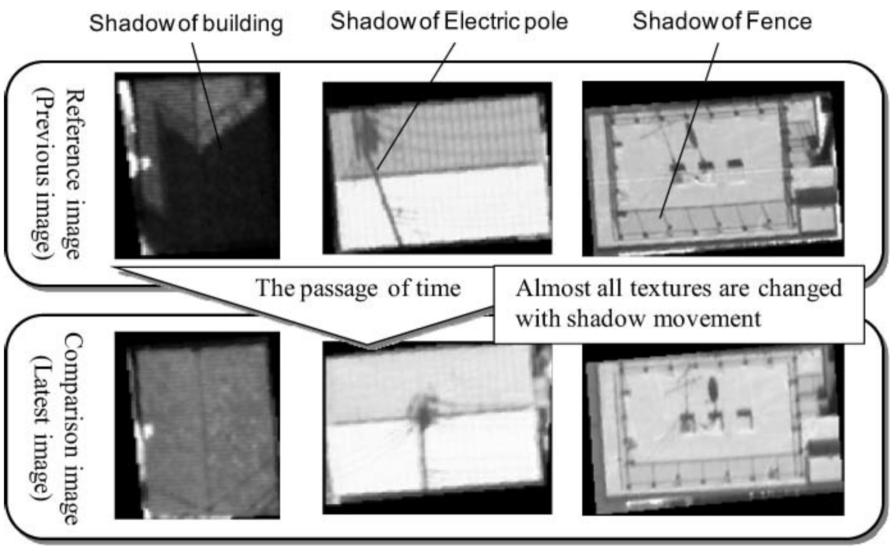


Fig.2.10. Shadow as a factor in decreasing the recognition rate of object change

"Newly built" buildings on a vacant land allotment cannot be detected because the comparison amongst the images is made only for existing structures. Detection of "newly built" buildings follows the preparation of a 3-D vacant allotment database in which all spaces not covered by buildings, roads and other existing urban features as building objects are prepared from existing digital maps. Identification of "newly built" areas is thereafter made using the same processing procedure.

To achieve greater precision, changes can be detected through comparison using both roof and wall surfaces because, in addition to roofs, vertical or wall surfaces are visible in three-line sensor imagery. However, some problems remain with the subtraction processing of images observed at different times. For example, shadow that is cast by adjacent structures (Fig.2.10) may reduce the reliability of object change recognition. This is why shadow area removal is included in the algorithm as shown in Figure 9. In the following section there is a more detailed description of shadow detection.

2.10.1 Model-Based Change Detection with Shadow Area Removal

If shadows in an image are detected beforehand, an "unshadowed" image can be generated using an image enhancement technique *(Li et al., 2004; Yu and Chang, 2005)*. However, it is difficult to decide upon threshold brightness values to delineate the boundaries of bright and shadow areas. Brightness values in the same features require to be sampled to preset the image-enhancing model parameters. Usually this sampling task requires a manual operation for reliable results. To automate the procedure herein, we try to improve the success rate of the change detection algorithm without generating the "unshadowed" image. Both the geometrical detection and image segmentation approaches are combined.

Geometrical Detection Approach

The elevation and azimuth of sunlight give the shadow area in the object space correctly, as shown in Fig.2.11. Moreover, when the detected shadow area is back-projected onto the image, its area can be detected automatically. The elevation and the azimuth of the sun can be calculated with a time stamp of the image acquisition and solar orbit information *(Nakajima et al., 2005)*.

The elevation and azimuth may, furthermore, be obtained by stereo measurement of shadow features in an image.

Fig.2.11. Detection of shadow area using the geometrical approach

Image Segmentation Approach: Active Binarization Processing

Various objects can be recognized in ultra-high-resolution imagery, such as three-line scanner (TLS) images. For example, there are vehicles and street trees, as well as pedestrians, antennas, electricity poles, hanging laundry, and garden objects, and even the shadows of these features are in the images. If models of all the objects are constructed, it is easy to achieve accurate shadow detection using the geometrical approach. However, complete 3-D model construction is unrealistic. Therefore, the image segmentation approach is also applied to detect shadow areas that remain after shadow detection processing using 3-D geometrical data. An active binarization processing is applied herein to make image masks to remove areas that are likely to contain shadows. An actual threshold value for the binarization is determined as the concave edge point of an image histogram at 10–20% brightness (Fig.2.12).

As a result of the above process, bright regions are almost completely separated from shadow areas. Using threshold values for the reference and comparison images, a bright region in both is extracted, whereas a dark region in each image is identified for a further comparison.

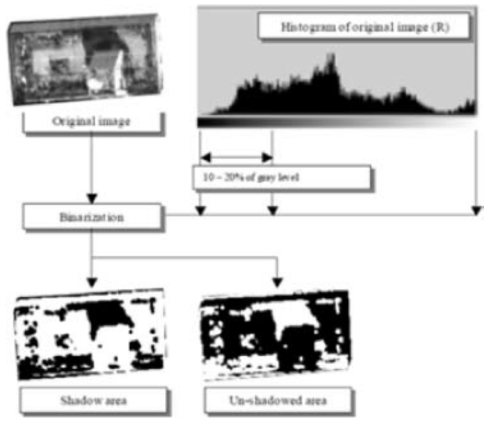


Fig.2.12. Active binarization processing

2.11 Change Detection Experiment

Building changes in urban data were extracted using the model-based change and shadow area detection algorithms. The following items were tested.

1. Model-based change detection (cross-correlation).
2. Improved model-based change detection (cross-correlation and shadow detection).
3. Improved model-based change detection (histogram subtraction and shadow detection).

The histogram subtraction and the cross-correlation calculation are applied to evaluate an object's similarity in the two images. Additionally, each threshold for change detection was set to detect changed building objects with a 100% success rate because changed building objects are rare, as shown in the data set described below. The purpose of this experiment was to confirm the accuracy and performance of this detection approach from the viewpoint of building recognition.

2.11.1 Study Area

The selected dense urban area is in Tokyo, Japan. This area includes detached buildings along a main street.

2.11.2 Data

- Aerial images: Time-series three-line sensor images (reference and comparison) as shown in Fig.2.13 were used. The spatial resolution is approximately 5 cm. Table.2.1 shows the image details, including the acquisition time. Two buildings changed in one month.
- 3-D building data: High-resolution 3-D models constructed using the three-line sensor triplet reference images. A screenshot of this model is shown in Fig.2.14. The spatial resolution is 10 cm. These test data consist of 767 buildings.

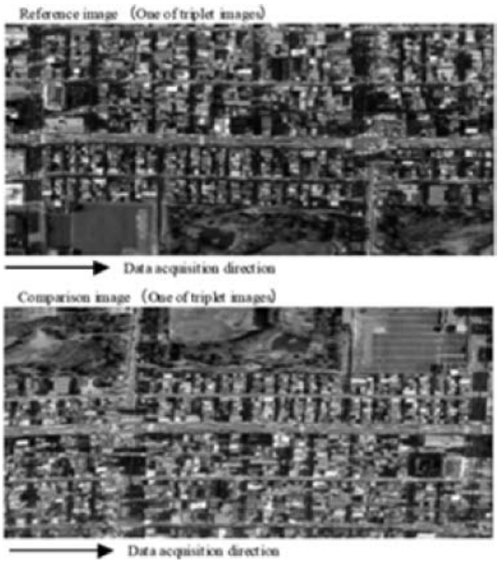


Fig.2.13. Aerial images (time-series three-line sensor images)

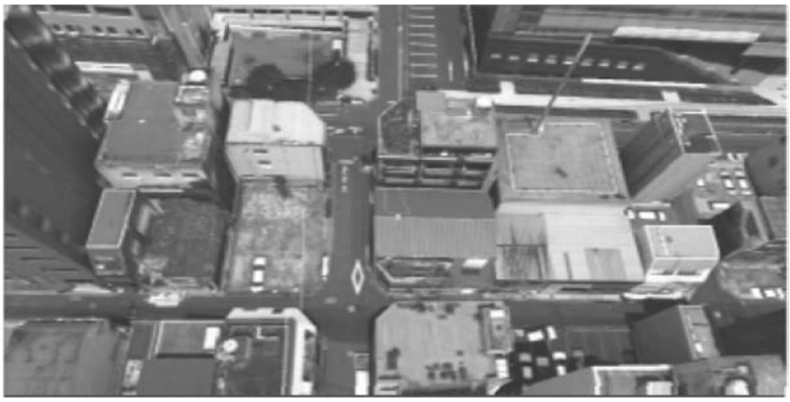


Fig.2.14. 3-D reference data (precise 3-D data) constructed from three-line sensor images

Table.2.1. Details of three-line sensor images used for the experiment

Study area: Tokyo, Japan Situation: Overcrowded

	Date and time of data acquisition	Altitude	Weather
Reference image	10:01, 15 Dec. 2003	450[m]	Fine
Comparison image	11:42, 20 Jan. 2004	450[m]	Fine

2.11.3 Results

The results of this experiment are shown in Table.2.2 to 2.7. In this research, a percentage value, the number of successfully recognized objects or detected changes divided by the total number of objects, is defined as the "object recognition rate". Changed buildings detected manually are categorized as a "change of building". Moreover, the other objects should be categorized as unchanged objects. The recognition rate for those objects that have not actually changed is referred to here as the "invariance detection rate" and the recognition rate of objects that have actually changed is the "change detection rate". In Tables.2.2, 2.4, and 2.6, objects that have changed are separated from those that have not.

Moreover, these results are categorized according to image conditions in the reference and comparison images. We compare the recognition rates according to image conditions, i.e., differences between the reference and the comparison images caused by many factors, as shown in Tables.2.3, 2.5, and 2.7 as follows.

1. Fine (no influence): No situation change between the reference and the comparison image.
2. Shadow of contiguous object: Noticeable changes caused by contiguous building shadows.
3. Shadow of building components: Noticeable changes caused by building components such as cooling towers.
4. Continuous texture: One-pixel texture gap that may lead to misrecognition as noticeable changes in the image comparison.
5. Smear: Smear noises in images.
6. Specular reflection: Saturation of sensor due to specular reflection of sunlight.
7. Minor changes: Changes in fences, gardens, and roofs.
8. Change of buildings: Structural changes, including exteriors.

Table.2.2. Result of model-based change detection without shadow removal: Cross-correlation

Threshold (Normalized cross-correlation)=0.860

Object type	Number of successfully recognized objects / Total	Object recognition rate
Unchanged object	[645/765] (Number of recognized objects as same object / Total)	84% (Invariance detection rate)
Changed object	[2/2] (Number of recognized objects as different object / Total)	100%
Total	[647/767]	84%

Table.2.3. Classification of the result of model-based change detection without shadow removal under different image conditions: Cross-correlation

Condition of image comparison	Number of successfully recognized objects / Total	Object recognition rate
Fine	[428/460]	93%
Shadow of contiguous object	[77/145]	53%
Shadow of building component	[44/55]	80%
Continuous texture	[54/57]	95%
Smear	[7/8]	88%
Reflection of sunlight	[5/5]	100%
Changed thing on roof	[30/35]	86%
Change of building	[2/2]	100%

Table.2.4. Result of model-based change detection with shadow removal: Cross-correlation

Threshold (Normalized cross-correlation)=0.887

Object type	Number of successfully recognized objects / Total	Object recognition rate
Unchanged object	[685/765] (Number of recognized objects as same object / Total)	90% (Invariance detection rate)
Changed object	[2/2] (Number of recognized objects as different object / Total)	100%
Total	[687/767]	90%

Table.2.5. Classification of the result of model-based change detection with shadow removal under different image conditions: Cross-correlation

Condition of image comparison	Number of successfully recognized objects / Total	Object recognition rate
Fine	[437/460]	95%
Shadow of contiguous object	[101/145]	70%
Shadow of building component	[51/55]	93%
Continuous texture	[54/57]	95%
Smear	[7/8]	88%
Reflection of sunlight	[5/5]	100%
Changed thing on roof	[30/35]	86%
Change of building	[2/2]	100%

Table.2.6. Result of model-based change detection with shadow removal: Histogram subtraction

Threshold (Normalized cross-correlation)=0.887

Object type	Number of successfully recognized objects / Total	Object recognition rate
Unchanged object	[685/765] (Number of recognized objects as same object / Total)	90% (Invariance detection rate)
Changed object	[2/2] (Number of recognized objects as different object / Total)	100%
Total	[687/767]	90%

Table.2.7. Classification of the result of model-based change detection with shadow removal under different image conditions: Histogram subtraction

Condition of image comparison	Number of successfully recognized objects / Total	Object recognition rate
Fine	[460/460]	100%
Shadow of contiguous object	[144/145]	99%
Shadow of building component	[55/55]	100%
Continuous texture	[57/57]	100%
Smear	[8/8]	100%
Reflection of sunlight	[5/5]	100%
Changed thing on roof	[35/35]	100%
Change of building	[2/2]	100%

2.11.4 Discussion

The overall results are shown in Table.2.8. The basic model-based change detection method achieved an 84% recognition rate. Moreover, with shadow area removal, the recognition rate improved from 84% to almost 100%. In addition, the cross-correlation and histogram subtraction were applied to evaluate the similarity of the images. There are two characteristic points, as follows.

The first is an improvement of the model-based change detection procedure. The procedure without shadow detection processing often provides false results as shown in Table.2.3. In particular, the failed examples are described as “shadow of contiguous object”. On the other hand, the procedure with shadow area removal gives a good result. Shadow detection apparently improves the reliability of object recognition processing.

The second point is the sensitivity of functions in evaluating 3-D texture similarity. As shown in Tables.2.5. and 2.7, the cross-correlation is more sensitive than histogram subtraction in recognizing object changes. Even if the changed area is a part of a building, minute changes can be recognized through cross-correlation, as shown in “changes on roof” in Table.2.7. However, the histogram subtraction is advantageous in recognizing major changes without being affected by minute noise interference. As a result, the authors confirm that histogram subtraction is effective in detecting large changes such as the demolition and replacement of buildings, and cross-correlation is effective in detecting small changes such as building extension and remodeling. A combination of two or more methodologies may therefore be most effective for reliable change detection, although a decision about the weighting of parameters is a problematic issue.

Table.2.8. Overall result of model-based change detection

Change detection methodology		Number of successfully recognized objects / Total	Object recognition rate
Without shadow detection			
	Cross-correlation	[647/767]	84%
With shadow detection			
	Cross-correlation	[687/767]	90%
	Histogram subtration	[766/767]	100%

2.12 Summary: 3-D Spatial Urban Data and Their Dynamic Revision

Although 3-D spatial urban data are now commonly recognized as important data for different kinds of urban analysis and simulation, it is considered that the development and revision of 3-D data is rather costly. We demonstrate, however, that very detailed 3-D urban data can be developed quite efficiently and virtually automatically by combining different popular data sources such as 2-D digital maps, DSM (LIDAR data), and high-resolution digital imagery. Change detection is the most difficult part of data revision and can also be automated using detailed 3-D urban data, although some level of operator intervention is needed. This suggests that once detailed 3-D urban data coverage with texture information is developed, even though it may require a certain level of initial investment, it can be kept current efficiently by overlaying new digital airborne imagery. This approach is probably at a much lower cost than is needed for traditional 2-D digital map revision.

References

Kass M, Witkin A, Terzopouloe D (1988): SNAKES (Active Contour Models). International Journal of Computer Vision, pp. 321-331

Gerke M, Heipke C, Straub BM (2001): Building extraction from aerial imagery using a generic scene model and invariant geometric moments. Proceedings of the IEEE/ISPRS joint Workshop on Remote Sensing and Data Fusion over Urban Areas, pp. 85-89

Gruen A, Zhang L (2001): TLS data processing modules. Proceedings of the 3rd International Seminar on New Developments in Digital Photogrammetry, Gifu, Japan, 24-27 September, 2001, pp. 69-70

Gruen A, Zhang L (2002): Sensor modeling for aerial mobile mapping with Three-line Scanner (TLS) imagery. Symposium of Commission II, Integrated System for Spatial Data Production, Custodian and Decision Support Xian, China, 20-23 Aug. 2002

Gruen A, Zhang L (2002): Automatic DTM generation from Three-Line-Scanner (TLS) images. ISPRS Commission III Symposium, PCV'02, 9-13 September 2002, Graz, Austria

Gruen A, Zhang L, Wang X (2003): 3D city modeling with TLS (Three Line Scanner) data. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXIV-5/W10, 24-27 February 2003, Scuol-Tarasp, Switzerland

Gruen A, Zhang L (2003): Sensor modeling for aerial triangulation with Three-Line-Scanner (TLS) imagery. Journal of Photogrammetrie, Fernerkundung, Geoinformation, 2/2003, pp. 85-98

Li Y, Sasagawa T, Gong P (2004): A system of the shadow detection and shadow removal for high resolution city aerial photo. Proceedings of International Society for Photogrammetry and Remote SensingL. Matikainen, J. Hyyppa and H. Kaartinen (2004): Automatic detection of changes from laser scanner and aerial image data for updating building maps. Proceedings of International Society for Photogrammetry and Remote Sensing

Murakami H, Nakagawa K, Shibata T, Iwanami, E (). Potential of an airborne laser scanner system for change detection of urban features and orthoimage development. The International Archives of Photogrammetry and Remote Sensing, Volume XXXII, Part 4, ISPRS Commission IV, GIS - Between Visions and Applications

Nakagawa M, Zhao H, Shibasaki R (2000): Comparative study on model fitting methods for object extraction. Proceedings of 21st Asian Conference on Remote Sensing

Nakagawa M, Shibasaki R (2003): Development of methodology for refining coarse 3D urban data using TLS imagery. Proceedings of International Society for Photogrammetry and Remote Sensing Commission VIII, WG 6, 2003

Nakagawa M, Shibasaki, R, Kagawa Y (2002): Fusing stereo linear CCD image and laser range data for building 3D urban model. Proceedings of International Society for Photogrammetry and Remote Sensing Commission IV, WG IV/7, 2002

Nakagawa M, Shibasaki R (2003): Comparative study of data selection in data integration for 3D building reconstruction. Proceedings of 24th Asian Conference on Remote Sensing

Nakagawa M, Shibasaki R (2003): Integrating high resolution air-borne linear CCD (TLS) imagery and LIDAR data. Proceedings of URBAN 2003

Nakagawa M, Shibasaki R (2004): Development of SNAKE-aided methodology for refining coarse 3D urban data using STARIMAGER / TLS (Three Line Sensor) imagery. Proceedings of Urban Data Management Symposium

Nakagawa M, Shibasaki R (2004): Development of methodology for refining coarse 3D urban data using TLS imagery. Proceedings of International Society for Photogrammetry and Remote Sensing, pp. 1324-1329

Nakajima T, Tao G, Ochi S, Yasuoka Y (2002), Simulated recovery of information in shadow areas on IKONOS image by combining airborne laser scanner (ALS) data. The 23rd Asian Conference on Remote Sensing

Nakamura K, Nakagawa M, Shibasaki R (2002): 3-D urban mapping based on the image segmentation using TLS data. Proceedings of 23rd Asian Conference on Remote Sensing, Katmandu

Sirinyildiz T (2004): Change detection analysis by using IKONOS imagery. Proceedings of International Society for Photogrammetry and Remote Sensing

Vu TT, Matsuoka M, Yamazaki F (2004): LIDAR-based change detection of buildings in dense urban area. Proc. International Geoscience and Remote Sensing Symposium, IEEE, CD-ROM
Vosselman G, Tangelder JWH (2000): 3D reconstruction of industrial installations by constrained fitting of CAD models to images. Mustererkennung 2000
Vosselman G, Gorte BGH, Sithole G (2004): Change detection for updating medium scale maps using laser altimetry. Proceedings of International Society for Photogrammetry and Remote Sensing
Vogtle T, Steinle E (2004): Detection and recognition of changes in building geometry derived from multitemporal laser scanning data. Proceedings of International Society for Photogrammetry and Remote Sensing
Yu Y, Chang JT (2005): Shadow graphs and 3D texture reconstruction. International Journal of Computer Vision 62 (1-2): 35-60
Zhang C, Fraser CS (2005): Automated registration of high resolution satellite imagery for change detection. Proceedings of International Society for Photogrammetry and Remote Sensing. Hannover Workshop

3. Monitoring of Urban Infrastructure and Environment by Use of Remote Sensing

Yoshifumi Yasuoka

Institute of Industrial Science, The University of Tokyo, 4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan

3.1 Introduction

Degradation of infrastructure and environment has become a critical social problem in most cities of the world during the past decade. Asian megacities in particular have suffered serious damage from earthquakes or floods. On a local scale, we have experienced building collapse or dangerous concrete block falls in railway tunnels or under highway bridges due to concrete disintegration. Environmental degradation has also been serious in urban areas, and air pollution and water quality deterioration have had fatal impacts on urban life. While rapid urbanization has provided increased convenience and benefit for the inhabitants, on the other hand, it has caused serious problems and has sometimes prejudiced urban safety and sustainability.

Monitoring of urban infrastructure and environment is essential in the proper management of urban safety and sustainability. However, it requires the measurement of a wide variety of parameters covering physical, chemical, biological, and geographical aspects. Furthermore, it needs to consider extensive parameters encompassing the local to regional scale within short- to long-term periods. It is, therefore, not easy to monitor these varied parameters and to establish a database system for urban safety and sustainability using conventional ground survey methods alone. Remote sensing from space is expected to provide a new tool for regularly observing a wide range of variables over extensive areas.

Development of remote sensing technology has been very rapid, and today various types of remotely sensed products are available, ranging from high spatial resolution data for local monitoring to coarser wide coverage data for regional/global surveillance. These products cover land, ocean and atmosphere. It is, however, not easy to extract effective information for urban safety and sustainability from the enormous amount of data. In this paper, new technologies in remote sensing are surveyed, and their applications are introduced, with emphasis on the monitoring and assessment of urban infrastructure.

3.2 Principles of Remote Sensing

3.2.1 Spectral Characteristics

Remote sensing is an observation tool to identify objects, or measure and analyze their characteristics without directly contacting them. It utilizes electromagnetic radiation as a medium for the measurement. The measurement principle in remote sensing is based on the fact that all matter reflects, absorbs, transmits, and emits electromagnetic radiation in a unique way with respect to wavelength. These unique properties in matter with respect to electromagnet radiation are called its “spectral characteristics (spectral signatures)”, and objects are identified, measured, and analyzed based on their different spectral signatures.

3.2.2 Remote Sensor

In remote sensing, the reflected or emitted electromagnetic radiation from a target is detected by a device called a “remote sensor”. Cameras or scanners are typical examples of these. A vehicle to carry the sensor is called a “platform”, and aircraft or satellites are usually used.

Human eyes can only detect a specific range of electromagnetic radiation called the “visible range”. However, remote sensing can utilize a wide variety of wavelengths covering the visible, near-infrared, and infrared to microwave ranges with various types of sensors. Utilization of different wavelengths enables the monitoring of various types of environmental parameters. For example, vegetation is characterized primarily in the near-infrared range, whereas thermal characteristics are distinguished in the thermal infrared wavelength band.

The performance of a remote sensor is determined by various specifications including spectral range, spectral resolution, spatial resolution, observation width (swath), or observation frequency. Different types of remote sensor have been developed with respect to these specifications. Table 3.1 summarizes the properties of typical remote sensors used for environmental and disaster monitoring.

High spatial resolution sensors such as LANDSAT TM, SPOT HRV, or IKONOS are used for local or regional observation, whereas low spatial resolution, but wide coverage and high observation frequency sensors such as NOAA/AVHRR, ADEOS/OCTS, and TERRA/MODIS are used for continental or global scale vision.

Table.3.1. Specifications of typical remote sensors

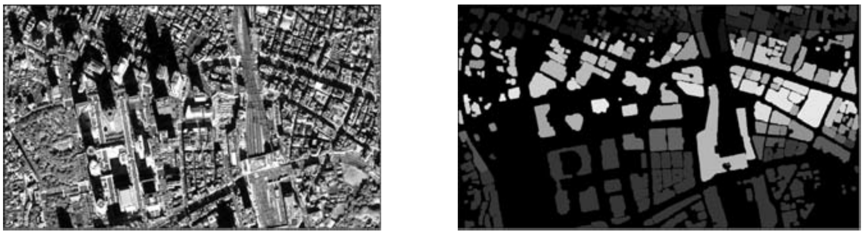
Satellite	Sensor	Wavelength (μm or GHz)	No. of bands	Spatial Res. (m)	Swath (km)	Cycle (day)
LANDSAT	TM	0.45-12.5	7	30	180	17
SPOT	HRV	0.50-0.89	4	10-20	60	26
ERS-1	SAR	5.3 GHz	1	20	100	35
JERS-1	OPS	0.52-0.86	4	18	75	44
	SAR	1.275 GHz	1	18	75	44
NOAA	AVHRR	0.58-12.5	5	1000	2700	0.5
ADEOS	AVNIR	0.40-0.92	4	8-16	80	41
	OCTS	0.40-12.5	12	700	1400	41
TERRA	ASTER	0.52-11.3	14	15-90	60	16
	MODIS	0.66-14.2	36	250-1000	2330	16
IKONOS	Pan/MSS	Vis./Near-infrared	1/4	1-4	11	11
ALOS	AVNIR-2	0.42-0.89	4	10	70	46
	PRIS	0.52-0.77	1	2.5	70/35	46

3.3 New Technical Developments in Remote Sensing

3.3.1 High-Spatial Resolution Observation

Spatial resolution is one of the most important observation performance factors in remote sensing. It has been dramatically improved in the last 20 years, and, today, one-meter spatial resolution is realized in satellite sensors. From these images, for example, individual buildings or tree canopies can be identified from space. High spatial resolution observation enables us to retrieve more detailed information on human settlements, land surface characteristics, or topography from remotely sensed data. Fig.3.1

shows an example of building distribution detected from an IKONOS image with a one-meter spatial resolution over the Shinjuku area of Tokyo, Japan. In this image, very fine spatial structures of buildings and roads are identified (Guo, 2003).



Original image Extracted buildings

Fig.3.1. Distribution map of buildings in the Shinjuku area of Tokyo, extracted from IKONOS image

3.3.2 Hyper-Spectral Observation

The number of spectral channels in conventional remote sensors has been limited to 10 or at most to several tens in satellite and airborne systems. New hyper-spectral sensor systems have the capability of observing the land surface using a couple of hundred channels. For example, the Hyperion on EO-1 has 256 channels. Airborne sensor systems such as CASI and AVIRIS also have more than 200 channels and their spectral resolution is as narrow as nanometers in wavelength. Data from such hyper-spectral sensors have indicated the possibility of observing new ecosystem parameters, including vegetation water stress or detailed vegetation categories that could not be observed by conventional sensors. Recently, new observation methods using the hyper-spectral remote sensors have been developed to detect concrete degradation.

3.3.3 Microwave Range Observation

With optical remote sensing we cannot observe the ground through cloud or dense haze. Microwave remote sensing has an advantage in all weather observations due to its longer wavelength. This observation capability enables us to monitor land surface conditions regularly, even in heavily clouded regions, including tropical or high latitude regions. A synthetic aperture radar (SAR) is a typical microwave sensor that enables high spatial resolution observation. Microwave remote sensing also has the capability of monitoring precipitation and soil moisture.

3.3.4 Three-Dimensional Observation

Detection of three-dimensional (3-D) structures on the ground is one of the essential information mechanisms to enable assessment of the environment and the extent of disaster. The information derived may be used for base data in wind simulation, run-off modeling, or landscape analysis. Since urban infrastructure is complicated by buildings, roads, or trees, it is not easy to extract 3-D information using conventional observation or survey methods alone. New remote sensing technologies may provide details of 3-D structures with a high spatial resolution. Laser ranging observation, for example, enables us to produce height distribution maps of buildings or trees. Fig. 3.2 shows an example of 3-D structures within the Shinjuku area of Tokyo observed from an airborne laser scanner (ALS) image. In this example, the land surface relief is removed from the original ALS data, and the relative height of objects including buildings or trees is illustrated by its intensity of gray level. It indicates that urban 3-D structures are extracted with high spatial resolution.

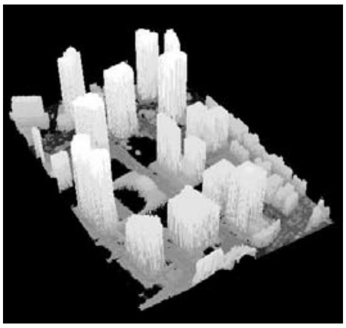


Fig. 3.2. 3-D structure of buildings and trees in the Shinjuku area of Tokyo, observed from ALS data.

3.4 Applications of Remote Sensing to Urban Assessment

The development of remote sensing technology has been very rapid, and a huge amount of data from different sensor types is now available to user communities. In this section, some application examples of remote sensing are introduced with an emphasis on their use in urban safety and sustainability assessment.

3.4.1 Assessment of Urban 3-D Landscape

Urban structure is one of the most essential factors that define the characteristics of urban safety and sustainability. Land use patterns or the distribution of buildings and vegetation play a key role in microclimate simulation, traffic navigation, or landscape planning. It is, however, not easy to model 3-D structures in an urban area since they are very complex.

In this application, an urban 3-D model is produced from the ALS data shown in Section 3.3.4 combined with high spatial resolution satellite data (IKONOS). Fig.3.3 demonstrates an example of an urban 3-D image with buildings and trees in the Shinjuku area of Tokyo (Yasuoka et al., 2005). Heights are extracted from the ALS data, and land-cover information including buildings and trees is extracted from IKONOS data. The trees in Fig.3.3 are simulated by a growth model after identifying their position, canopy size, and species from both the IKONOS image and the ALS data. This model enables us to simulate tree growth and conditions for the different seasons. Here, the 3-D tree model is generated using Nat-FX and 3-D modeling software. Nat-FX is a 3-D tree growth model developed based on the Atelier of Modeling of Architecture and Plants (AMAP).

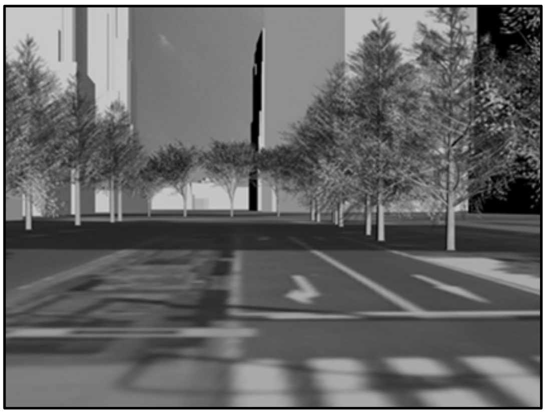
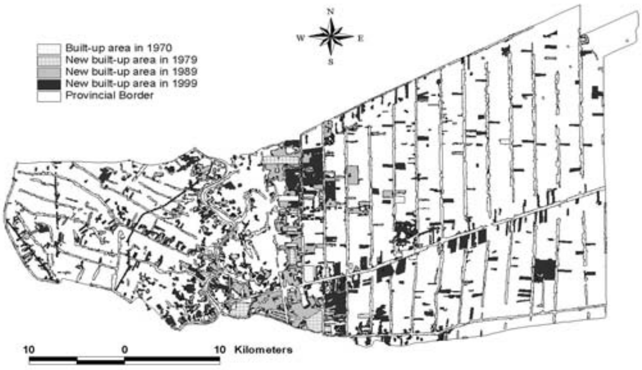


Fig.3.3. Urban 3-D model produced from IKONOS satellite image and airborne laser scanner (ALS) data. Trees are simulated using a growth model after identifying tree positions and species from remotely sensed data

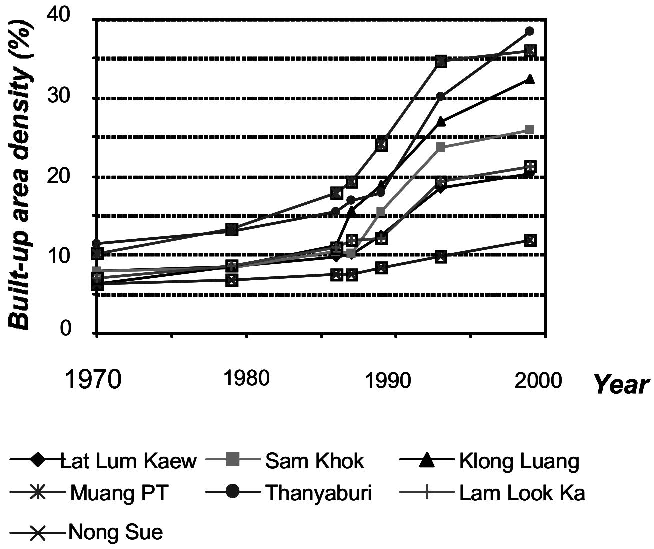
3.4.2 Monitoring of Urban Expansion with Satellite Images

The history of urban expansion is a most important parameter in assessing urban safety and sustainability. However, the long-term monitoring of land surface conditions in urban areas is not easy with ground survey alone since it requires the surveillance of complicated spatial structures of buildings, vegetation, and roads.

Remote sensing methods have been used to assess the spatial distribution of urban expansion by combining them with geographic information systems (GIS). An example in Fig. 3.4 demonstrates an assessment of urban growth around the Pathum Thani area near Bangkok, Thailand, from satellite data (Hung et al., 1999). It shows the rapid expansion of the Bangkok built-up area, and indicates the changes in population, environment, and other social factors. Spatial analysis using remote sensing and GIS enables us to measure changes in urban spatial and temporal structures. Furthermore, we can integrate different characteristics of the environment, disasters, or socioeconomic factors to assess urban sustainability and safety.



(a)



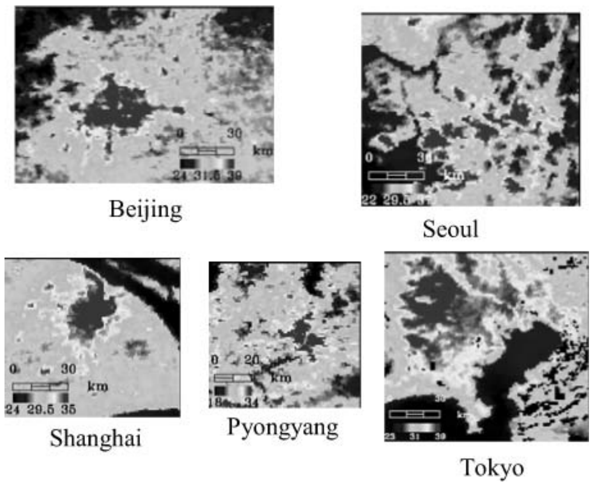
(b)

Fig. 3.4. Urban expansion in the Pathum Thani area, Bangkok (1970–1999). (a) Spatial expansion of the built-up areas. (b) Increased ratio of the built-up areas, region-by-region

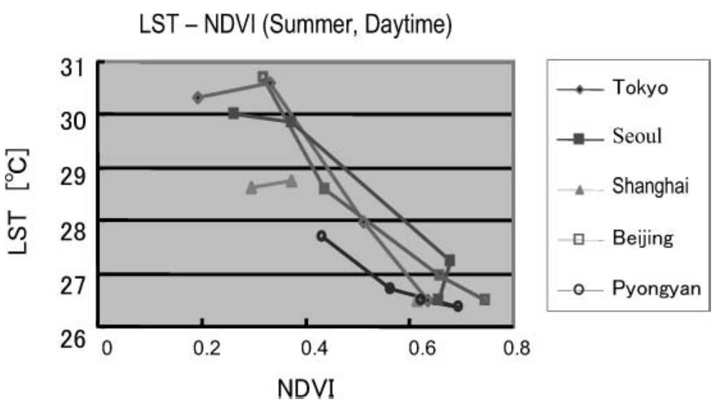
3.4.3 Monitoring of Heat Island

The heat island effect is a typical phenomenon in urban areas associated with an increase of population and human activity. It may have negative impacts on the physical environment and social infrastructure in most mega-cities in the near future. Monitoring and prediction of a heat island, however, is not easy since the thermal conditions of urban areas are not visible.

Remote sensing has provided an observation tool to monitor land surface temperature (LST) and to assess heat island conditions in cities using infrared wavelengths. Fig.3.5 illustrates heat island conditions in Asian cities (Hung, 2005). Fig.3.5 (a) shows the LST distribution in Beijing, Seoul, Shanghai, Pyongyang, and Tokyo, observed from MODIS data, and Fig.3.5 (b) illustrates the relations between the LST and the normalized difference vegetation index (NDVI), which is also derived from MODIS data. The NDVI is a very popular index showing how much of a unit area is covered by vegetation. Fig.3.5 indicates that the LST in urban areas has a negative correlation with the total vegetation amount in the unit area, such that the lower the vegetation cover, the higher the LST. It also implies that heat island conditions depend on the size of an urban area.



(a)



(b)

Fig. 3.5. Heat island conditions in five Asian cities monitored by MODIS. (a) Land surface temperature (LST) maps. (b) Relations between LST and NDVI in five cities

3.5 Conclusions

According to the United Nations forecast, in the middle of this century, the percentage of population in urban areas will be more than 60%, and the total number of mega-cities in the world will exceed 22. Urban safety and sustainability will be a critical factor in global management and the monitoring of urban conditions is a first step towards managing urban systems. It is not easy, however, to collect adequate information and survey data over extensive areas periodically and regularly.

Remote sensing has potential advantages in urban monitoring that are summarized as follows:

1. it does not disturb the object in measurement
2. it can cover extensive areas in a short time
3. it can measure parameters in the same spatial and temporal scales
4. it can cover land, ocean, and atmosphere where sometimes we cannot make direct observations

The development of remote sensing technology has been very rapid, and various types of remotely sensed material are available, ranging from high spatial resolution data for local monitoring to wide coverage data for regional/global monitoring.

Examples in this paper demonstrate the effectiveness of remote sensing in urban monitoring. Of course, it is not realistic to realize urban monitoring systems entirely by remote sensing. It is expected that a monitoring system will integrate ground observation, survey, and remotely sensed data for a complete urban assessment.

References

Guo T, Yasuoka Y (2003) Reconstruction of buildings from satellite image and LIDAR data. Proc. of the 24th Asian Conference of Remote Sensing (CD-ROM)

Hung T, Yasuoka Y (1999) Integration and application of socio-economic and environmental data within GIS for development study in Thailand. Proc. of the 20th Asian Conference of Remote Sensing (CD-ROM)

Hung T, Uchihama Y, Yasuoka Y (2006) Assessment with satellite data of urban heat island effects in Asian mega cities. International Journal of Applied Earth Science and Geoinformation 8: 34–48

Yasuoka Y, Yamagishi Y, Guo T, Endo T (2003) Extraction and 3-D visualization of trees in urban environment. Proc. of the Third Symposium on Urban Safety of Mega Cities Asia (USMCA), India (CD-ROM)

4. Visualization of Historical Data in Tokyo

Yukio Sadahiro[1], Eihan Shimizu[2] and Takashi Fuse[2]

[1]Department of Urban Engineering, The University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

[2]Department of Civil Engineering, The University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

4.1 Introduction

Public participation, which plays an important role in urban planning (Craig et al. 2002; Faga 2006), is based on people's continuing interest and concern for a place. Attractive locations draw the interest of a wide variety of people and capture attention by responding to popular demand for such places. This enables them to continue to meet the needs of people, consequently these spots are always lively for both residents and visitors.

Interest in places can take various forms. Some people are interested in shopping, while others like visiting museums and art galleries. Watching the passers-by is entertaining, especially in multiethnic cities.

One of the great interests shared by both residents and visitors alike is the history of a place. A young couple in a town may wish to know how the area looked before they moved there. Visitors to an old city may wish to know how the city was built more than a hundred years ago. Although variations exist in its degree, scale, and extent, an interest in history is widely shared.

People learn the history of a place from various sources: books, pictures, TV programs, and so forth. The main sources of spatial information are paper maps and old documents. Because the latter usually require specialists with a historical background to understand them, maps are the most popular source of historical spatial information.

With the introduction of widespread GIS, paper maps have been replaced by digital spatial data (Longley et al. 2005; Campagna 2005; Maantay et al. 2006). Existing maps are scanned and converted into a digital form and new maps are being created as spatial data alone. Historical maps are not exception, as they are converted into digital format and widely used in academic fields varying from history and archaeology to geography and city planning. Unfortunately, their usage is still limited to academic purposes, because such spatial data are not easily accessible by ordinary people. People must first learn how to use a GIS package in order just to browse spatial data. Although web-based map servers are easy to use, they usually provide only new maps.

An easy-to-use interface for historical spatial data enhances the interest of ordinary people in the antiquity of places (Knowles 2002). This motivated us to develop GIS-based tools for visualizing historical data on Tokyo, Japan. These are Dragon Fly and Hongo History. The former is an extension of a commercial product, and the latter is original software developed specially for this COE project. They each have their own advantages, and are complementary to each other.

Though the systems are applicable to any place or country, they were customized for use in Japan for two reasons. First, the systems have to handle the Japanese language and Chinese characters. Second, the systems visualize old pictorial maps that are drawn in a manner specific to Japanese map makers.

Section 4.2 describes the process of data creation. Sections 4.3 and 4.4 outline the system configuration and functions of extended versions of DragonFly and Hongo History. Section 4.5 summarizes the conclusions with a discussion.

4.2 Data Creation

The system contains a variety of spatial data to be visualized, dating from the mid-19th century to the present. They mainly cover the downtown area of Tokyo, although variations exist in both the extent and granularity due to different maps being used as data sources.

Among them, topographic and land/building use data play an important role in the visualization of the historical landscape. The creation of these data is described as follows.

4.2.1 Topographic Data

Topographic data for four periods were created from paper maps. Additionally, as there already exists a Digital Elevation Model (DEM) of five meters resolution available from the Geological Survey Institute, the system contains topographic data derived at five different times: 1909, 1928-30, 1955-56, 1983-84, and 2003.

The area covered by the dataset is shown in Fig.4.1. It corresponds to the region within six paper maps published by government institutes.

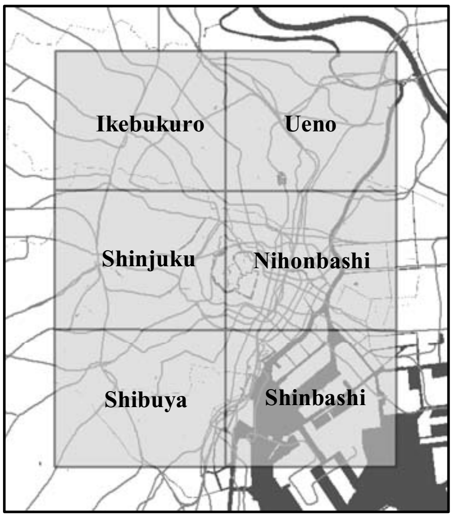


Fig.4.1. The area covered by topographic data. Each rectangle indicates the coverage of an original paper map

The paper maps were scanned as image files. Due to measurement error and some physical distortion, they could not be overlaid perfectly on the latest map, created in 2003, on which the DEM was generated. To fit the old maps to that of 2003, a geometrical correction was employed. One hundred and forty two control points were chosen whose location can be specified on the DEM, and were used as generators of Triangular Irregular Network (TIN) (Longley et al. 2005). In each triangle, an affine transformation was applied to obtain corrected images which fitted the DEM (for details, see Shimizu et al. 2005).

From the image files, contour lines and spot points were digitized (see Table.4.1). The map area was divided by TIN generated from spot points. In each triangle, the elevation value was estimated from that of spot points by linear interpolation. Water surfaces were also digitized separately (Fig.4.2).

Table.4.1. The number of contour lines and spot points digitized in paper maps.

	1909	1928-30	1955-56	1983-84
Spot points	420	361	343	1314
Contour lines	5138	3136	2363	13735

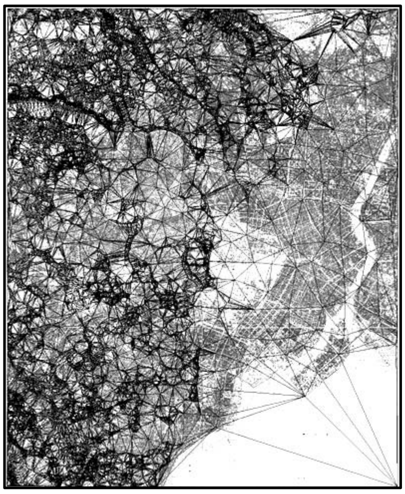


Fig.4.2. Interpolation of elevation model using TIN

The topographic data obtained from the paper maps are shown in Fig.4.3. Although there is no distinct change in the north and west inland area of Tokyo, it was found that the coastal line changed dramatically during the 20th century mainly because of land reclamation.

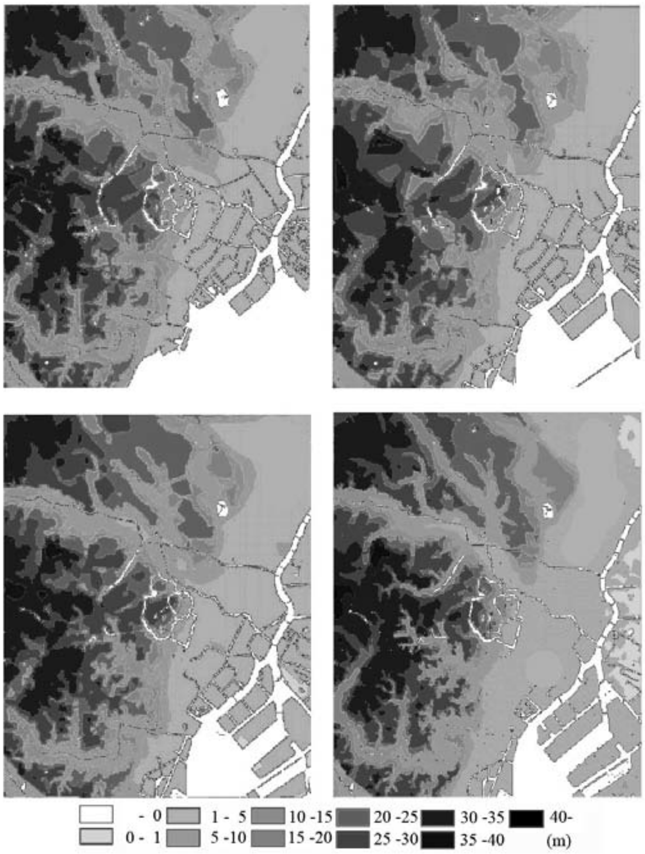


Fig.4.3. Topographic data for Tokyo, from 1909 to 1984

4.2.2 Land Use Data

Tokyo Metropolitan Government has undertaken a land/building use survey every five years since 1986. The result is a vector format spatial data, which covers the whole city.

However, such detailed data are not available for land use before 1986. In this project, land use data of the Edo period of the 19th century were created from the old Tempo Oedo Chizu paper map published in 1843 (Fig.4.4). This is a pictorial map, originally used for sightseeing in the Edo period.

Fig.4.4. Tempo Oedo Chizu (1843)

As the original map was distorted to a certain extent, a geometrical correction was necessary to enable its use with existing spatial data. First, the map was scanned as an image file, and then 1253 control points were chosen whose location could be specified on both the old map and the spatial data. A TIN was generated from those points, and an affine transformation was applied to the image data in each triangular region (for details, see Shimizu and Fuse 2005).

Land use data were created from the corrected image by manual digitization. Four thousand three hundred lots were digitized, and the land use data were added as their attribute. Each lot was classified into one of five categories: Daimyo yashiki (residence of feudal lord), Hatamoto yashiki (residence of samurai directly serving the Tokugawa shogunate), Kumi yashiki (residence of general samurai), Choninchi (residence of merchant or craftsman), and temple, or shrine (Fig.4.5). For the data of Daimyo yashiki, attribute data were also added that include the Daimyo's name, territory, relation to the Tokugawa shogunate, and so forth (see also Ai et al. 2004).

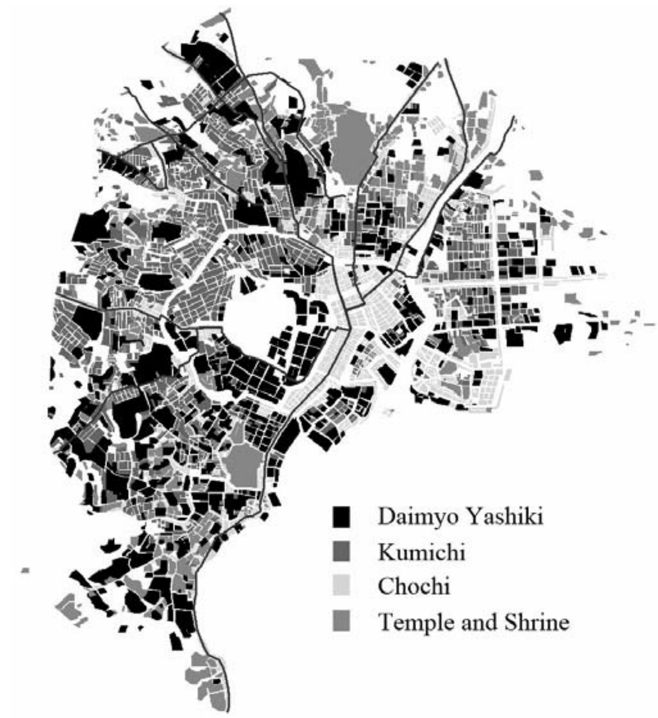


Fig.4.5. Land use data for Edo in 1863

4.2.3 Building Data (Micro Scale)

As well as the land use data, detailed information is available for the Tokyo buildings. Tokyo Metropolitan Government provides polygon data for buildings with information concerning the shape, usage, height, structure, and additional facts. As the data are based on the land/building use survey, these are available for 1986, 1991, 1996, and 2001.

Only paper maps were available for older data. There is a large range of these showing the use of buildings, with a wide variation in the scale and extent. Because digitization of such detailed maps is very costly, a small area was extracted for which the spatial data of buildings were constructed. The area consists of seven *Chochomokus* (administrative units each of which contains 50-100 census tracts): Hongo-4, -5, -6, Nishikata-1, -2, Mukogaoka-1, and Hakusan-1 (Fig.4.6). The area is called the *Hongo area* in the following account.

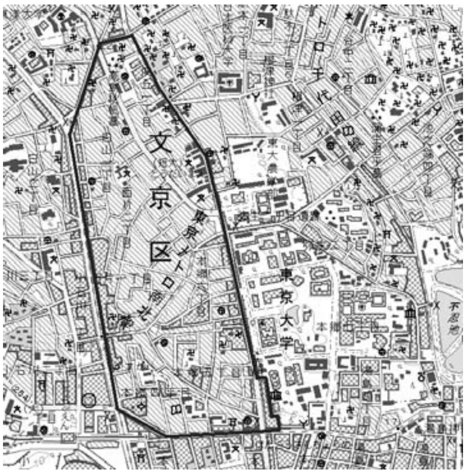


Fig.4.6. Hongo area in which building data were created from paper maps

Two sets of maps were used to create spatial data of buildings. One is the Jutaku Chizu, and the other is the Kasaihoken Tokushu Chizu (Fire Insurance Map).

Jutaku Chizu is a set of paper maps published by Zenrin Co. Ltd. at scales of 1:1500 and 1:3000. They contain the shape, name, number of stories, and type of structure of each building (Fig. 4.7). Maps for 1963, 1965, 1970, 1974, 1980, 1986, 1989, 1995, and 1999 were used as data sources. They were scanned into image files, and converted by a geometrical correction so that they could be overlaid on the Tokyo Metropolitan Government spatial data.

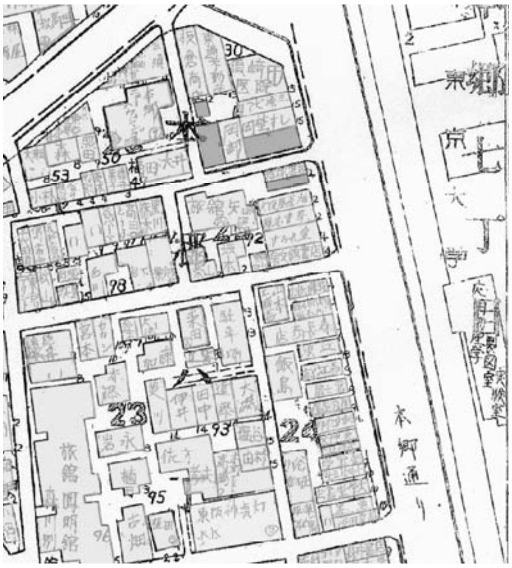


Fig. 4.7. An example of Jutaku Chizu

Another set of maps used for spatial data creation is called Kasaihoken Tokushu Chizu. These maps, printed from the 1920s to the mid-1950s, were created by several publishers and were used by insurance companies for their assessments. They contain detailed information about buildings and are quite similar to Jutaku Chizu, with scales ranging from 1:600 to 1:1200 (Fig.4.8).

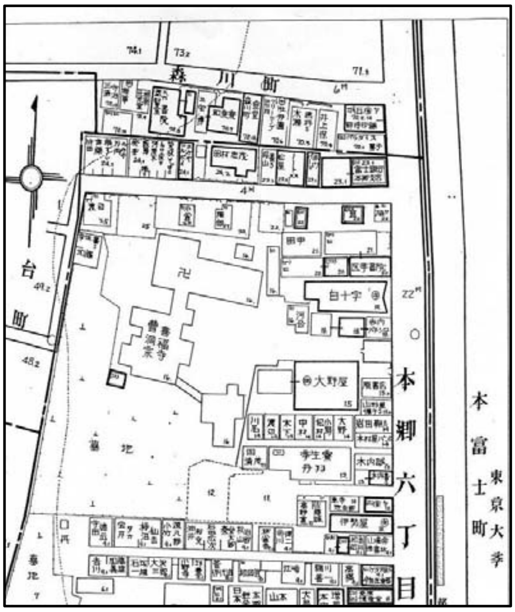


Fig.4.8. An example of Kasaihoken Tokushu Chizu

The Hongo area is covered by two sets of maps of different time periods: those of 1934-37 and of 1952-53. The former consists of 13 maps, while the latter comprises 40 maps.

Geometrical correction of the maps was done using Zmap Town II, which is a 2004 digital version of the Jutaku Chizu. The gravity centers of buildings were used to construct a TIN. An affine transformation was applied to the scanned images in each triangle separately, which gave a good fit with Zmap Town II.

Attribute data were also created from the Kasaihoken Tokushu Chizu. The maps contain the name of owner/store/restaurant, number of stories, and type of structure of each building. The use of buildings was inferred from their names and classified into one of 98 categories. A field survey was also undertaken to increase the reliability of the data.

4.2.4 Demographic Data

Demographic information was basically obtained from census data. The first census in Japan was taken in 1920. Since then, a census has occurred every five years except 1945, the final year of World War II. The data are aggregated at Chochomoku level to retain the confidentiality of individuals. As each census tract consists of about 50 households, one Chochomoku hosts 5,000-10,000 people.

Chochomoku units are not stable over time in Tokyo, primarily because the address system has been gradually changing for fifty years. The old system was based on land ownership, with every lot having a different address. On the other hand, in the new system, the address is determined by the geometry of blocks and lots, by which it is easy to specify the location of a given address. In this study, the latest Chochomoku system is used to represent the historical change of demography.

4.3 System Development 1: DragonFly

To evoke people's interest in the antiquity of places, the historical spatial data should be widely available to the public. To this end, two computer-based systems were developed that visualize three-dimensional spatial data.

One system is based on DragonFly, a commercial product of Maplink. DragonFly is a server-client system that visualizes three-dimensional spatial data on demand through Internet Explorer as images of two- or three-dimensional urban landscapes. The Apache Web Server is installed on a server machine with spatial data. Clients should have ActiveX installed, which is activated on Internet Explorer.

DEM data for the five different time periods mentioned earlier are stored on the server as base maps. Aerial photographs of the Tokyo area are overlaid on one of the DEM datasets as a background image.

A client calls up ActiveX on Internet Explorer in order to communicate with the server. The client then sends the position and orientation of the desired viewpoint as a set of XY coordinates, height, and direction. Having received a request, the server generates a TIN model from DEM data and sends it to the client with photo image data. The client places the image data on the TIN to create a three-dimensional view of aerial photographs or other maps (Fig.4.9).

One of the features of DragonFly is its fast 3D graphic engine. Huge amounts of spatial data in polygon format are used to describe the history of Tokyo. As these are overlaid on aerial photographs and high resolution satellite images as 3D images, the efficient handling of spatial data is essential. DragonFly uses a very fast algorithm in 3D visualization, which enables a user to browse urban images very comfortably without jerks. A user can easily change the position and angle of viewpoint using a mouse and control keys.

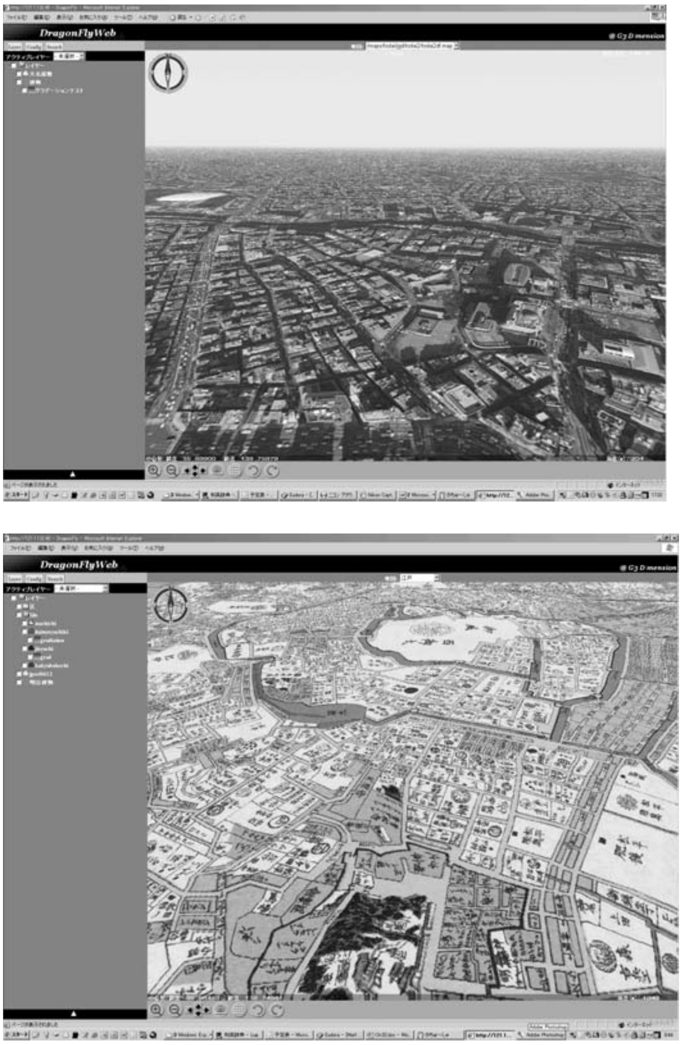


Fig.4.9. Aerial photograph and Tempo Oedo Chizu overlaid on DEM data

The original DragonFly was extended in this projects in order to visualize not only image data but also vector data in the ESRI Arcview Shape format, the default format used in ArcGIS, with a more user-friendly interface.

The first step in the extension was to deal with Shape format. This was essential, because land/building use data are created on ArcGIS. A CGI program is installed with the Apache Web server that handles spatial data stored in Shape format. When the server receives a request from a client, the CGI program extracts the Shape data and sends them to the client.

Having received the data, DragonFly opens them on the client computer and visualizes incorporating other spatial data (Fig.4.10).

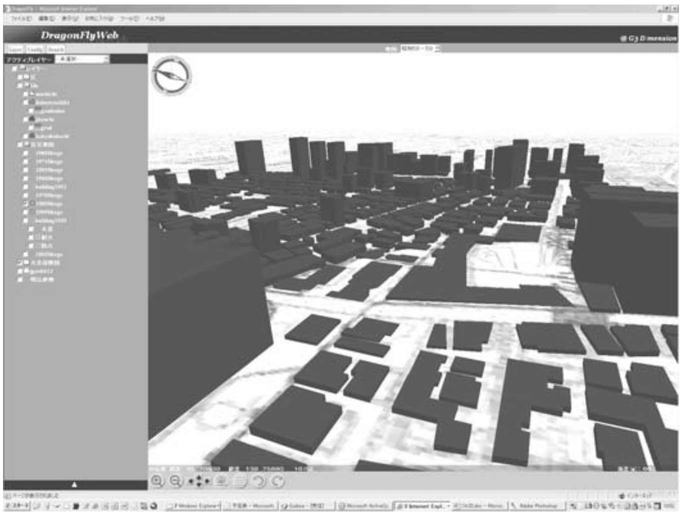


Fig.4.10. Buildings in the Hongo area in 1989. The data were created in ArcGIS and saved in Shape format

The original version can only use one color to represent multiple polygons. To improve the method of visualizing polygon data, new schema of symbolization were introduced. First, polygons are drawn in different colors according to a specific attribute value (Fig.4.11). Second, for a numerical attribute, color progressions are available that indicate the value of an attribute. Third, transparency is available so that the building use pattern can be examined through a three-dimensional view (Fig.4.12).

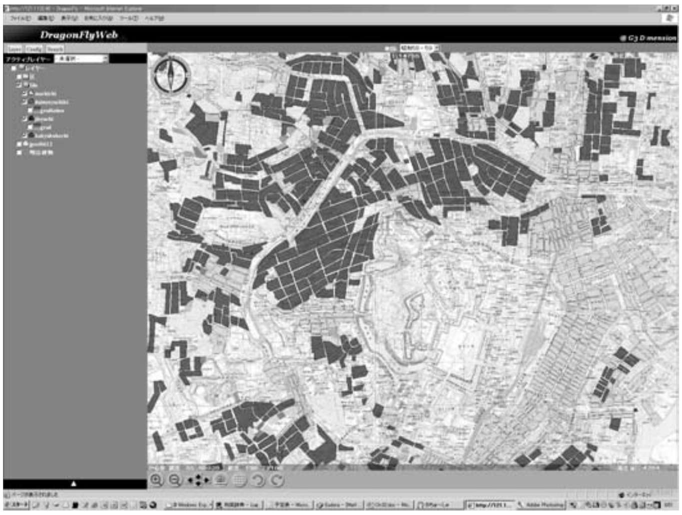


Fig.4.11. Land use pattern in 1843 shown on the map of 1983. Different colors indicate different land use categories

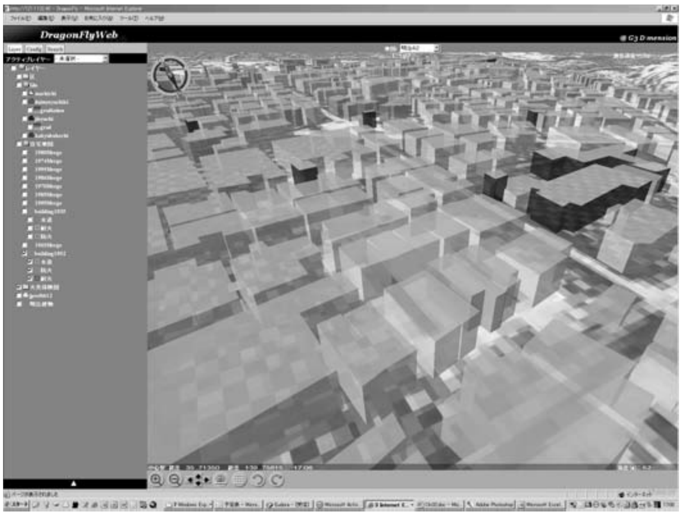


Fig.4.12. Buildings in the Hongo area in 1952-53. Colors indicate the structure of buildings. Transparency makes it easier to understand the local structure of the area

In addition to the extension of the visualization scheme, the user interface was improved for users without experience of GIS. Spatial data can be easily added or deleted. The order of data layers is changed by dragging layer names, and symbolization can be either changed flexibly or chosen from the defaults.

4.4 System Development 2: Hongo History

One of the advantages of DragonFly is, as mentioned earlier, its great ability to visualize three-dimensional spatial data. This facility is very effective when detailed three-dimensional data such as terrain elevation model and building height information are available. Realistic three-dimensional visualization enables us to understand the structure of cities more easily.

On the other hand, DragonFly cannot explicitly handle the temporal dimension embedded in spatial data. For instance, information about the appearance and disappearance of buildings can be visualized only as an attribute of spatial objects.

Historical data include, by nature a temporal dimension in order to contain the change of spatial objects. To complement DragonFly, another software called "Hongo History" was developed (Nakano, 2007) which visualizes three-dimensional spatiotemporal data as a movie. The name includes Hongo because it focuses on the visualization of local changes in that area (Fig.4.6), which are often overlooked if visualized by existing methods. The animation of topographical change permits us to easily understand the land reclamation in the Tokyo Bay area. Concentration of population is clearly displayed by visualizing time-series population distribution.

Hongo History has three windows, each of which can visualize different spatial data of the same region (Fig.4.13). The main window is located on the left, and is chiefly used to visualize the physical environment of the area such as topography, buildings, and traffic facilities. Two small windows on the right visualize other properties, for example population density, land use, building structure, and so forth. A user can easily compare different spatial data through the windows at various scales by changing the position and angle of viewpoint using a mouse and control buttons.

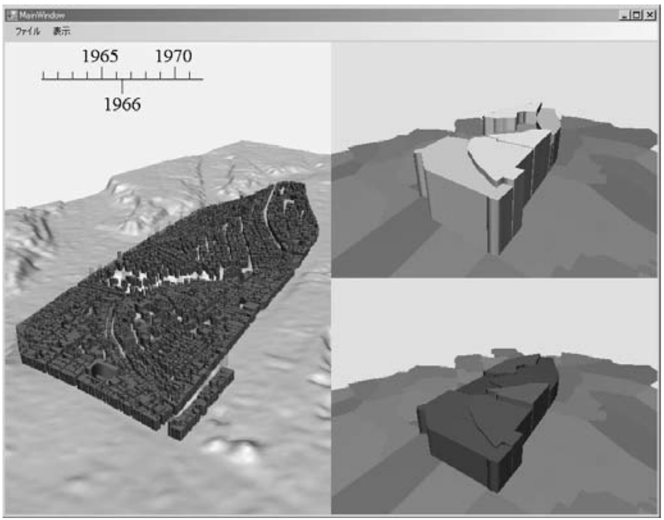


Fig.4.13. Three windows of Hongo History. The windows show different data of the same region

The main window has a scale bar indicating the time represented by spatial data. The time can be changed by pressing the arrow buttons on the keyboard, which generates a movie showing the changes in the Hongo area.

As mentioned earlier, the spatial data used in this study were obtained as cross-sectional information. Consequently, interpolation is necessary to create smooth and continuous movies. Linear interpolation was adopted to interpolate such numerical variables as elevation and population density. The overlap of multiple colors is used to represent changes concerning categorical variables such as the land use pattern. When an apartment is converted into a restaurant, the color of the building changes from yellow to red. By way of overlap of both colors, the latter is half-transparent, and overlaid on the former. Overlap is also used for numerical variables if linear interpolation yields an unnatural result for, say, a building height (number of stories) or road width (Fig.4.14). Old objects gradually disappear, while new objects appear as overlaps on older ones.

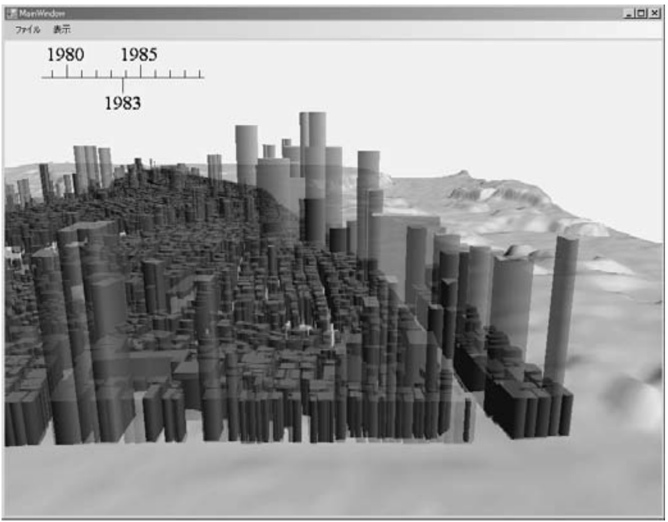


Fig.4.14. Interpolation of cross-sectional spatial data. Old buildings fade out while new buildings gradually appear

Because the animated visualization of spatio-temporal data is very smooth, a user may overlook dramatic changes that occur within a short time period. To avoid this, Hongo History can detect significant events in spatio-temporal data and show them to a user explicitly.

Hongo History can detect the following events:

1. Building construction/destruction
2. Building reconstruction
3. Road widening
4. Sudden increase/decrease of attribute values.

To detect these events, the system compares the spatial data for two different times. If spatial data are completely accurate and free from error, detection is straightforward. A building construction, for instance, can be detected by searching for a new polygon that does not overlap other polygons at an earlier time. However, as data error is unavoidable in a GIS, the detection of events requires a careful examination of polygon overlap (Sadahiro and Umemura, 2001).

Suppose spatial data of two different times t_1 and t_2 ($t_1<t_2$). Polygon j at time t_i and its area are denoted by P_{ij} and a_{ij}, respectively. Let o_{ij} be the area of overlap of P_{1i} and P_{2j}.

For spatial changes such as those mentioned above, detection begins with the examination of the relationship between overlapping polygons derived at two different times. If o_{ij}/a_{1i} and o_{ij}/a_{2j} are both smaller than a threshold α, say, 5%, the overlap is considered as data error (Fig.4.15a), and the polygons are regarded as having no specific relationship. If one of the variables is larger than α, the relationship between P_{1i} and P_{2j} is classified into one of three categories: 1) P_{1i} contains P_{2j}, 2) P_{2j} contains P_{1i}, and 3) P_{1i} and P_{2j} are overlapped with each other. If o_{ij}/a_{2j} is larger than a threshold β, say, 95%, P_{1i} is regarded as containing P_{2j} (Fig.4.15b). If o_{ij}/a_{1i} is larger than β, P_{2i} contains P_{1i} (Fig.4.15c). If both of the conditions are satisfied, P_{1i} and P_{2j} are overlapped with each other (Fig.4.15d).

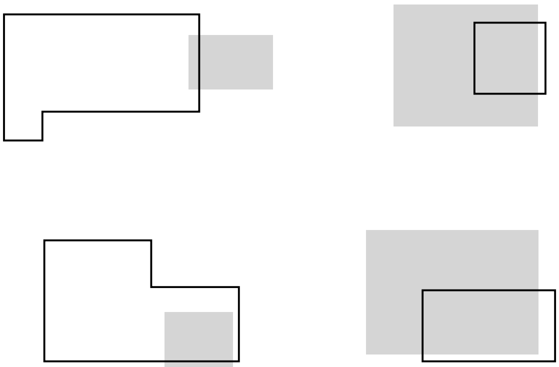


Fig.4.15. Four types of relationship between polygons of two different times. Gray shaded and solid line polygons indicate polygons at t_1 and t_2, respectively. (a) P_{1i} and P_{2j} are independent, (b) P_{1i} contains P_{2j}, (c) P_{2j} contains P_{1i}, and (d) P_{1i} and P_{2j} are overlapped with each other

Construction of a new building is detected by considering the relationship between a polygon at t_2 and its overlapping polygons at t_1 (Fig.4.16). If a polygon at t_2 has no relationship with polygons at t_1, it is regarded as a new building. Building destruction can be detected in a similar way.

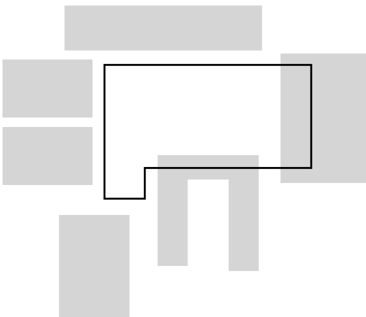


Fig.4.16. Detection of building construction. Gray shaded polygons indicate existing buildings while a solid line polygon is a new building

Building reconstruction is represented as a more complicated change of polygons. It is classified into five categories by the relationship between polygons of different times. These are expansion, shrinkage, merge, split, and recomposition. Suppose a polygon P_{2j} contains another polygon P_{1i}. If P_{2i} does not have any relationship with other polygons at t_1, change from P_{1i} to P_{2j} is regarded as an expansion (Fig.4.17a). A shrinkage occurs in the opposite case, where P_{1i} contains P_{2j} and does not have a relationship with other polygons at t_2 (Fig.4.17b). If P_{2j} contains more than one polygon at t_1 and has no relationship with other polygons at t_1, change of multiple polygons at t_1 into P_{2j} is regarded as a merge (Fig.4.17c). If P_{1i} contains more than one polygon at t_2 and has no relationship with other polygons at t_2, change from P_{1i} into polygons is a split (Fig.4.17d). Changes of polygons not classified into one of the above four categories are called recomposition (Fig.4.17e), which often involves multiple polygons of different times and the relationship is not limited to containment but overlaps.

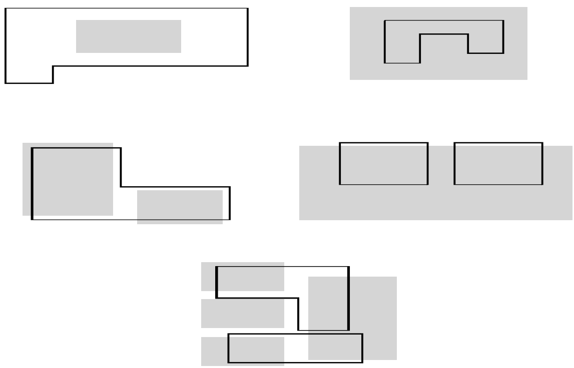


Fig.4.17. Five types of building reconstruction. Gray shaded polygons indicate existing buildings while solid line polygons are new buildings. (a) Expansion, (b) shrinkage, (c) merge, (d) split, and (e) recomposition

Road widening is a special case of polygon expansion. The system considers only polygons representing traffic roads and detects road widening if the change of a road polygon is classified into expansion by the procedure mentioned above.

Sudden increase/decrease of attribute values can be detected by comparing only the attributes of spatial data. Examples include the change of an old ten-story apartment block into a new fifty-story building.

Significant events that are detected are visualized by three-dimensional symbols inserted in a usual display. Building reconstruction, for instance, is indicated by colors; old buildings are shown in blue whereas new buildings are colored red.

4.5 Conclusion

In this paper, two systems have been developed for visualizing historical data in Tokyo. DragonFly is outstanding for its great ability to visualize three dimensional spatial data. It can handle a huge amount of data in a very short time. Hongo History, on the other hand, is useful for understanding the historical change of an urban environment. Using the two systems together, people can enjoy seeing the history of their own cities and towns, which leads to a wide interest in city planning and urban regeneration.

Finally, we discuss the limitations of this paper for future research. First, for user convenience, it is better to integrate the two separate systems into one. As integration often degrades the ability of each system, careful consideration is necessary to ensure an optimum tradeoff between functionality and operability. Second, algorithms of change detection should be further refined. At present, they are based on the area of polygon overlap, with no consideration of the shape, orientation, and other properties of the polygons and their overlaps. As these properties also determine the importance of changes, they should be taken into account in the detection algorithm. Third, spatiotemporal interpolation methods should be further sophisticated. Although linear interpolation is intuitively natural and understandable, it often causes unexpected results especially when applied to both spatial and temporal dimensions at the same time. An interpolation method that considers both of these dimensions should be developed.

References

Ai H, Onishi K, Miura Y, Yamauchi N, Sadahiro Y (2004) Spatial analysis of land use in Edo using old paper maps. Papers and Proceedings of Geographic Information Systems Association 13: 335-338

Campagna M (2005) GIS for Sustainable Development. CRC Press, London

Craig WJ, Harris TM, Weiner D (2002) Community Participation and Geographical Information Systems. CRC Press, London

Faga B (2006) Designing Public Consensus: The Civic Theater of Community Participation for Architects, Landscape Architects, Planners, and Urban Designers. Wiley, New York

Knowles AK (2002) Past Time, Past Place: GIS for History. ESRI Press, Redlands, CA

Longley A, Goodchild MF, Maguire DJ, Rhind DW (2005) Geographical Information Systems: Principles, Techniques, Management and Applications. Wiley, New York

Maantay J, Ziegler J, Pickles J (2006) GIS for Urban Environment. ESRI Press, Redlands, CA

Nakano J (2007) Visualization of Three Dimensional Historical Data: A System Development. Master's Thesis, Department of Urban Engineering, University of Tokyo

Sadahiro Y, Umemura M (2001) A computational approach for the analysis of changes in polygon distributions. Journal of Geographical Systems 3: 137-154

Shimizu E, Fuse T (2005) A method for visualizing the landscape of old-time cities using GIS. In: Okabe A (ed) GIS-based Studies in the humanities and social sciences. CRC Press, London, pp 265-277

5. Urban Transport Data Fusion and Advanced Traffic Management for Sustainable Mobility

Masao Kuwahara and Shinji Tanaka

Institute of Industrial Science, The University of Tokyo, 4-6-1, Komaba, Meguro-ku, Tokyo 153-8505, Japan

5.1 Overview

Recent innovative technology on positioning and communication has realized several caches of advanced sensing data on transport. In addition to conventional traffic detector data, advanced vehicle identification (AVI), probe vehicle, electronic toll collection (ETC), and vehicle information and communication system (VICS) data have become available. The most unique feature of these advanced data is their provision of the capability to trace an individual vehicle motion time-dependently along its travel route. For example, the trajectory of a probe vehicle can be measured by matching the vehicle identification number (ID) transmitted from the vehicle at a certain frequency. VICS information through roadside infrared beacons also identifies the ID of a vehicle passing each of the beacons. Compared to the information from conventional traffic detectors, which measure spot speed, flow, and occupancy, the advanced data represent much richer information and may be utilized for sustainable traffic management.

With regard to the above, it has long been known that urban traffic congestion occurs due to a surprisingly small amount of excess demand, equal to travel demand less highway capacity. Within local streets, intersections are usually capacity bottlenecks, due to conflicting traffic streams flowing through an intersection. On motorways, sags, tunnels, merging and diverging sections, and tollgates may pose bottlenecks.

Through our daily experience of frequent as well as heavy traffic congestion, we tend to believe that many locations on a highway network have capacity problems and an excessive demand. However, the number of bottlenecks is actually not great, and heavy traffic congestion leading to a 10–20 km queue can be caused by as little as 10 to 20% of excess demand. This seems quite different from our usual impression of traffic congestion.

The above observation means that a modest capacity improvement and/or a slight travel demand adjustment could substantially alleviate congestion. Consequently, better traffic management involving travel information provision, traffic regulation, and travel demand management could indeed possibly be effective in establishing a sustainable mobility. Such management schemes must be designed based on the efficient utilization of advanced sensing data.

In this chapter, the fundamental characteristics of advanced traffic data are first summarized. Then, a framework of data fusion is discussed. Each set of traffic data has its information limitations. As a typical example, traffic detectors measure a large number of passing vehicles, but at spot locations, whereas probe data provide individual vehicle trajectories, but currently only for a small number of vehicles. To draw a complete picture of the state of urban traffic, a fusion of data is therefore required. The design of a data fusion framework and a pair of case studies are presented. Finally, some effective traffic management schemes such as travel time information provision and travel demand management are introduced, together with traffic simulation modeling, which is a promising analytical tool for dynamic traffic congestion.

5.2 Data Variety and Its Characteristics

5.2.1 Vehicle Detectors

Vehicle detectors are the most commonly used data collection device in road and traffic management. These instruments are installed not only on highways but also in general streets.

There are two types: loop detectors and ultrasonic wave detectors. Loop detectors are installed in the road surface, whereas ultrasonic wave detectors are installed at the roadside or overhead. In the early days, loop detectors were most commonly used for repeated road use traffic data collection, however they present maintenance problems, due to abrasion and road construction. Ultrasonic wave detectors are superior, in that they require less maintenance, and therefore are the most commonly used nowadays.

Fig.5.1 outlines the detection procedure using ultrasonic wave detectors and Fig.5.2 shows double node detectors.

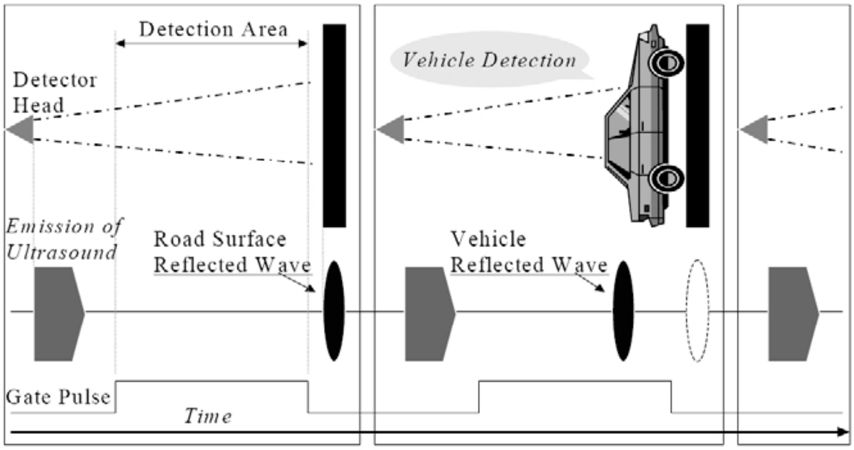


Fig.5.1. Vehicle detection technologies by pulse ultrasonic detector

Fig.5.2. Overhead ultrasonic vehicle detectors (double node)

Vehicle detectors use simple detection logic. These instruments measure the passage of a vehicle through a section and can have either single or double nodes. Single node detection can only collect volume and occupancy, but double node detectors can also measure speed.

5.2.2 Probe Vehicles

Probe vehicles, also known as floating cars, can provide information about their location at different time intervals. These vehicles provide time-stamped coordinates as a minimum, and sometimes other characteristics, for example speed, braking condition, and turning indications are also given. Information derived from these vehicles can be used to assess the traffic conditions in their vicinity. The vehicles are characterized as mobile sensors, as they provide information about the surrounding traffic conditions whilst moving through the road network.

Probe vehicles relay their position information to a central location such as a traffic management center where data from all the probe vehicles is collected, processed, and disseminated to road users in the form of useful information. Probe vehicles can use either mobile phones or GPS equipment to collect and communicate their location information. Mobile phones inside vehicles act as traffic probes by sending signals to a central location, which locates them using triangulation. Alternatively, each vehicle is equipped with a GPS unit that locates the vehicle coordinates and a radio unit that transmits the position to the central unit. GPS-equipped vehicles provide the most accurate information but are costly.

Probe vehicles are advantageous over other traffic information sources in terms of continuity of information, because each vehicle relays its information as it moves in a traffic stream, instead of providing static observations collected from roadside sensors. At the same time, there are disadvantages, as the information collected from a single vehicle may not be representative of all the vehicles around it. This situation demands a larger sample of probe vehicles in order to get meaningful and statistically significant information that can provide data concerning the population of all vehicles on the road. For statistically significant information, a good spatial and temporal coverage from probe vehicles is needed. Ideally, all roads should be covered all the time.

The use of probe vehicles is simplified if combined with a fleet management system such as those used for taxis or buses. Usually, such fleets have in-vehicle units, which communicate the present location and can be used for extracting traffic information, although the information provided may be limited. For example, in the case of buses, only fixed route traffic information can be acquired, while with taxis, mostly short-haul trips are recorded. In an ideal situation, all vehicles will be providing their location information to a central unit, which will process and disseminate the best possible traffic network state information to users in order for them to make knowledgeable decisions. The major hurdle in achieving this ideal state is a fear that this information network can be used for the surveillance of individual users.

Other possible uses of probe information include incident detection and the automatic updating of digital road maps in the event of a new road being added. There are many other applications.

5.2.3 Automatic vehicle identification (AVI)

As the name implies, an AVI traffic sensing system is based on automatic identification of the vehicles on the road. The system consists of a fixed infrastructure on the road that uniquely identifies the vehicle when it passes near to it. In contrast to probe vehicles, which provide continuous traffic stream location data, AVI systems only identify a vehicle when it passes near to a detector. AVI systems can be used for different purposes such as automated charging, traffic violations detection, fleet management by public transport companies, vehicle actuated traffic control, and so forth.

AVI systems can use different types of identification technologies. Two of the main technologies are:

1. License Plate Recognition: these types of systems mainly consist of an on-road video camera and a processing unit that processes the image and extracts information to uniquely identify the vehicle, which in most cases is via the license plate. These types of systems do not require an onboard unit, and the roadside camera and processing unit suffice. The limitation of this type of system is inherent in the limits of the video detection and image processing systems. Accuracy of these systems can vary according to different weather and lighting conditions. This type of instrumentation is used in London for enforcing road congestion charging, as it identifies the license plates of vehicles entering the congestion charging zone.
2. Transponder/Interrogator Systems: these types of system consist of an on-road interrogator and an in-vehicle transponder. The in-vehicle transponder communicates with the on-road interrogator whenever it approaches to within a certain distance. Nowadays, the most commonly used technology for these types of systems is radio frequency identification (RFID). Each vehicle carries an in-vehicle unit with a portable or fixed RFID tag that transmits its information to a tag reader on the roadside. This approach is used in Japan for the electronic toll collection (ETC) system. This method requires each vehicle to have a holder which carries a pre-paid ETC card with an

RFID tag inside which is identified by the roadside gantries. Tolls are deducted, and the vehicle is allowed to enter the highway system.

5.2.4 Electronic Toll Collection (ETC)

The ETC system was started in the Chiba and Okinawa area of JH (Japan Highway Public Corporation, currently Nippon Expressway Company Limited) and also at 11 tollgates of the Metropolitan Expressway (MEX) in March 2001. The number of ETC tollgates is gradually increasing, and now most of the tollgates on expressways in Japan are equipped with ETC. Using ETC onboard equipment, there is no need to stop to pay at the tollgate on an expressway, because the charge will be automatically deducted from the ETC credit card after detection by roadside antenna alongside the tollgate. Increasing use of ETC is expected to reduce traffic congestion, because the traffic capacity of the tollgate and the passing speed of vehicles increase as the proportion of ETC equipped vehicles rises. In fact, the number of ETC vehicles on MEX rose to about 70% in 2006, and the traffic congestion problem at mainline tollgates is, to a large extent, now resolved. In addition, tollgate carbon dioxide (CO_2) emissions were reduced by 38% when the proportion of ETC equipped vehicles reached 60%.

Concomitantly with the above, expressway companies are continuously storing up ETC user records (ETC-OD Data), because the company charges the toll through a credit card company. ETC-OD Data consist of ETC card ID, entrance/exit time, usage ramp, vehicle type, and so on. The ETC card ID is assigned by the expressway company when a driver uses the ETC system for the first time. For security reasons, the ETC card ID is randomized, but the same ETC card always has the same ID. Thus, we can analyze traffic condition on the expressway and user behavior using ETC-OD Data. Furthermore, we can analyze user activity on the expressway focusing on one particular client, for example how frequently and when each of the on/off ramps is used by an individual driver.

If we focus on one particular user, we can analyze their frequency, daily variation of usage time, travel time variations, and so on. Furthermore, if we aggregate the number of ETC users on each on/off ramp, we can measure more than 60% of origin-destination (OD) traffic volume on the expressway, together with its variation, because ETC-OD Data is collected continuously and the current average proportion of ETC users in Japan is greater than 60%. In addition, it is possible to fuse ETC-OD Data with other data sources. For example, fusion of ETC-OD Data and detector data is expected to help in route identification. Because ETC-OD Data only tell us the on/off ramp used for the trip, the route is impossible to identify from ETC-OD Data alone. However, ETC travel time, calculated using entrance and exit times, can be mapped to detector travel times to ascertain the possible route between the on and off ramp. If the relationship between ETC and detector travel times is significant, then the ETC user route can be identified. Similarly, ETC-OD Data may also be fused with other traffic data sources, for example, probe and VICS.

5.2.5 Image Sensors

Image type vehicle detectors are becoming increasingly popular due to the recent progress in the development of image processing technology. This method utilizes a normal TV camera installed at the roadside, as shown in Fig.5.3, which processes the image taken to obtain traffic information, that is, vehicle count and type, spot speed, occupancy, and queue length.

Fig.5.3. Image sensor

The camera has its own view angle of a certain size, a part of which is used to detect traffic flow (count, speed, etc.) and vehicle existence (queue). The conceptual image of the detection area is shown in Fig.5.4.

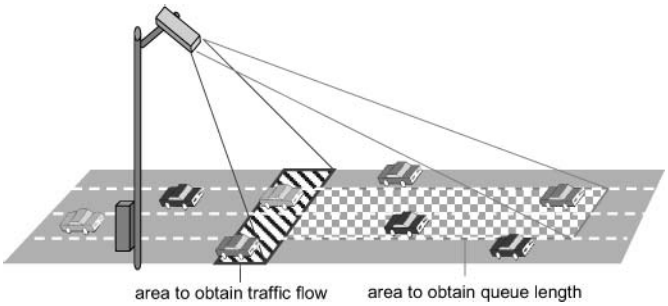


Fig.5.4. Detection area

The advantages of image sensor, compared with conventional types of vehicle detector, are as follows:

1. It can cover more than one lane using a single camera sensing unit
2. It can cover a wide area, which enables it to obtain queue length
3. Fewer sensing units mean less maintenance cost
4. The visual image might be helpful in understanding incidents and events on the road.

5.2.6 Measurement Vehicle

An experimental vehicle carries several kinds of sensors and an integrated data recording system. A software algorithm is also developed for obtaining the dynamic characteristics of the vehicle and those of others nearby. A measurement vehicle can collect speed, acceleration, spacing, longitudinal and lateral position, all simultaneously.

The real-time kinematic global positioning system (RTK-GPS) is used to locate the position of this measurement vehicle on the road. This RTK-GPS can provide position information with an error of less than 10 cm. The speed of the experimental vehicle is calculated successively using axle rotation pulse information. A tri-axial dynamical angle sensor is used to measure the heading direction and angular velocity of the vehicle. Laser sensors are used to measure the front and rear space clearance as distances to the leading and following vehicles. Four charge coupled device (CCD) cameras are installed to capture video images of the surrounding traffic. These images are later processed using the video processing software to extract traffic conditions.

The core of the on-board system utilizes high-precision time information provided by the GPS for data collection. The synchronizing signals and the time codes are successively created in the "synchronized signal generator with GPS" (SSG-GPS) with high-precision time information. Any data collected at a given time is synchronized accurately with each frame of the video image (1/30 second). They are then input to the "driver's behavior data processing equipment" (DB-DPE) with a conversion of time-code and recorded in the personal computer through Ethernet. At the same time, the differences in the sampling frequency between the various measuring instruments are corrected, for example by rearranging the intervals in multiples of 1/30 second. A general illustration of the onboard system is shown in Fig.5.5.

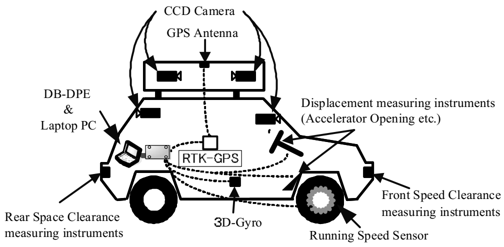


Fig. 5.5. Appearance and devices of the measurement vehicle

5.3 Framework to Combine Various Data Sources for Urban Transport Management

5.3.1 Introduction

In order to combine various data sources for urban transport management, we have to overcome their incompatibility, as mentioned in the previous chapter, and accommodate developing detection methods such as via cell phone data. This section proposes a framework for handling and processing data collected by various systems uniformly. The proposed framework is a three-layer approach, separating data storage from the processing and application layers. The advantage of such an approach is the independence of each layer, which allows a fast partial update and an easy distribution of developing tasks based on the predefined structure. The following provides a detailed view of each layer in the framework, and its usage.

5.3.2 Data Storage Layer

Data stored from different sources could be handled separately for simplification. However, this would result in a huge overhead while processing the data and all the algorithms used would be dependent on the individual data structure. To overcome this drawback, the data is pre-processed and stored in a unified structure. Using an object-oriented database, a uniform data object can be used for further processing and also relate to values in underlying source-related data objects, thereby extending the uniform data object. In other words, data can be handled independently from its source, and can be treated commonly.

The disadvantages of object-oriented databases, such as those used for general-purpose queries on the same information using pointer-based techniques, which tend to be slower and more difficult to formulate than relational ones, can be neglected due to the specific purpose and the ability of optimization for that purpose. Furthermore, object-oriented database systems in such special applications mostly outperform the traditional relational database applications.

In addition, search bots are included to gather data from remote databases. This measure allows data to be stored at their collection point and overcomes data redundancy and an overgrown database. Remote connections outside the university network will be secured according to the confidentiality of the data.

5.3.3 Data Processing and Handling Layer

As the data processing can be based on a uniform data object, the processing and handling is completely independent of data storage, and can be developed in parallel. The major task of this layer is compilation. The different data sources need to be matched in time and space to allow an overview of the available information for a given zone or area.

In a second step, this data is going to be fused to a single dataset, combining values from different sources to a single value. To achieve this, fusing techniques will be used based on Kalman filtering, Bayesian reasoning, and neural networks depending on the data sources that have to be fused. These combined data sets can then be used for further applications invoked by the application layer of the framework.

5.3.4 Application Layer

The top layer of the framework is the application layer. This is the interface that enables outside programs to access either the database directly or the fused data sets from the processing layer. Introducing this layer as an interface serves the purpose of a database management system, and ensures the integrity and security of the data. Allowing direct access could lead to gridlocks if several applications request related data simultaneously.

In other words, the application layer functions as middleware for any application that uses the database and its processing algorithms. Network accessible applications can use all framework functionalities remotely, allowing decentralization. Public interface descriptions will be provided to allow developers to connect their applications, and a web-based browsing tool will complete the layer, allowing users to upload and extract raw data sets.

5.3.5 Usage for Urban Transport Management

Having dealt with the technical issues, we will now focus on the usage of the framework to add more substance to the modeling and implementation decisions made for urban transport management.

Fig. 5.6 is a scenario for usage of the framework in various applications as well as ways of updating the database and the processing tool provided.

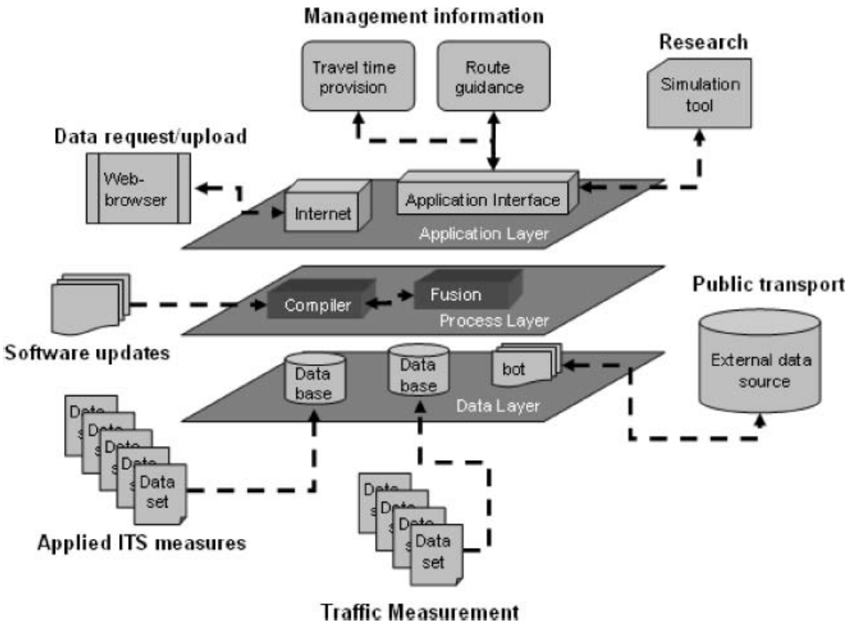


Fig.5.6. Possible usage scenario for the framework

The data layer is fed by different data sources and is updated event based, i.e. updated when new data becomes available. The process layer is hidden and only accessible for authorized software updates of the used algorithms. The application layer makes all information public, allows web based access to the database, and can be used to feed management and information requirements such as travel time provision or route guidance systems.

With the change from offline to online systems in the world of transportation, the data can also be used to feed online simulation tools to allow for anticipation of actual conditions. Finally, the database allows access for research institutions to develop and test new algorithms or software tools for advanced traffic management.

In the following sections, we present case studies (see section 5.4) and possible applications (see section 5.5) of such a framework in advanced urban transport management for a sustainable city.

5.4 Case Studies

5.4.1 Bus Travel Time Analysis Using Probe Data

Introduction

The travel time of a bus on an arterial route varies considerably throughout the day, as well as during the days of the week. To predict the travel time accurately, its variability should also be taken into consideration.

In this study, bus probe data are used. These data provide information about the bus location at specific intervals, for example every second, and can be used to track the bus trajectories, which in turn can provide important insights into cruising and stopping patterns, and durations.

The travel time of a bus can typically be divided into two main components: cruise time and stopping time. Stopping time of a bus can be further subdivided into bus dwell time at bus stops, and during intersection delay. Cruise time is affected by time of the day, day of the week, land use pattern (commercial, industrial and residential), number of lanes in the road section, traffic volume, and number of bus stops, as well as other factors. Bus dwell time at a bus stop depends on the number of passengers boarding or alighting, which in turn depends on the land use and population density in the locality. Intersection delay is affected by the signal parameters and traffic demand at a given time. This research attempts to explore the bus travel time variability on an arterial road and determines the effects of the factors outlined above.

Route Data

The bus probe data collected on a bus route starting from Shin-Yokohama station to Kami-Sueyoshi intersection, with a total length of 5.8 km, is used in this study. This route passes through different land use zones. There are 24 signal intersections on the route, and the number of lanes varies from two to four. There are 14 bus stops outbound and 15 inbound.

Bus Probe Data

Bus probe data from real world transit operations provide a valuable input to the prediction of bus travel time. GPS devices were installed in twenty buses running along the route, and the data were collected for a period of one year, from August 2003 to August 2004. The data include location, instantaneous speed, and cumulative odometer readings.

The raw data were processed and separated into inbound and outbound trajectories, and 5,115 inbound and 4,640 outbound bus trajectories were identified for further analysis.

Bus Travel Time Tnalysis

In this section, bus travel time variability is analyzed, and different factors inducing this variability are explored in detail and their effect quantified.

Bus Travel Time Variability

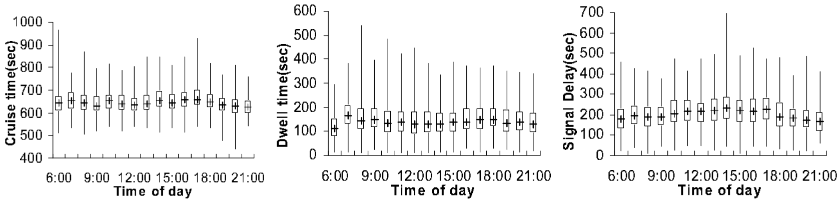
To analyze the variability of bus travel time, a preliminary analysis of the total travel time as well as cruise time, bus stop dwell time, and intersection delay was conducted. It was found that over 65% of bus travel time is composed of cruise time, whereas intersection delay and dwell time account for 20% and 15% respectively. Analysis reveals that total travel time has a coefficient of variation of about 12–15% in both directions. A further breakdown of the travel time components reveals that the variation in cruise time is not more than 10%, while intersection delay has a variation of around 35% and bus dwell time has the highest variation of over 45%. It is also found that around 35–40% of the buses have deviations of more than two minutes from the posted timetables.

Table.5.1. Mean (μ), standard deviation (σ) and coefficient of variation (CV) of bus travel times

	Inbound Direction				Outbound Direction			
	Cruise Time	Dwell Time	Delay Time	Travel Time	Cruise Time	Dwell Time	Delay Time	Travel Time
μ(sec)	663	141	213	1076	648	144	208	1070
σ(sec)	70	70	70	160	51	66	78	133
CV (%)	10.5	49.3	33.0	14.8	7.9	45.5	37.6	12.5

Bus Travel Time Variability by Time of the Day

Fig.5.7 shows the variation in cruise time, dwell time, and intersection delay experienced by the buses for different times of the day using Box–Whisker plots. It is evident that although the mean travel times or delays are constant, the variations are considerably different by the time of the day. For example, the cruise time shows almost consistent variations for different times of the day, while the bus stop dwell time has higher variations during the morning, showing the higher bus usage during the morning rush hour. Variability in intersection delay seems random, indicating the real nature of intersection delay.

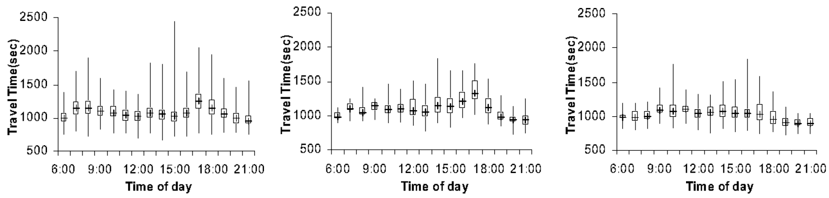


a) Cruise time variation b) Dwell time variation c) Intersection delay variation

Fig.5.7. Variation of bus travel time components by time of the day

Bus Travel Time Variability by Day of the Week

Bus travel time also shows variation with the day of the week. The days were grouped into three categories: weekday, Saturday, and Sunday/holiday. Box–Whisker plots of the travel time variations for these categories are shown in Fig.5.8 a), b), and c) respectively. The travel times are lowest for Sunday/holiday. Saturday travel times are closer to weekday travel times than Sunday/holiday travel times. This observation can be explained in association with the traffic volume. On Sundays/holidays, the lower traffic volume on the road allows the buses to speed up, resulting in lower travel times.



a) Weekday b) Saturday c) Sunday/holiday

Fig.5.8. Variation of bus travel time by day of the week

Effect of Land-Use Pattern on Cruise Speed

The cruise speed along a link is almost constant throughout the day, but varies considerably from link to link based on the land use pattern in the local area. For example, Fig.5.9 shows the cruise speed for three links in different land use zones. The cruise speed is almost the same for the commercial and industrial zones, but is considerably lower in the residential zones.

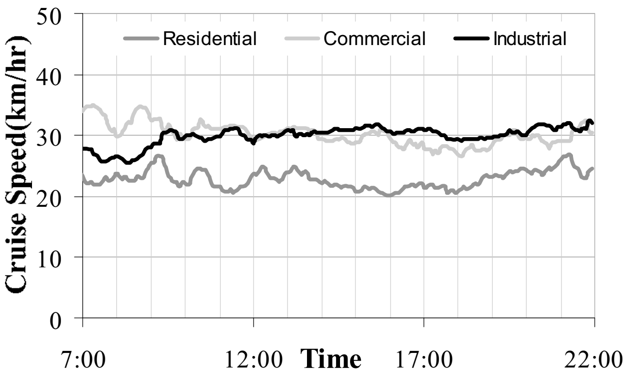


Fig.5.9. Cruise speed in different land use zones

Conclusion

The travel time along an arterial route varies considerably with the time of day and the day of the week. This variation is mainly caused by the dwell time at bus stops and delays at intersections whereas the cruise time is almost constant at both link and route level.

Fusion

Overview

The concept of data fusion is not new, and is being routinely exploited in daily applications. The best example is the human brain and perception system. Human sensors acquire information that is processed in the brain with experience in order to get a better estimate of the state. Weather forecasting is also an excellent example of a data fusion system. Various atmospheric observations are collected and are processed at numerical weather prediction centers to forecast a future weather state. In recent years multi-sensor data fusion has been deployed in both military and non-military applications for such things as automated target recognition for smart weapons, monitoring of complex machinery, medical diagnosis, smart buildings, and in civil aviation related areas such as air traffic control, and as aids in aircraft landing control.

All these applications use data fusion because this provides better performance than the use of a single data source. Measurement errors, and limitations, as well as missing data related to individual sources, are compensated for when data from many sources are combined.

Different Types of Traffic Data

Traffic detectors and probe vehicles are playing a large role in data collection for route guidance and traffic management systems. Traffic detectors have commonly been used to measure flow, time occupancy, and density. Travel time and queue length are estimated based on the detector data, while probe vehicles are used as moving sensors. In the case of probe vehicles, the data regarding the movement of a vehicle, such as its location and speed, are recorded at regular time intervals of, for example, 20–30 seconds. Traffic detectors collect data at fixed locations and provide average traffic state information such as volumes and vehicle occupancy at a given interval of, for example, five minutes. Hence, this information can typically be characterized as spot average estimates of the traffic state. On the other hand, the probe vehicle provides real-time information about the traffic state that it experiences as it navigates through the traffic. The readings taken by the probe vehicle instruments can be characterized as space-time individualistic records transmitted to the central system using mobile phones. Both types of data have relative advantages and disadvantages.

Purpose of Traffic Data Fusion

Traffic detector data are rich in spatial and temporal coverage, but lack quality, as they provide point estimates of traffic. On the other hand, probe vehicles provide better quality information about the traffic state, but lack temporal and spatial coverage due to their small number. To increase the temporal and spatial coverage of probe vehicles, a large number of probes are needed, which may not be possible in the near future due to higher system costs. Of course, probe vehicles will be an ideal source of traffic information when 100% of the vehicles in the network act as probe vehicles, but until we reach that stage, it is better to combine different information sources to increase the credibility of the information. As discussed above, the limitations of each data source are compensatory in nature such that lower quality of detector data is compensated for by high quality information from probe vehicles, and lesser quantity of probe information is complemented by a larger quantity of traffic information from detectors.

Techniques of Data Fusion

The following are the most commonly used methodologies in data fusion models.

Voting Technique: An approach that assigns a weight to each source reflecting its reliability. The output is a weighted average of each estimator. Several techniques are available to estimate weights, and the majority of them are based on heuristics.

Bayesian Inference: This is an algorithm based on the Bayes theorem in probability theory. Here evidence or observations (*a priori* knowledge) are used to update or infer conditional probabilities (*a posteriori* knowledge) of hypothesis truth.

Dempster–Shafer Theory: A generalization of the Bayesian theory, used to take into account the ambiguity and uncertainty of sensors. According to the certainty of decisions made by each sensor, probability masses are assigned to sensors and the masses are combined with Dempster's rule of combination.

Kalman Filter: An efficient and recursive filter that estimates the state of a dynamic system from a series of incomplete measurements. This technique gives excellent results for the correction of systematic errors in any type of prediction based on a recursive combination of recent forecasts and measurements.

Application

An arterial corridor approximately 450 meters long was simulated to generate required travel time data (i.e., probe, detector, and real travel times). Fig.5.10 shows simulated and fused data over 150 minutes of simulated time. The simulated time duration consists of congested and slightly congested durations within a normal weekday.

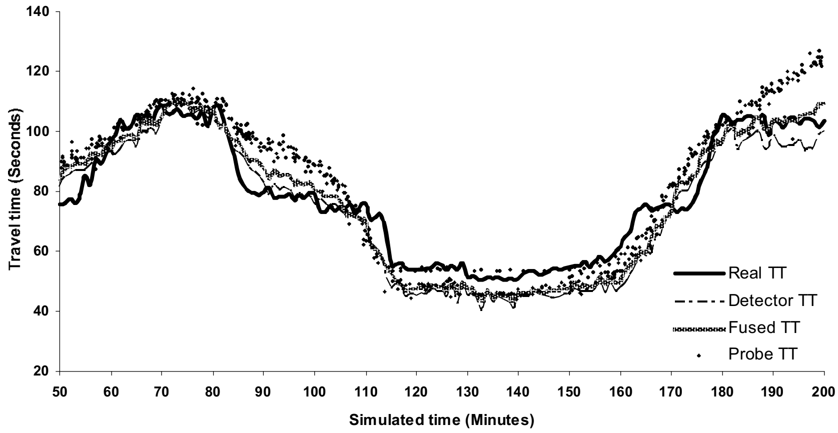


Fig.5.10. Real travel time, travel time from various sources, and fused travel time

As the ambiguity and uncertainty of data were not considered, the voting technique was used to fuse the probe and detector travel times.

The voting estimator π_w is calculated as the weighted average of each estimator (φ_w) as in Equation 5.1 and weights (w_k) are determined with standard deviations of errors of each sources. l is the number of sources used.

$$\pi_w = \frac{\sum_{k=1}^{l} w_k \varphi_k}{\sum_{k=1}^{l} w_k} \quad , where \quad w_k = \frac{1}{\sigma_k^2} \qquad k = 1, \ldots, l \tag{5.1}$$

The fused probe and detector travel times were compared with real travel time and to evaluate performance of fusion, a measure of error, i.e., the mean absolute percentage error (MAPE) (Equation 5.2) was used. Obtained values are shown in Table.5.2.

$$MAPE = \frac{1}{N}\left[\frac{|\,Estimated\ travel\ time - Real\ travel\ time\,|}{Real\ travel\ time}\right] \times 100 \tag{5.2}$$

Table.5.2. Error measures

	MAPE
Probe	9.2
Detector	9.5
Fused	8.4

Conclusion

According to the performance figures shown in Table.5.2, it is clear that the measurement error is reduced when traffic detector data and probe data are fused together, highlighting the benefits of data fusion.

5.5 Advanced Urban Transport Management for Sustainable Mobility

5.5.1 Travel Time Prediction

Travel time information helps the users of the transport system to make better travel decisions resulting in an efficient utilization of the available transport resources. Travel time information can be provided to drivers before starting the trip, for example, through the Internet or by radio, as well as en-route, using variable message signs. Pre-trip travel time information helps users to decide on the optimal route as well as the departure time necessary to reach their destination on time, while en-route information can only help them to decide upon a better route if alternatives are available. In this way, travel time information not only helps to reduce journey times, but also results in less overall congestion of the road network as demand spreads over space, as different routes are taken over time and different departure times are selected. Even if alternatives are not available and a user cannot choose another less-congested route, travel time information helps by reducing stress, especially during congested periods, as a traveler will know beforehand how much time will be needed on the road.

Traveler information systems can be either reactive or proactive. Reactive systems provide either historical information or, at the most, information about the current traffic state, which may be outdated by the time travelers come on the road. On the other hand, proactive systems provide knowledge of the traffic state that the user will experience, and are necessary in order to build public confidence in the information provided. A proactive system requires the prediction of the future traffic state using present and past traffic state information; hence it is important to develop an accurate travel time prediction model.

Different techniques are being used to develop travel time prediction models. These include traffic pattern recognition, statistical time series methods, Kalman filtering, and artificial neural networks. Here, we describe the basic framework of a traffic pattern recognition method for travel time prediction.

The basic hypothesis of the traffic pattern recognition model is that traffic conditions are recurrent in nature, and if the present traffic state is defined in a way which properly relates to travel time, similar historical traffic states can be searched and used to extrapolate the present traffic state to predict the travel time. Figure.5.11 shows the outline of the proposed model in which current traffic detector data are used to define the present traffic pattern, which is searched for similar instances in the historical database, and then *n* most similar patterns are selected from data on past examples to extrapolate the present traffic state and predict travel time.

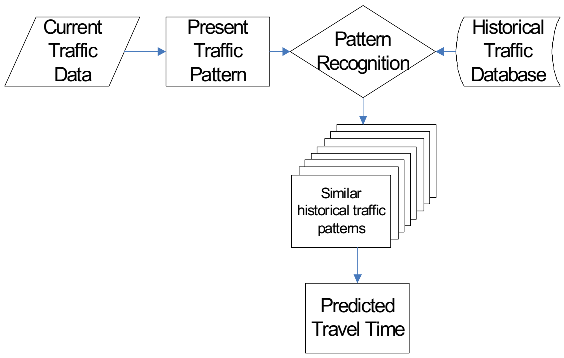


Fig.5.11 Outline of travel time prediction model

The traffic pattern is defined as a matrix on a spatial as well as a temporal scale. On the spatial scale, the traffic pattern includes the whole section of the road for which travel time needs to be predicted. On the temporal scale, it includes sufficient length of time to define the image of traffic reflecting the effect on travel time. Congested regions affect the travel time considerably. To capture this effect, weights are applied to different values in the matrix based on the congestion level at a given point and location. Speed is used as an indicator of congestion level at a given time and location and hence of weights. Sum of the squared difference between the current traffic pattern and the historical traffic patterns is used as a criterion for finding similarities. The historical traffic pattern having the minimum sum of squared difference is regarded as the most similar. Once the most similar patterns are found, travel time corresponding to these patterns is extracted and averaged across them to predict the travel time.

The Tokyo Metropolitan Expressway network is used to evaluate the performance of the model. Results from the Shibuya and Shinjuku inbound lines are presented. Fig.5.12 shows the comparison of actual and predicted travel times for three days. The results indicate a good correlation between predicted and actual travel time. Comparison of the results with those from the instantaneous travel time model indicates the superior performance of the pattern recognition model.

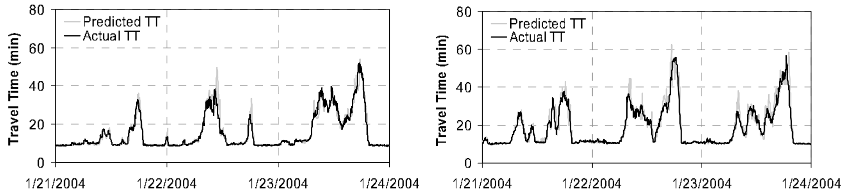


Fig.5.12. Travel time prediction performance a) Shibuya Line, inbound b) Shinjuku Line, inbound

5.5.2 Simulation

As traffic states usually change with time, and past traffic congestion is a result of this, we have to use a dynamic methodology to analyze the phenomenon. In this sense, traffic simulation is an effective tool in evaluating urban traffic status, traffic management schemes, and related matters in a dynamic way.

Recent progress in computer processing power enables implementation of traffic simulation on quite a large-scale network, whereas only static assignment was possible before. It means that measures and policies such as large infrastructure development or road pricing which may affect the whole of the city traffic can be evaluated by describing traffic congestion.

Data preparation is one of the most important steps in implementing traffic simulation. For this, we need to combine various imputs such as network data, origin-destination (OD) zone, OD table, signal parameters, regulations, and other contributing factors such as travel time information for validation of the simulation result.

The following is an example of implementation in the Tokyo metropolitan area, which has the five prefectures of Tokyo, Kanagawa, Chiba, Saitama, and Ibaraki and a total population of more than 30 million. The whole area is divided into 360 zones. The zone size is largest in the peripheral areas and becomes progressively smaller towards the center, as shown in Fig.5.13, which is in conformity with the variation in population and employment density. The road network used for the Tokyo metropolitan area consists of 45,237 unidirectional links with 22,148 nodes. A graphical representation of this is shown in Fig.5.14, which has various categories designated as expressways, national, prefectural or other arterial and local roads. Digital road map data were used for this figure.

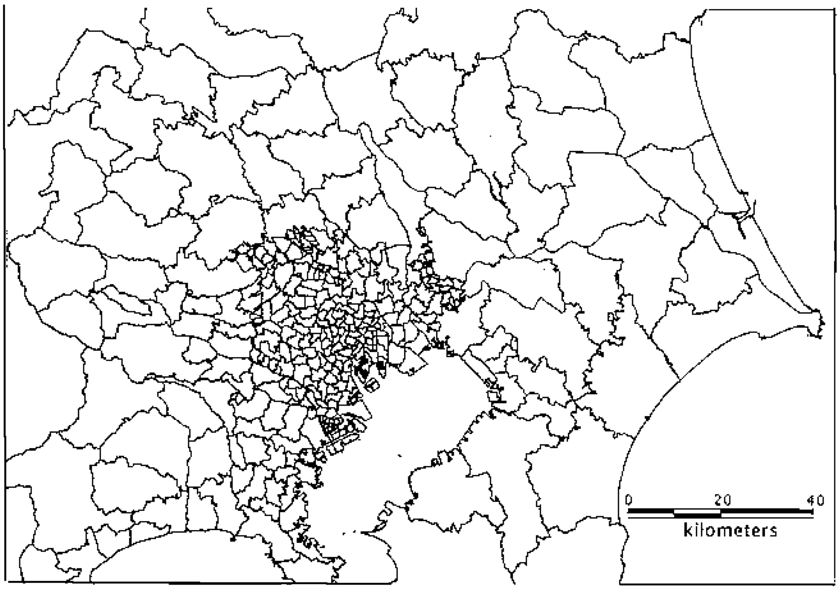


Fig.5.13. Traffic analysis zones in the Tokyo metropolitan area

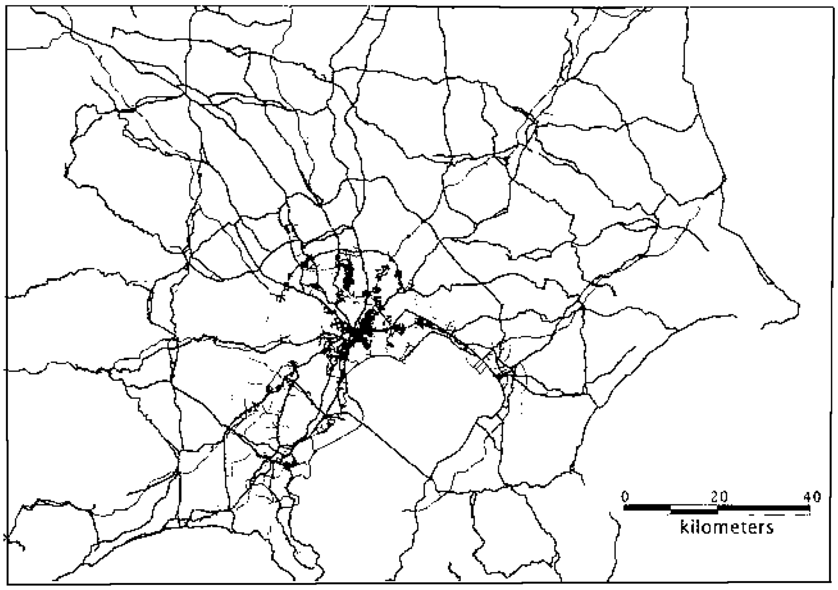


Fig.5.14. Tokyo metropolitan area road network

Fig.5.15 shows the preliminary results of the observation and simulation comparison for link travel time. The observed travel time for 4,845 links in the network, which represent approximately 11% of all links, was obtained and used as the observed link travel time. The deduced correlation coefficient is 0.84, and further parameter tuning may improve this result.

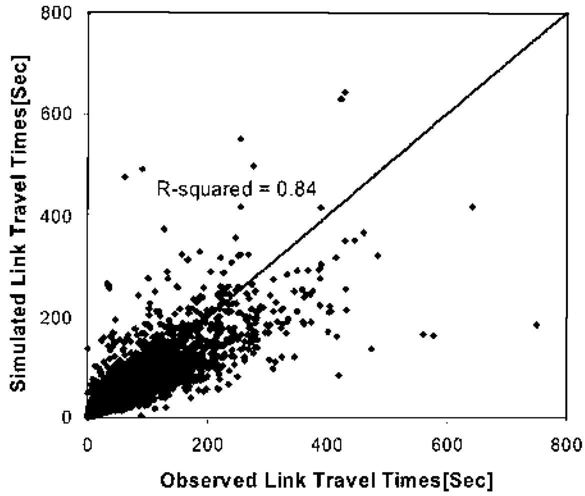


Fig.5.15 Simulated vs. observed link travel times

Traffic simulation has great potential for use not only for current status analysis and policy evaluation, but also for real time traffic control. In this application, near future traffic situations will be predicted by simulation utilizing current data gathered by an online data collection system, and remedial countermeasures will be determined based on this result. Although the precision of the method is still under development, the trend to use traffic simulation for dynamic analysis will become increasingly important.

5.5.3 Demand Spread Over Time

Travel demand management (TDM) includes consideration of the spatial demand distribution (demand over different routes), utilization of various transport modes, increasing vehicle occupancy, and related factors, as well as temporal demand distribution (demand spread over time). In considering such management, we consider a TDM scheme with promising potential to alleviate congestion. This is sometimes called the peak cut scheme, in which the travel requirement is shifted over time so that the demand does not exceed the highway capacity.

First of all, let us review an important property of congestion. The lower figure in Fig.5.16 shows demand distribution on a straight highway section with a capacity limit. Demand exceeds capacity from time T_a until time T_b. During this time period, the excess demand is accumulated on the highway, hence travel time as well as queue length increase until time T_b. The congestion cannot terminate at time T_b but lasts until the much later time of T_c. It should be noted that the excess demand period (T_a to T_b) is normally much shorter than the entire congestion period (T_a to T_c). Fig.5.17 shows a different demand pattern in which demand does not exceed capacity. As seen here, even if total daily demand is the same as in the previous figure, traffic congestion does not occur, and travel time and queue length stay in a free flow condition throughout the day. In this way, the management of temporal demand distribution aims to spread travel over time so as to reduce excess demand.

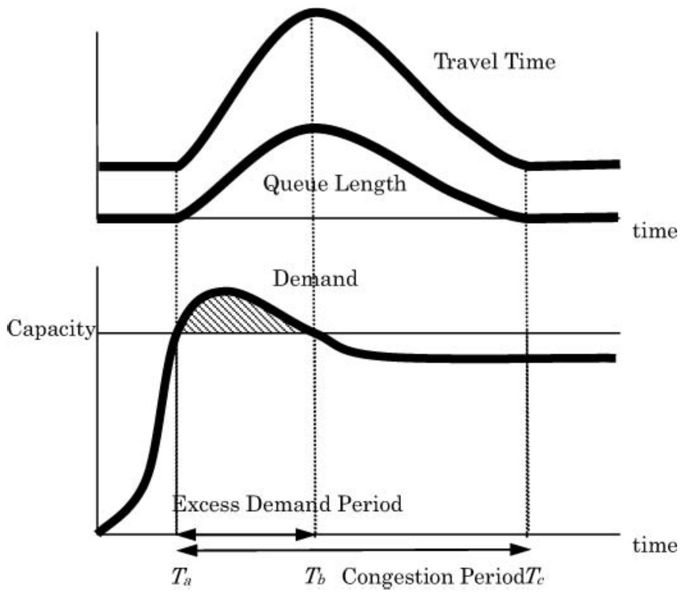


Fig.5.16. Demand distribution pattern and traffic congestion (I)

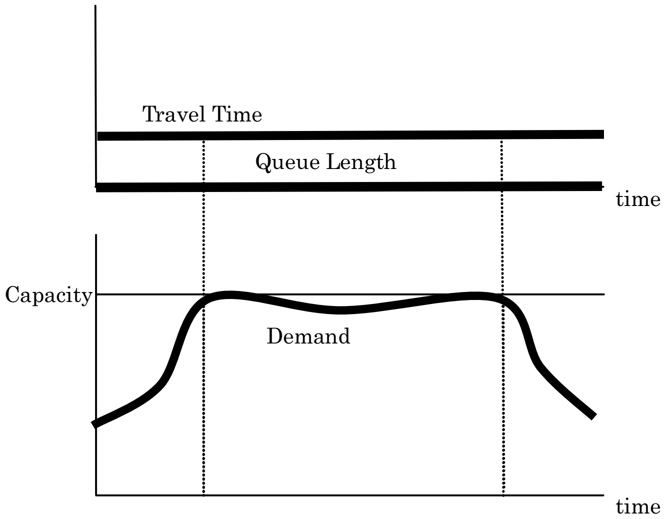


Fig.5.17. Demand distribution pattern and traffic congestion (II)

As case studies, the morning peak congestion on the metropolitan expressway (maximum observed queue length = 7 km) and the recreational congestion on the Kanetsu expressway (maximum observed queue length = 23 km) are examined. Computer simulation reveals that even only 10 to 20-minute departure time shifts of trips could considerably alleviate or completely eliminate the traffic congestion. The results may not be the same for other traffic congestion issues, however alleviation through management of the temporal demand distribution seems quite promising, because traffic congestion does not last for 24 hours and time periods without excess demand can be easily identified, even in densely populated urban areas.

Let us next consider the mechanism of the temporal demand distribution using Fig. 5.18. We suppose that commuters travel to work places along a highway with a bottleneck at location B. Two observers measure passing times of vehicles at location B and also at location A, well upstream from the bottleneck. The horizontal distance between cumulative curves A and B indicates the required travel time of each vehicle from location A to location B. In the early morning, the distance between cumulative curves A and B is small, and represents the known free flow travel time. However, the travel time gradually becomes longer towards the morning peak and returns to the free flow figure at the end of the peak. The delay can be evaluated by drawing the dashed line parallel to the cumulative curve B. As the distance between the dashed line and curve B represents the free flow travel time, the delay is evaluated from the distance between curve A and the dashed line. Therefore, if everyone could arrive at location A at a time located along the dashed line, all the commuters could travel from location A to location B in the free flow travel time without any delay.

Following on from the above, if we instruct everyone to depart from their home tomorrow at a later time which is exactly the amount of the current delay, everyone can be expected to pass through location A at a time along the dashed line and travel during the A to B free flow travel time without experiencing any congestion. Furthermore, as everyone can get through location B at the same time as today, they will get to work at their accustomed time. In other words, this scheme tries to overcome delay at the bottleneck by staying longer at home. Normally, you tend to leave home "earlier" tomorrow if you experience some delay today. However, in this concept, you should leave home "later" by the amount of today's delay time. It sounds a bit curious, but this is actually quite logical.

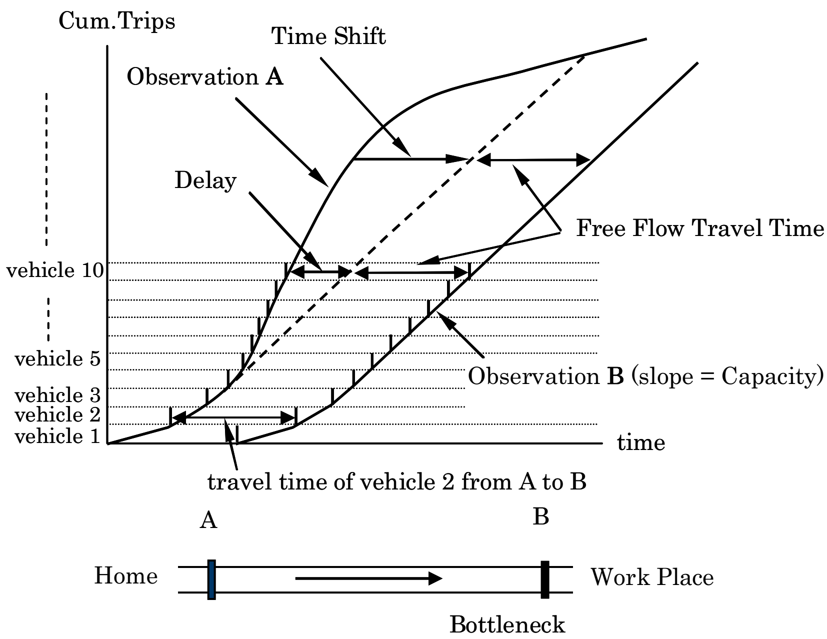


Fig. 5.18. Mechanism of demand spread over time

The most difficult aspect of the outlined scheme is, however, how to persuade all the commuters to follow this instruction. If all the commuters obey the instruction perfectly, the congestion could be completely eliminated, and everyone would arrive at the office at the same time as today. If the guidelines are not followed by everyone, the congestion may not be completely eliminated, and some commuters following the instruction may arrive at their offices later than they did today.

However, according to our preliminary examination the congestion could be substantially alleviated if even a portion of the commuters followed the instruction, hence the scheme should be considered to have great potential. As some commuters who follow the instruction might arrive at the office later than today, we need to introduce some form of compensation for them. Possible approaches would include the introduction of a flexitime working system, secure parking space at the office, or other benefits.

To supply sufficient incentive for commuters to shift their departure times, several supportive, practical strategies could be designed. Travel time information provision would be one of the most feasible supports so that travelers can judge when to depart. Currently, travel time is provided by means of TV/radio broadcasts, telephone/fax services, Internet sites, and VICS. Most of these sources just provide commentary on the current traffic condition, which is useful information for route selection (spatial demand distribution) but not for the temporal demand distribution. To decide when to make a trip, we have to know how the traffic condition will change over time or how the traffic condition has traditionally changed. That is, not only the current traffic condition but also traffic information for some time period, such as 30 to 120 minutes, into the near future should be provided to travelers. In this way, they can choose their most appropriate trip departure time. Even if accurate travel time prediction poses some difficulty, an account of previous comparable instances would also be very useful in helping to make a decision on departure time. For instance, the travel time profiles from the day before and from one week ago would certainly help.

Acknowledgement

This chapter was written with a great assistance by the following staffs and students: Hiroshi Warita, Isao Nishikawa, Shamas Bajwa, Marc Miska, Hiroaki Nishiuchi, Geetha Weerasooria and Charitha Dias. Their valuable contribution is greatly appreciated.

6. New Technologies in Urban Regeneration – Community-based Urban Planning Support System Enhanced by Urban Vulnerability Assessment Technologies

Takaaki Kato

Department of Urban Engineering, The University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

6.1 Introduction

The Great Hansin-Awaji Earthquake Disaster in 1995 gave our society many lessons we should learn. The most important one of these, from the aspect of urban planning, is to improve inner city built-up areas, which consist of densely crowded old wooden houses and poor infrastructure. The huge earthquake mainly affected such districts in Kobe, killed approximately 6,000 persons, and damaged a great amount of property (Fig.6.1).

Crowded wooden housing accumulated in large cities through the urbanization process in Japan. The periods following the 1922 Kanto Earthquake Disaster and the succeeding era of high-speed economic growth after World War II, saw opportunities to build in these areas. Such areas had the role of providing accommodation needed in rapid urbanization. Most of them have not been renovated and remain with many problems: vulnerability caused by many existing, seismically unfit buildings, highly inflammable dwellings, and poor infrastructure. These factors are exacerbated by community level socioeconomic problems such as a high rate of aging, and a sagging economy (Fig.6.2). All these problems remain to be discussed and improved.

Urban improvement for earthquake disaster mitigation has been one of the important issues to arise from the Great Hanshin-Awaji Earthquake Disaster. Immediately after the disaster, two important laws were established to promote a decrease in urban vulnerability. These were the Dense Wooden Housing Area Improvement Act and the Building Retrofit Implementation Act. The institution in charge of improving urban vulnerability was upgraded. Moreover, the Earthquake Disaster Urban Renaissance Headquarters, which is an organization of the Cabinet and Prime Minister of Japan, was designated 8,000 ha, with 2,000 ha areas in each of Tokyo and Osaka, as strategic improvement areas in 2001. A goal was set to make these districts satisfy the criteria of the minimum safety standards against urban earthquake disaster by 2011. Urban improvement of dense wooden housing for earthquake disaster mitigation has been an important agenda. Corresponding to this, various measures have been undertaken during these years.

In this period, the development of planning support technologies such as urban earthquake disaster simulation, vulnerability assessment technology, and planning support based on GIS have been implemented, and a planning environment supported by high-end technology has been established for community-based planning for the dense wooden housing areas.

In this chapter, I focus on the new methods of approach to the improvement of the dense wooden housing areas. I introduce two technologies:

1. Urban earthquake disaster simulation, vulnerability assessment technology.
2. A planning support system to utilize the above technology in participative community-based planning for the dense, wooden housing areas.

Fig.6.1. The Great Hanshin-Awaji Earthquake Disaster. Inner city

Fig.6.2. Typical dense wooden housing area in Tokyo

6.2 Urban Earthquake Disaster Simulations and Urban Vulnerability Assessment Technologies (UVAT)

6.2.1 History of Simulations and UVAT

A wide range of simulations and Urban Vulnerability Assessment Technologies (UVAT) are now available in Japan. These technologies are utilized by various sections of local governments. Variation between simulations and UVAT is not wide. While simulators describe the situation of a disaster dynamically, UVAT evaluates the vulnerabilities in an urban area statistically. Simulators are sometimes assumed to be tools for presentation, but this is not so in the basic sense. UVAT sometimes includes some simulators. In such cases, vulnerability indices can be made by summarizing the outputs of simulation.

I show some typical examples of simulations and UVAT. An urban fire spread simulator is a good example of simulations. It describes how a fire will spread in a built-up area dynamically under conditions of fire breakout location, wind direction and velocity. As typical examples of UVAT, two schemes published by the Tokyo Metropolitan Government can be shown: Earthquake Area Vulnerability Assessment (EAVA) in the urban planning section; and Difficult Areas for Firefighting in the firefighting section.

Herein I concisely review a history of simulations and UVAT in Japan. UVAT has a long history. We note that UVAT originated from a Ranking Against City Fire in the 1950s. Its measurement was rather simple, with a limited availability of statistical data and computation in those days. However, the purpose and usage of the ranking correspond closely to its contemporary counterpart. The ranking orients and promotes measures against disasters including firefighting, and is evaluation-based. It has had a certain influence on implementation of the present UVAT: EAVA, developed by the Tokyo Metropolitan Government; and the Disaster Risk Evaluation developed by the Ministry of Land, Infrastructure, and Transport (MLIT).

Simulation studies began after the 1970s when computers began to be more widespread. Research preceded the simulations on urban fire spread and evacuation because large scale evacuation from urban fire after an earthquake disaster was one of the most serious issues. Large area evacuation from a spreading urban fire was essentially a dynamic fleeing from the fire by evacuees heading to a large open space that would make them secure from injury. Simulation technology enabled additional tests to represent several situations to understand variables such as the fire breakout location, number of fire breakouts, or weather conditions.

Studies were carried out to increase contextual precision during the following two decades. In those days, they used aggregated data from 250 m or 500 m grid cells. Digital maps had begun to be available and computing performance had progressed rapidly. Corresponding to this situation, some advanced studies started to establish a simulation system on the digital map that consisted of individual building polygons. These studies applied the existing simulation methods to polygon data instead of grid aggregated data. Tokyo Fire Department developed an urban fire spread simulation based on this method for firefighting strategic planning.

The Great Hanshin-Awaji Earthquake Disaster in 1995 was an epoch-making event that has impacted upon disaster prevention measures and simulations and UVAT. Evacuations from widespread fire that took place before this event, fortunately did not occur in this disaster, because large fire damage that would have been inevitable on the basis of disasters before 1995, did not occur. Each area damaged by an urban fire was as little as a few tens of hectares because of the good fortune that the wind velocity was low. This fact demonstrated that the fire spread could be blocked by detailed spatial factors in built-up areas such as access roads, small open spaces, individual houses, or their combination. Therefore, urban district improvement was focused upon as an important issue for disaster mitigation and development in the simulations. UVAT consequently advanced to the next stage: to understand the relationship between urban fire and small spatial factors, and to construct models at an individual building scale to explain the progression from fire breakout in a room to a fire involving multiple buildings.

In the disaster, another unknown phenomenon was observed. Many street blockades were caused by buildings collapsing and these prevented the successful deployment of such response activities as firefighting, rescue, and evacuation to shelter (Fig.6.3). This was revealed as a new vulnerability on a district scale. Street blockades also have a relationship to the spatial factors at district scale because the issue can be improved by reinforcing the seismic resistance of houses facing a road, and upgrading the local road networks and road width.

Fig.6.3. Street blockade caused by housing collapse

As described above, simulation and UVAT technologies began to be applied to disaster phenomena on a city scale in the 1970s, and have been developed to explain the disaster situation at district scale and the relationship between district-level spatial factors and vulnerability since 1995. Moreover, in the 2000s, Geographic Information Systems (GIS), which have a high affinity to simulation and UVAT, have become popular technology because of the availability of smaller computers and upgraded PC performance. An integrated planning and decision-making support system (PSS), including simulation and UVAT as an application system of GIS, has been developed. It has made simulation and UVAT open to nonprofessionals such as administration officers and residents. At present, various persons concerned with decision making or planning who have no skill in GIS and UVAT utilize simulation and UVAT through the PPS in actual decision making or urban improvement planning.

6.2.2 The Present Situation Around Simulations and UVAT

We consider a fire spread simulation and assessment method for the obstruction of response activity caused by street blockade, which is called activity assessment, as examples of advanced simulation and UVAT in Japan. Both methods were developed by MLIT in an integrated technology development project entitled “Development of assessment and countermeasure technology for disaster prevention in town planning" (fiscal years 1998 to 2002) that many researchers specializing in urban planning and engineering participated in, including the author.

Urban Fire Spread Simulation

The latest fire simulations try to describe the spreading processes, which range from a room fire in a house to a multiple buildings fire. They use an integrated inflammation model and explain post-earthquake urban fire spread and contrast it with the simulation models before the Great Hanshin-Awaji Earthquake Disaster. This formulates large-scale urban fire directly based on past fire disaster cases and experiments.

These simulations explain the process in which a fire in a building spreads in one fire compartment and expands to the next. They include district-scale spatial factors in the modeling scheme, and their results affect urban improvement planning such as widening access roads, renewal of buildings, or development of pocket parks, which are small open spaces.

An inflammation model is applied to each structural classification for fire resistance at four levels: wooden, fire preventive, semi-fireproof, and fireproof buildings. The mode of inflammation corresponding to structural characteristics is set (Fig.6.4). Ignition to the next building can be caused by radiation, flame contact, or hot airflow.

In the simulations, the wind velocity and wind direction are conditions that must be specified. The results are obtained in the form of the number of buildings burned and the percentage of them destroyed by fire in the entire region.

The minimum data required are those for the structural classifications as above. In addition, the window area and wall location in each building are required. The former data are comparatively easy to prepare. Because the data needed for the simulator are not included as items in the urban planning basic survey, some local governments do not possess this information. If these data are not available, the evaluation is performed by replacing the available data with fire prevention classifications by adding the floor number classification to the construction year and the structural classification used in the evaluation of building collapse risk. In the case of Tokyo, the fire prevention classification data are available for the entire region. The latter data are generally difficult to prepare, and therefore the simulation program includes an option to set a window on each wall automatically if the window–wall area ratio is given. In this case, of course, the precision is reduced

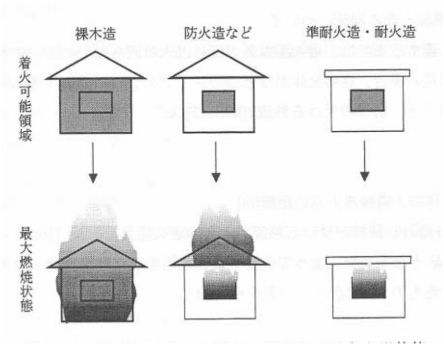


Fig.6.4. Setting the phases in the process of inflammation [MLIT(2004)]

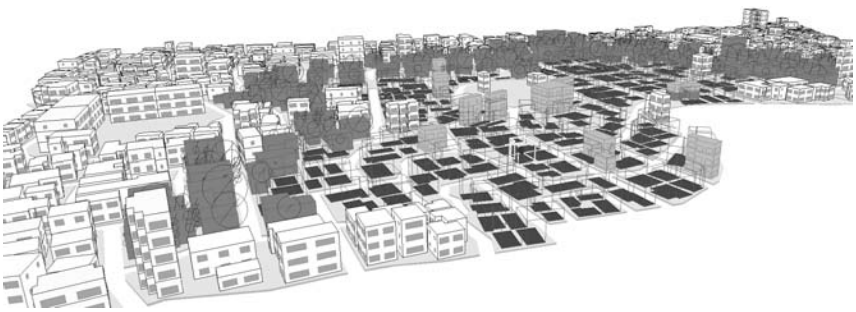


Fig.6.5. An output example of the urban fire spread simulation by MLIT

Post-Earthquake Activity Assessment

Activity assessments evaluate the obstruction to response activities caused by street blockades. They calculate probability access to facilities such as firefighting water supplies, emergency shelters, or rescue bases in the district. The accessibility depends on each probability as follows: collapse of houses, amount of debris on each road link (that lying between two crossing points), and eventual street blockades by that debris. The model considers details like the earthquake-resisting capacity of buildings, width of road links, and road networks in the district. In this way, the effects of earthquake retrofits, reconstruction of buildings, construction or improvement of roads, and establishment or improvement of facilities against disaster are fixed into the model. The assessments use static indices whilst they employ Monte Carlo simulations in the calculation process.

Fig.6.6 shows the concept of emergency activities defined by this method. This assessment program defines many kinds of emergency response activity such as the probability for fire-fighting to reach a house from water supply facilities, for rescue to reach a house from a rescue bases.

Fig.6.6. An output example of activity assessment

GIS Technology Connecting Simulations and UVAT to Users

The advanced simulations and UVAT are even more elaborate than those being used, which can be calculated by anyone, and therefore another technology that can create a bridge between them and users who are not computer professionals is required. This is a planning support and decision-making system (PSS) based on GIS. Functions corresponding to each phase in a PSS will be required from the user viewpoint.

These systems have a common system structure. They generally consist of an urban spatial database linked to a GIS, vulnerability assessment function or simulator, and a user interface management system with high usability to permit input of an alternative plan or countermeasure. Figure 7 shows the planning process for the planning support system. As the first step we use a vulnerability assessment function to recognize the present susceptibility to house collapse, fire spread, and street blockade in the district, and then we set a goal against each issue. As the second step we use the input interface to draw an alternative. This means that we create a situation after taking an alternative measure, or implementing an alternative plan that is described in this system. We apply the vulnerability assessment function or a simulator to the district described by the alternative, and we check the effectiveness from the mitigation viewpoints. We reconsider the measures and draw up another alternative if we need it. This cyclic process refines the measures or plan. This is the most important point of this system. As a result, the measures or plan are optimized, and we can derive a better plan or the best plan corresponding to the local characteristics of the district.

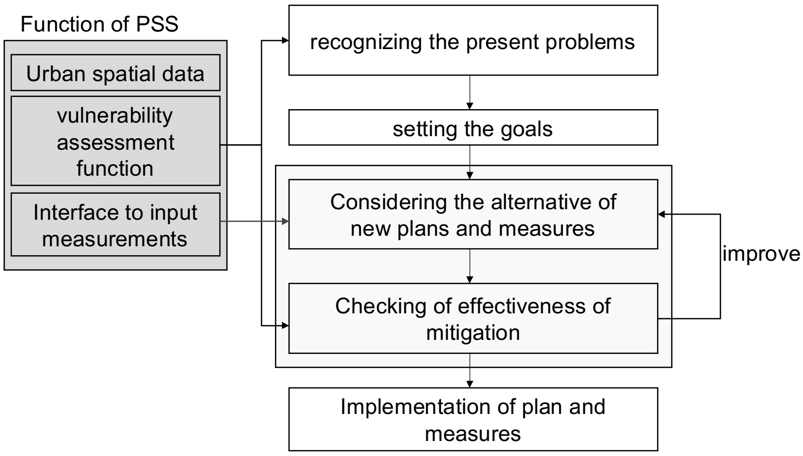


Fig.6.7. A general utilization flow of PSS

6.3 Planning Support System for Urban Earthquake Disaster Mitigation: BOUSAI-PSS

6.3.1 Overview

BOUSAI-PSS has been the only PSS for urban earthquake disaster mitigation in practical use in Japan. The object of the system is to facilitate and develop residents' participative, community-based planning for earthquake disaster mitigation.

Development was commenced by an industry–government–academia research group in the MLIT project of 1998 to 2002 (see section X.X) and has grown continually. The current system version is 2.0 BOUSAI-PSS and version 3.0 will be released in 2007.

At present, the system has been distributed, maintained and upgraded by the BOUSAI-PSS Administration Committee, which is a nonprofit organization set up by the original research group. The number of users has grown, numbering more than 40: 14 local authorities, 17 private companies, five nonprofit parties, and six universities/research units in November 2006, and is still increasing. In the near future, most local governments with dense wooden housing areas will use this system.

6.3.2 Postulated Development of BOUSAI-PSS

In designing the system, the top priorities are set for the practicality and usability of the system. We have attempted to understand and reflect upon the specific needs in normal planning and to achieve cost reduction in implementing the system.

The cost of the data used in the system was set within the budget for an implementation expense that can be borne by local governments without much difficulty but that does not compromise the accuracy of the evaluation, taking into consideration the current level of implementation and the future plans for GIS in local governments.

The users of the system are expected to be all the participating parties in community-based urban improvement planning, such as project leaders in local government, urban planning consultants, and residents living in a planning unit.

We adopted a distinctive process in developing the system. In order to reflect any new user viewpoints in the design of the system, we held workshops in which the local government project leaders and consultants participated. Points requiring improvement were clarified in these meetings and then incorporated at the time of development of subsequent versions of the system.

6.3.3 Structure of BOUSAI-PSS

BOUSAI-PSS mainly consists of the following three subsystems.

1. **Subsystem to assess the vulnerability to earthquake disaster**. This system evaluates the risk of building collapse; the risk that fire will break out in a building; the fire spreading risk, as well as evacuation, firefighting, lifesaving, and rescue operation difficulties. The condition set in this evaluation is ground surface acceleration.
2. **Interface management system for plan examination and administration function of planning records.** These interfaces cover objects such as buildings, roads, and open spaces, the shape and attributes of which change after an earthquake. The input interfaces are

user-friendly, consequently people without professional knowledge of GIS can use them.

3. **Display management subsystem.** to display the output from urban fire spread simulators and Activities Assessment and the comparative mitigation effectiveness of the alternative plans. Comprehensibility is emphasized. We can compare outputs under different conditions and the mitigation effectiveness of two different plans.

6.3.4 Expected Situations for Use and for Users

We expect this system to be used in community-based improvement planning and in activities for earthquake disaster mitigation. In concrete terms, we assume its use in the following situations will involve appropriate users.

Plan Examination by the Government

The users are government personnel or planning consultants in charge of the urban improvement planning project. The system functions as a tool for the examination of a draft and the content of an alternative plan by the planners. As shown in Fig.6.8, using the functions of each subsystem, an optimal plan is prepared by the repeated input of alternatives and examination by the subsystem of vulnerability assessment.

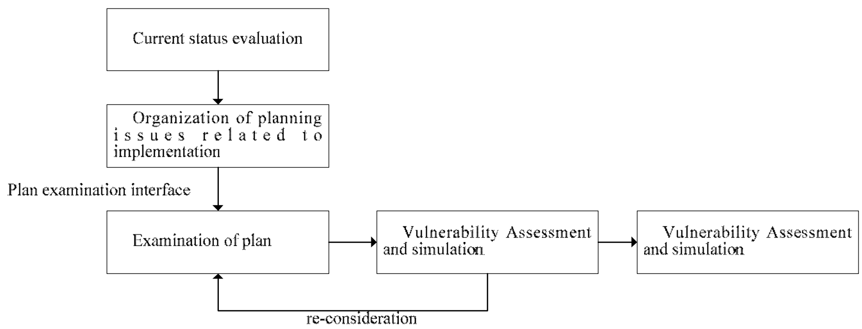


Fig.6.8. Plan preparation by principal users

Interactive Communication with Residents

The users are government personnel and advisors in charge of the project. The system functions as a tool to explain the necessity and importance of urban improvement plans to residents in order to promote planning and risk awareness in communication with residents. Previously, explanations tended to be given by the government to residents as a one-way communication. In this revised system, interactive communication rather than explanations can be achieved between the government and residents by securing bi-directional and instantaneous features in vulnerability assessment and simulation, and incorporating residents' proposals. The level of discussion at a planning meeting or workshop is expected to be one step above that previously experienced.

Examination of the Plan by Residents

Moreover, residents participating in a planning meeting or workshop will be expected to use the plan in the same way as the planners. Residents' understanding of the proposed plan is facilitated by the repeated presentation of plans and vulnerability assessments for multiple alternatives. The system is expected to function as a tool to promote communication among them if expert personnel in charge of the project and residents use it collectively as a planning support tool for urban improvement.

6.3.5 Significance of Introducing an Urban Improvement Planning Support System for Earthquake Disaster Mitigation

Government Accountability for the Derived Plan

The need for accountability for the derived plan to residents as well as within the government itself is increasing. It is necessary to objectively explain the rationale of plans. This system is considered to offer accurate plans for rational explanation using information based on GIS data and urban vulnerability assessment technology, which follows an engineering approach.

Deliberation on Regional Characteristics and Overall Features of the Urban Improvement Plan

Dense wooden housing areas need various improvements to the residential environment, consideration of the aging of society, and economic revitalization. These are important issues, along with improvement of disaster mitigation. It is necessary to consider a plan that accommodates the district characteristics comprehensively. However, it is difficult to consider both disaster prevention measures, which can be determined, and other regional characteristics, which are not quantifiable. Furthermore, current feasibility must be taken into consideration. To produce an optimal plan, it is desirable to examine various alternatives and choose the most suitable. This system is considered to minimize laborious data entry by planners and to offer a suitable environment for the evaluation of various alternative plans by quickly evaluating characteristics from the viewpoint of disaster mitigation.

Effective Use of Government Resources

GIS introduction has progressed fairly well in local governments. However, because most GIS are usually used to accumulate and read geographical data, their full potential has not been fully utilized. The implementation cost is not generally small compared with the government budget; moreover, when the system is not fully utilized it means a loss to society. Because local governments have a financial limitation, society demands the effective utilization of existing government resources. GIS is a kind of middleware, i.e., general-purpose software. It is, therefore, difficult to obtain new knowledge from GIS itself without using application software. To fully utilize GIS potential, the development of application software for different objectives is required. The considered PSS derives a great contribution from GIS and spatial data and contributes to the effective use of government resources.

6.3.6 Subsystem of BOUSAI-PSS

Subsystem to Simulate and Assess Vulnerability to Earthquake

The subsystem used to simulate and assess vulnerability to earthquake includes an urban fire spread simulator and activity assessment as described above, in addition to a building collapse assessment, which gives the previous two functions an input condition.

The building collapse assessment gives the percentage of completely and half-collapsed buildings obtained by means of a fragility function, which uses data on the velocity of ground surface shake as its descriptive variable to the probability of collapse of each structure. The data used include a year of construction of buildings and the classification of structures, which is required by the fragility function. The years used for the construction date are 1971 and 1981, at which points the seismic codes were changed. The structural classifications are based on whether the buildings are wooden, reinforced concrete, or steel frame. The structural and construction year data are not included as items in the urban planning basic survey regulated by the Urban Planning Law. Thus, some local governments do not possess these data and must therefore collect this information.

Explanations of the fire spread simulator and activities assessment are described above.

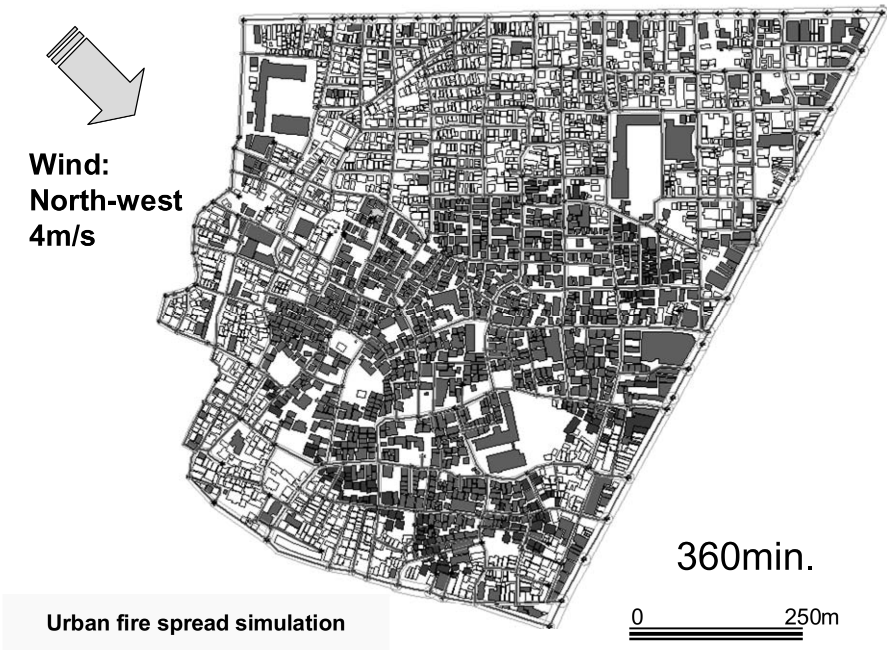


Fig.6.9. Urban fire spread simulator

Interface Management Subsystem for Plan Consideration and Administration Function of Planning History

The following items are used as elements in the plan:

- Improvement to reduce urban vulnerability in the district: promotion of reconstruction of buildings, and promotion of collaborative reconstruction of wooden buildings to fireproof them.
- Road improvement: widening of existing roads and construction of new roads.
- Creation of open spaces: construction of pocket parks.
- Construction of facilities for emergency response: new water supply bases for fire fighting, rescue bases, and shelters.

The following are the planning interface functions required to realize the above elements in the plan:

- Change of building attributes, variation of shape, and the addition, removal and elimination of polygon data.
- Change of road attributes, and input and elimination of width and line data.
- Input and elimination of open space polygon data, change of shape.
- Input and elimination of facility point changes of attributes.

The processing required for each element in the plan is not fully automated, since, to enable confirmation of processing and to reflect the requirements of planners, it is designed for semiautomatic processing. For example, processing using GIS functions is easy, such as the case of selecting building data to be removed, or moved accompanied by new road construction information, when automatic processing is used. In other cases, a method requiring user confirmation is introduced.

With respect to data management, as a result of independent plan consideration, a database was designed to maintain the history of proposals. For example, let us assume a case when plan A' is prepared as a modified derivative of A. Plans A' and its derivative A" are then both derivatives of A and are entered. However, plan A" is rejected as a candidate. Then a new plan, which is a derivative of A', is prepared. To avoid repetitive data entry work, we introduced a database that manages such a plan history.

Fig.6.11 shows an example of alternative plan drafting. With practice, this process takes less then 15 minutes.

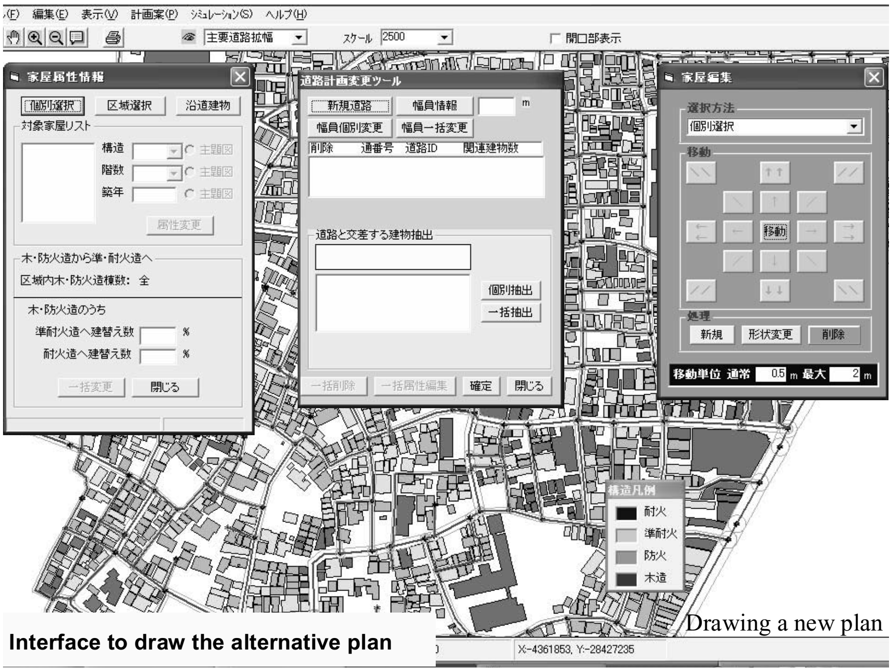


Fig.6.10. Interface management subsystem for plan consideration

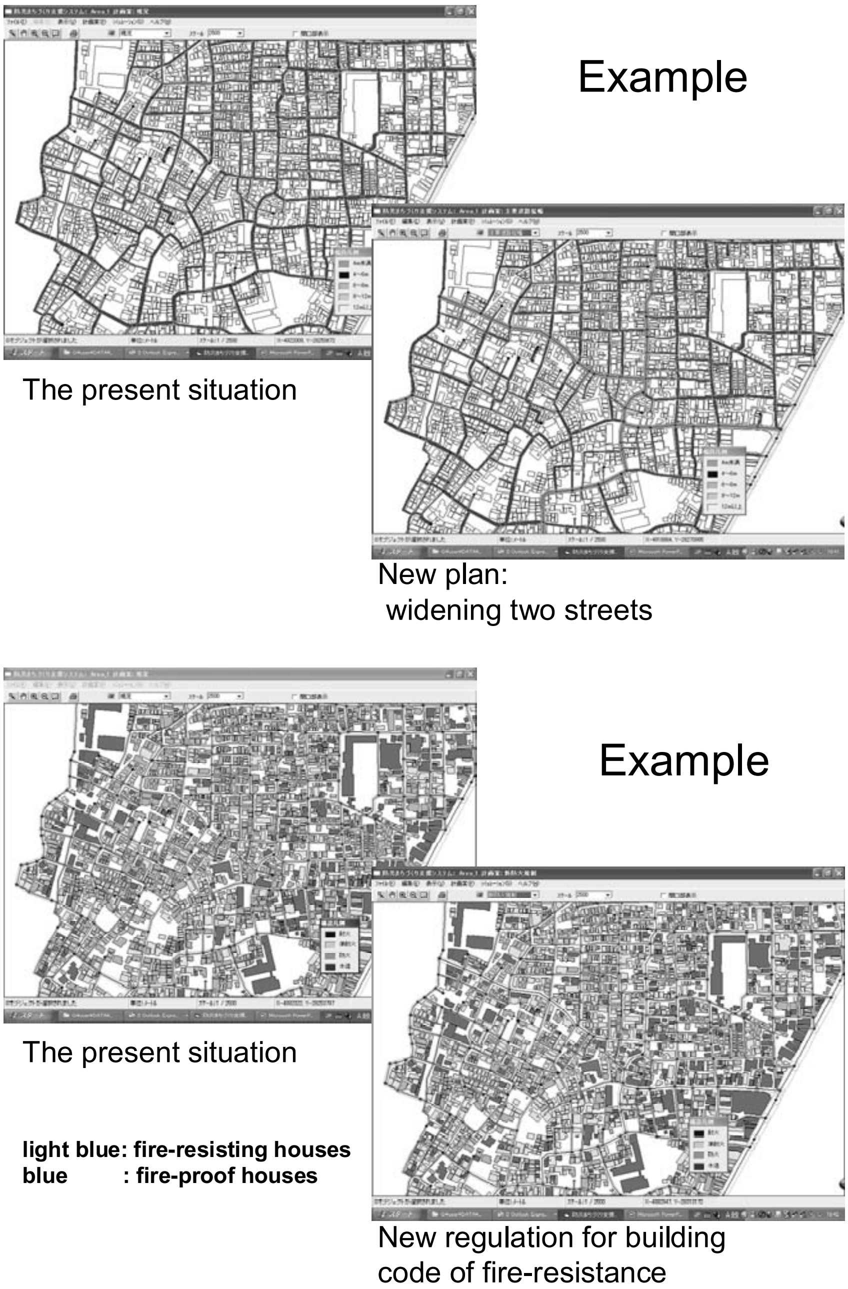


Fig.6.11. Example of alternative plan drafting

Display Management Subsystem

This subsystem is designed to display the output from urban fire spread simulators and activities assessments, and illustrate the comparison mitigation effectiveness of alternative plans. For the former function, comprehensibility is emphasized. It can dynamically display output from urban fire simulation. However, excessive reality in order to achieve high comprehensibility would not be allowed because it will threaten the viewers. An animation method in 2-D was adopted.

Moreover, a display to compare two outcomes is prepared. This display can be used for different conditions, to deepen the understanding of vulnerability, and for outcomes of an alternative draft or plan to examine the mitigation effectiveness.

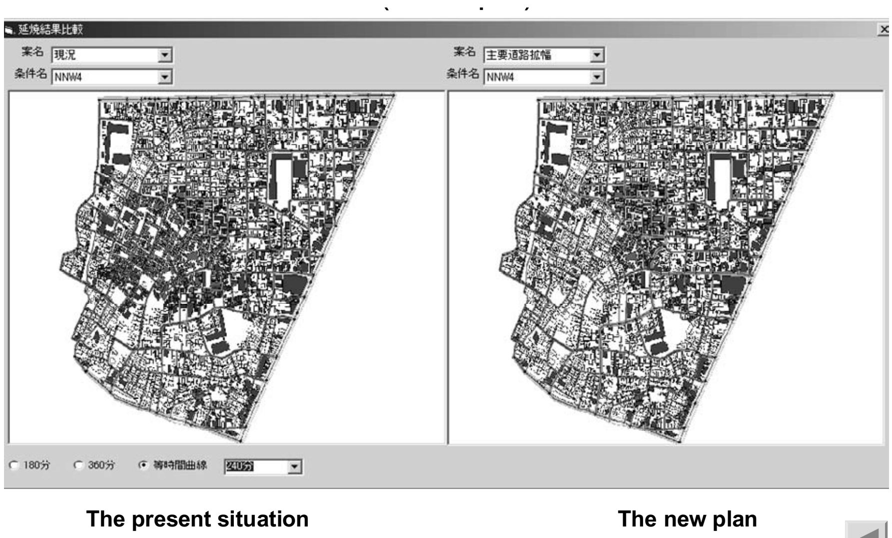


Fig.6.12. Examination of the mitigation effectiveness of alternative plans

6.4 Community-Based Urban Planning with the PSS in Japan

6.4.1 Topics and Issues on Community-Based Design with BOUSAI-PSS

There are some good community-based planning cases with PSS-equipped simulators or UVAT in practical use in Japan, although the total numbers in practice are still small. For the most part, BOUSAI-PSS has been primarily used by facilitators in workshops for residents.

In this section, we illustrate the topics and issues in community-based design and simulation using BOUSAI-PSS.

Making Good Use of Simulators in a Community-Based Design Procedure

The expected use of PSS with simulations and UVAT is expected to be in three phases in a community-based planning procedure as follows.

- The first phase: The risk communication with residents and presentation of the importance of a community-based plan to residents.

The system functions as a presentation tool. Local governments demonstrate the current vulnerability of the district to residents living in dense wooden housing. The system is displayed by a town community organization or in a lecture meeting as part of a local emergency awareness exercise. It permits the residents to recognize potential hazards and their susceptibility. The vulnerability of the district will be reduced through a community-based plan that encourages community-based activity, including creating a resident-oriented organization for planning.

- The second phase: Consideration of the goal and direction of the plan by checking the effect of possible measures to develop a consensus.

The system functions as a tool to promote better discussion and to support planning. Persons or parties related to planning repeatedly hold workshops presenting plan drafts consisting of possible measures for consideration in the system, and they check how measures will reduce vulnerability in the district. Local government project leaders, planning experts, and residents are all expected to be participative parties in planning. Finally, they set an interim target for vulnerability reduction and determine the direction of the plan through the above mechanism.

- The third phase: Examination of the plan content in detail.

The system functions as a tool to support planning. Persons in charge of planning and residents carefully examine the plan content in detail, such as the width of a specific road requiring improvement, the fire resistance classification and height of a building facing the road, together with the location of water facilities for firefighting, and the location and area of a pocket park.

Fig.6.13 is a case scene of risk communication with residents at an emergency drill for the community of Arakawa Ward, Metropolitan Tokyo. Residents understood the vulnerability of their home town following a realistic simulation under various conditions. This program has been held continuously to enlighten residents. Fig.6.14 shows an urban improvement planning workshop in Neyagawa, Osaka. The illustrations are scenes in a series of the workshops. They combined new tools and old, such as field work and map-based discussion, taking advantage of each tool, and considered the future of their home town.

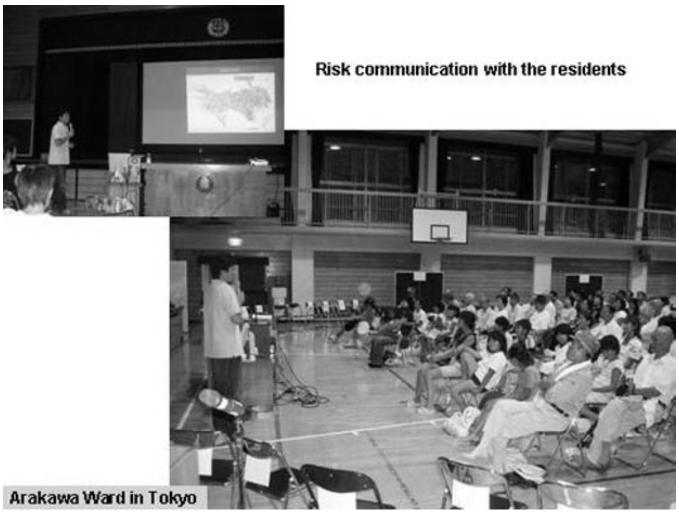


Fig.6.13. Risk communication with residents at an emergency drill at a community in Arakawa Ward, Tokyo

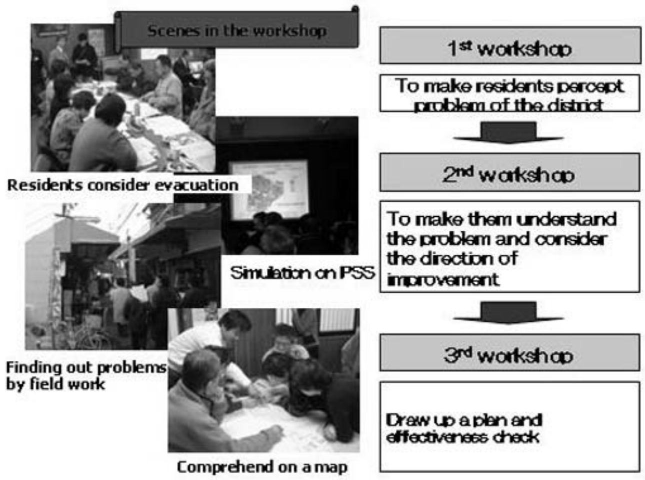


Fig.6.14. The first phase of urban improvement planning in Neyagawa, Osaka [JICE(2005)]

Following a review of the existing projects, most effort has been concentrated in the first phase. Additionally, activity in the second and third phases has been implemented by a section in charge of planning, but these are rare cases.

In the first phase, the correction to the risk perception of residents is especially remarkable. Residents in dense, wooden housing areas know that their town might be exposed to relatively high risks in an earthquake; however, this perception is unconscious. The system changes this to conscious perception with a display that visually shows the vulnerability of their houses and home town. Providing them with detailed information to understand the situation concerning their property is very effective in risk communication. Moreover, providing the means of repeatedly simulating outcomes under different conditions instantly deepens their recognition.

There is another effect in the first phase such that the simulator helps people understood the requirement for community-based urban improvement planning. The system shows them that their actions can improve safety when they make an effort, even if this is in small steps. It arouses their motivation to act and do something towards disaster mitigation. Providing the environment to evaluate measures of urban improvement instantly and repeatedly has proven to be effective in igniting discussion. This used to be impossible because of inadequate computer performance.

The second and third phases must also be very effective. We must wait for examples of these to accumulate. However, we can demonstrate the value from just a few cases. In making the draft, the simulator makes quantitative and objective comprehension possible. It will therefore lead to system planning with a great consideration of local characteristics and a high feasibility based on a firm local basis without being excessively influenced by more general planning standards. At the moment, the accountability of the derived plan is being enriched.

6.4.2 Perspective on the Application of BOUSAI-PSS to a Community-Based Planning Process

PSS technologies including simulations and UVAT have made measurable progress in the last decade and it has already been demonstrated that the effects of simulators and UVAT and BOUSAI-PSS in community-based planning procedures are remarkable. Technology relationships between computer and disaster science have become established to a certain degree and will expand. However, social technology to make full use of these may need to be developed. I can point out from previous experience that there are three major tasks to accomplish.

The first task is sharing and accumulating good methods and know-how in risk communication with residents. PSS technologies can bring about a remarkable result in the motivation of residents if they are appropriate; if they are not suitable, however, they can be harmful. They may have the potential to scare residents unnecessarily. In a worst case, they may cause residents to give up considering the vulnerability of their homes and town, to cease considering their environment, and lead to their abandonment of the planning. We have observed some responses to the simulation utilization where the PSS display almost caused the citizens to become scared. The PSS presentation should be given to the residents as showing them that there are measures for residents to take.

As another consideration, it is possible that emphasizing the importance of community-based planning would sound threatening to persons living in a site related to an alternative plan, depending on the circumstances. Of course, this is a reflection of the fact that the explanation given with PSS has a high cogency. These concerns primarily depend on the communication skill of the facilitators. Various factors such as the context of the appearance of PSS in a workshop program, and pre-information contents provided to residents before using a simulator or UVAT will be related. It is necessary that the risk communication skills of the workshop facilitators be sophisticated. Addressing such concerns in the proper manner will lead towards success.

The second task is to reduce obstacles in the decision to use the system for the urban planning section in local government. The utility of the system is well recognized by them through examples available to date. However, not all local governments have been willing to adopt the system. The reasons are that the initial effort and the cost in collecting and maintaining data are considerable. Furthermore, a training system for comprehensive facilitating skills, GIS operation, urban planning, and social partnership are required. Moreover, communication inherent in local government organizations causes them to feel that there might be some danger to the personnel in charge of planning in taking on risk communication. Any issues discussed above are cost related, and therefore successful examples will demonstrate the effectiveness of the system and the problem will be solved. Practice is the best of all instruction.

The third task is accepting the balance between short- and long-term measures. Implementation of urban improvement such as making or widening roads and promotion of housing rehabilitation needs a few decades. The current PSS gives us the environment to support long-term measures, but provides no support or answer to short-term actions that residents can begin immediately. People shown the display of the system, mainly residents, can sometimes sense the temporal gap between the clarified existing hazard in their home town and the effectiveness of long-term measures. The system should fill this gap. New functions corresponding to short-term measures that will mitigate the hazard in the district immediately, such as firefighting by residents, and a simple seismic retrofit of houses considering fire resistance should be appended.

6.5 Conclusion

In this chapter I introduced the community-based urban improvement planning support system equipped with simulation and vulnerability assessment technologies as supporting technologies to urban regeneration. I can say that the last decade has been a period of establishment for this technology, which was triggered by the 1995 Hanshin-Awaji Earthquake Disaster. Actual use of the technology by parties related to community-based urban improvement planning has just begun. The system will be upgraded to reflect the feedback gained from the actual use, and effort will be applied in social technologies to make full use of the system at community level. It is my wish that the next decade will be called the breakthrough period with PSS for urban earthquake disaster mitigation.

References

Ministry of Land, Infrastructure and Transport Government of Japan (2003) Report on Development of assessment and countermeasure technology for disaster prevention in town planning. Ministry of Land, Infrastructure and Transport Government of Japan, (in Japanese)

KATO Takaaki (2002), the Role and Function of Planning Support System for District Improvement Plan for Earthquake Mitigation, AIJ Journal of Technology and Design (in Japanese)

Japan Institute of Construction Engineering (2005), Report on Community-based Urban Improvement Planning for Earthquake Mitigation with GIS Application (in Japanese)

7. Application of Information on Human Activity-Travel Behavior in Urban Space and Time in the Information Age

Nobuaki Ohmori

Department of Urban Engineering, The University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

7.1 Introduction

Understanding mechanisms underlying individual travel behavior in urban space and time is essential for investigating effective policy measures for sustainable urban regeneration. Conventionally, travel is considered a demand, derived from the desire to engage in activities at certain locations. Hence, an understanding of the relationships between travel behavior and daily activity engagement is necessary to estimate individual and household responses to policy measures and to changes in environmental constraints. In this context, rather than a “trip-based approach,” an “activity-based approach” that originated from a series of studies in the 1970s at the Transport Studies Unit (TSU) of Oxford University (Jones et al. 1983) is useful, and has promise. This approach emphasizes that travel behavior is a result of decision making in activity participation under the spatial and temporal constraints of the urban activity and transport system which individuals face in their daily life and household interactions. It also recognizes the importance of integrating transport and land use planning.

Our society currently faces large social, economic, and environmental change such as an aging society with decreasing population and household size, rapid development and diffusion of information and communications technology (ICT), global environmental problems, and further issues. As values and lifestyles have changed, individual activity-travel behavior has also altered. Regarding transportation in the 20th century, motorization has provided people with high "mobility". However, it has also caused various negative environmental effects such as road congestion, air pollution, traffic accidents, and noise. In city localities, motorization has promoted relocation of large-scale facilities such as government offices, shopping centers, and hospitals away from the city center to suburban areas, and the level of public transport service has declined. People with lower mobility, such as the elderly and disabled, and people without car availability, including the passenger mode, face a situation whereby they cannot participate in out-of-home activities as they wish. Activity-travel behavior for elderly people in the future will be very different from that of the current aged group.

From another point of view, the activities in which people participate have changed in the information age. One can now participate in activity in the real urban space, and also in "cyberspace," using ICT. In cyberspace, a person can derive huge amounts of information on society, communicate with others, and participate in various activities such as telecommuting, teleshopping, teleconferencing, and telemedicine, all without traveling to specific locations. The Internet and mobile communication provide opportunities to make wider social networks. People can engage in activities not only at fixed locations, but also while traveling. As a result, more dynamic and flexible decisions about activity-travel schedules can be made. "Multitasking" and the "fragmentation" of activity are recognized as the emerging activity-travel patterns (Mokhtarian et al. 2006; Kenyon and Lyons 2007; Lenz and Nobis 2007).

From an overall perspective, the focus of transportation policy has shifted away from large-scale, long-range capital investment towards better management of existing facilities for improving community quality of life, taking into account the economic, environmental, and social aspects of sustainable transportation. To meet this new paradigm, the transportation planners and researchers are required to evaluate the effects of policy measures embodied in the concepts of transportation demand management (TDM) measures, intelligent transport system (ITS) technologies, and barrier-free and universal design on a more detailed and finite spatiotemporal scale. These planners are therefore required to understand how individual activity-travel patterns are affected by the policy measures.

Spatial data infrastructure has been discussed in the previous chapter. Furthermore, various databases have been prepared concerning, for example, population and employment statistics, land use, and the transport network. Detailed, accurate information, not only on the urban environment, but also on human activity-travel patterns, is available for the minute and definitive analysis of human activity-travel patterns in urban space and time. GIS and three-dimensional GIS can precisely record activity-travel patterns in space and time. Correspondingly, making better use of the data can contribute to understanding and evaluating policy measures for sustainable urban regeneration. Because many of the constraints exist within the time-space geography of a city, it is important that activity data be used in conjunction with supply or opportunity data (Harvey 2003).

This chapter discusses the application of information on human activity-travel behavior in urban space and time. The next section summarizes what information on human activity-travel behavior is useful for evaluating policy measures for sustainable urban regeneration. Section 3 provides a review of conventional survey methods and the possibility of new technologies to collect activity-travel data. In section 4, consideration is given to what kind of analysis on human activity-travel behavior is important for sustainable urban regeneration. The concluding section reviews the appropriate direction of the use of spatial information in the analysis of human activity-travel behavior. In particular, this chapter emphasizes the importance of taking into account not only those activities conducted in real space, but also those in cyberspace, accessed by ICT. The usefulness of ICT for data collection, analysis, and the representation of activity-travel behavior is also mentioned.

7.2 Information on Human Activity-Travel Behavior to Evaluate Policy Measures for Sustainable Urban Regeneration

This section summarizes the kinds of elements and items that are important for understanding human activity-travel behavior in urban space and time, with especial reference to the information age. Fig.7.1 shows the relationship between individual activity-travel patterns and an urban environment. A city has its own environment, broadly embodied in a land use pattern (type, location, and opening hours of activity opportunities), a transportation system (road and public transport network, with a timetable), an institutional framework, as individuals/households have characteristics (household members, income, residential location, car availability), and activity demand (agenda). Under the various constraints of an individual/household and urban environment, the choice set of alternative activity-travel patterns is generated (“space-time accessibility” as explained later). Among them, an individual chooses one activity-travel pattern (“space-time path,” also explained later). Aggregation of individual activity-travel patterns affects the urban environment in the shorter and longer term.

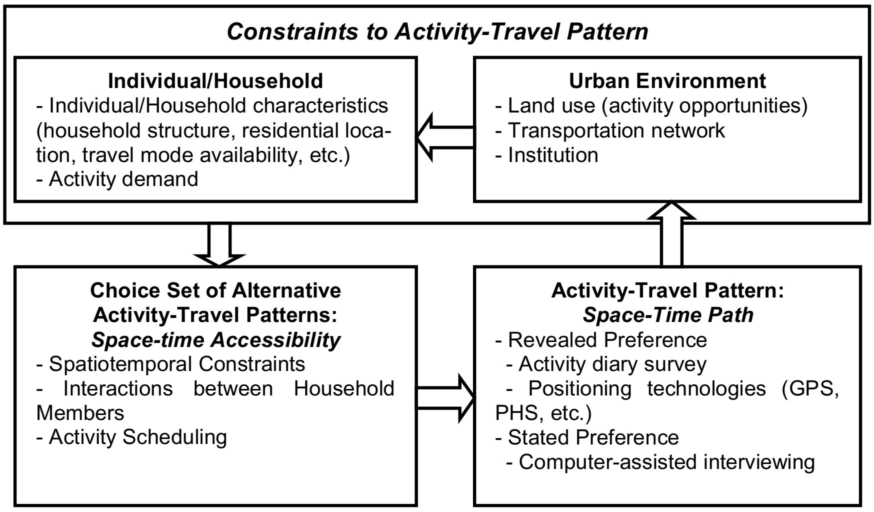


Fig.7.1. Activity-travel behavior in urban space and time

7.2.1 Travel and Activities

In the trip-based approach, the unit of analysis of individual travel is a trip whose basic elements derive from purpose (work, shopping, social or recreation, business, and school), with qualifiers such as start/end time, origin/destination, travel mode, route, cost, parking place, and accompanied persons. On the other hand, in the activity-based approach, the analysis unit is the activity itself. The elements of an activity are activity type, start/end time, location, accompanied persons, and if the activity is traveling, then trip information is qualifying, such as travel mode, route, cost, and parking place. Conventionally, activities are generally classified into the following three types:

- Mandatory/obligatory activities: sleeping, eating, personal care, medical attention. Individuals cannot outsource these types of activities to other individuals.
- Maintenance/subsistence activities: work, housework, childcare, grocery shopping, banking. Individuals can obtain benefit by outsourcing these types of activities to others.
- Discretionary activities: social, recreational, leisure, hobby, sports, watching TV, etc. Individuals can obtain benefit by outsourcing these types of activities to others.

7.2.2 Space-Time Constraints

The elements described above are mainly spatial and temporal information on individual activity-travel patterns, which is a “space-time path” as proposed by Hägerstrand (1970). Because individual activity-travel patterns are restricted by a variety of constraints, the available space-time area for the individual is limited in urban space and time. In order to recognize this, the concept of a “space-time prism” proposed by Hägerstrand (1970) is very useful. He suggested that there are three restrictions to human activity-travel patterns: (1) capability constraints, (2) coupling constraints, and (3) authority constraints.

Capability constraints mean that physiological characteristics and available mode restrict activity-travel patterns. For example, people have to sleep for at least 6 to 8 hours a day, and have meals three times a day. Those with car availability can travel faster than those without.

Coupling constraints mean that individuals and materials must exist together at specific locations and time. For example, an office worker has to work at the office from 9:00 a.m. to 5:00 p.m., and a working mother has to take her children to a childcare center.

Authority constraints mean that individuals cannot be present at specific locations at certain times. For example, people can only shop during the opening hours of a shopping center.

Not only information on the space-time path, but also information on the constraints to each activity is an important factor. It should be obtained to conduct an analysis of “space-time accessibility”. What is most important in this concept is that an individual’s trips and activities are connected in space-time, and activity-travel patterns are restricted by the space-time constraints of the urban environment. In addition, attitude, situation and reasons underlying activity-travel patterns are also important.

Additional information to the space and time dimensions when considering human activity-travel patterns are financial provision, calorie consumption, CO_2 emission, exposure to air pollution, noise, and a multiplicity of other influences. It is considered that people can participate in activity not only by traveling, but also by telecommunicating. In the information age, activities conducted in cyberspace by telecommunications have a very important meaning in daily life.

7.2.3 Telecommunications

In the past decade, the rapid development and diffusion of ICT, exemplified by mobile phones and the Internet, has provided people with much activity opportunity in cyberspace. The use of ICT affects individual activity-travel behavior, and our lifestyles and activity-patterns have dramatically changed. In particular, mobile communications that are not tied to a specific place or time have made personal decisions about activity scheduling more flexible. Fig.7.2 shows an example of dynamic rescheduling behavior by using telecommunications. Interactions between telecommunications and travel are classified into four types: substitution, complementarity, modification, and neutrality (Salomon 1985).

ICT penetration can be considered as one of the largest changes in lifestyle since motorization. Many new concepts have been proposed to better understand human activity-travel behavior in this information age. The most important could be "virtual mobility" and "virtual accessibility" (Golob 2001; Kenyon et al. 2002). As Golob (2001) suggested, the three space-time constraints proposed by Hägerstrand (1970) can be adapted to the modern world of ICT. Automobiles have enhanced physical accessibility, whereas ICT has enhanced virtual accessibility. Travel is considered a demand, derived from participating in activity in real space. Likewise, telecommunications is also considered a demand, derived from participating in activity in cyberspace. To better understand human travel behavior in this information age, we have to explicitly consider the relationships between activity, travel, and telecommunications.

The basic elements of telecommunications are start/end time, mode (exemplified by mobile phone, email or facsimile send/receipt), content, partner, and related factors. The use of telecommunications is restricted by space-time and authority constraints only within the "digital box" (Dijst 2004), which represents the space-time area within which the telecommunications means is available.

Harvey and Macnab (2000) discuss the spatial and temporal constraints on communication systems including telecommunications. Face-to-face contact requires the spatial and temporal coincidence of communicating parties. However, telephone contact requires only temporal coincidence. Moreover, email communication does not require any temporal or spatial coincidence.

Empirical studies on human activity-travel behavior with telecommunications (including mobile communications) have been conducted. Activity and telecommunications diary surveys for one day or multiple days have been conducted to analyze the effects of telecommunications on individual activity (re)scheduling and travel behavior (e.g., Ohmori et al. 2001; Nishii et al. 2005; Kenyon 2006). Some research concentrates on two-person communications behavior, including telecommunications. For example, Ohmori et al. (2006a) investigated meeting and waiting behavior at a train station in Tokyo. It was found that people engaged in dynamic decision making and rescheduling. The results suggest that the evaluation methods of meeting space should be reconsidered. Available activity opportunities around the meeting place are more important than the environment of the meeting place itself because, for many people, a meeting place is not for "waiting," but just "meeting." Niwa and Ohmori (2006) investigated the communication behavior of unmarried young couples in Tokyo. The study reveals the interaction between face-to-face meeting and telecommunications.

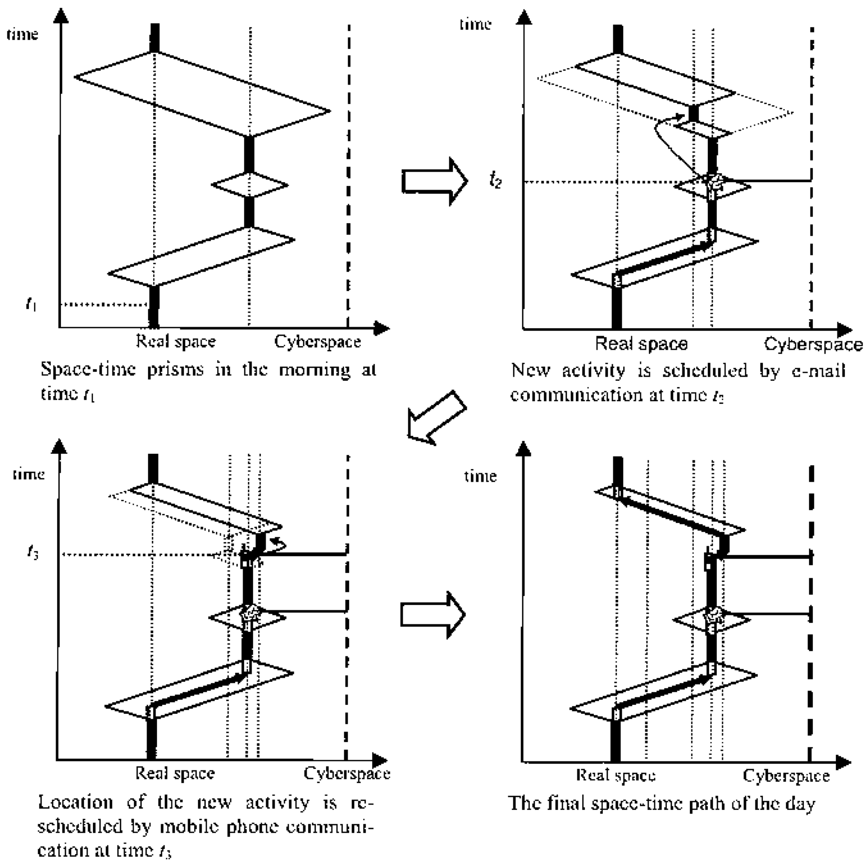


Fig.7.2. Dynamic change in a one-day activity schedule arranged by telecommunications

7.2.4 Positive Utility of Travel and Activities While Traveling

Travel has generally been regarded as disutility. However, some researchers argue the positive utility of traveling (Mokhtarian and Salomon 2001; Redmond and Mokhtarian 2001). They discuss three elements of travel utility: (1) activity at the destination, (2) activity while traveling, and (3) the activity of traveling itself. Of these, the second element will probably become greater, due to an increasing opportunity for conducting activity in cyberspace by ICT. Not only mobile phones equipped with a variety of functions but also miniaturized electronic devices, such as portable computers and music players, contribute to providing activity opportunities in real space while traveling (Lyons and Urry 2005; Ohmori 2006). Lyons and Urry (2005) argue for the productivity of travel in the information age. Some empirical studies on activities while traveling have recently been conducted. Lyons et al. (2007) investigated the use of travel time by rail passengers in Great Britain. Zhang et al. (2006) examined the effects on rail business travelers of the wireless Internet service in the Netherlands. Ohmori and Harata (2006) observed activities while commuting by train, and analyzed the difference between the different types of rail travel and a willingness to pay for a more comfortable train environment.

What travelers do while waiting for a train, bus or taxi at train stations or bus stops is also related to activity while traveling. Ohmori et al. (2004) observed what travelers were doing at bus stops. For urban regeneration, consideration of the city train stations and bus stops should have a greater role.

7.3 Survey Method for Collecting Information on Human Activity-Travel Behavior

This section describes the survey methods for collecting information on activity-travel behavior, reviews conventional methods, and considers the possibility of new technologies.

7.3.1 Conventional Method

A conventional survey method for collecting information on activity-travel patterns is a household travel diary. The main methods are a personal home interview, a telephone interview or a mail-back survey (Harvey 2003). The first multi-modal travel diary survey was conducted as a part of comprehensive transportation planning for the Chicago Area Transportation Studies (CATS) in 1956. The first survey in Japan was made for the Hiroshima area in 1967 and has since been called a “person trip survey”. Such person trip surveys have been conducted for urban transportation planning in Japanese cities with populations of about five hundred thousand and more. By 2007, more than 50 cities had already conducted the person trip survey at least once, and in Tokyo and Osaka, the fourth survey has already been conducted. Traditionally, paper-and-pencil interviewing (PAPI) has been applied in Japan. Surveyors visit randomly selected subjects at home to distribute self-administered questionnaire sheets, and then return to collect the completed sheets. In the United States, computer-assisted telephone interviewing (CATI) has been more popular.

The travel diary survey collects only trip information, whereas an activity diary survey collects all the activity engaged in during a reporting period, including the trip. The activity diary survey, when compared with the travel diary survey, has the advantage that it can capture more trips, and shorter and nonroutine (e.g., non-work/shop) travel, because it is easier for respondents to recall what they did on the day. Recently, activity-based travel diary surveys have been conducted in United States cities.

A travel/activity diary survey can provide information on a revealed preference (RP) of activity-travel behavior. Yet, it is important to know how travelers change their behavior over time in response to specific changes in the transportation system, such as a new transit line, or how they respond to changes in the general characteristics of system performance, such as an increasing level of congestion. For this purpose, a stated preference (SP) survey is appropriate. The survey asks respondents for their preference under hypothetical situations.

7.3.2 New Technology

New information technology can be used to improve the accuracy and efficiency of individual trip reporting. Wermuth et al. (2003) classified computer-assisted data collection techniques into three groups: computer-assisted real-time survey, computer-assisted retrospective survey, and computer-assisted stated preference methods.

For computer-assisted real-time surveys, positioning technologies or tracking technologies, such as a GPS and a global system for mobile communications (GSM), can be used to collect information on the spatiotemporal movement of persons and vehicles. Without filling in the questionnaire sheet, information on longitude and latitude, automatically collected at specific time intervals in real-time, can specify origin/destination, route and speed of trips. The Lexington area travel data collection test in 1996 was the first trial to apply a GPS to household vehicle travel surveys (Murakami and Wagner 1999). A handheld computer including a GPS was employed as a data collection device. In Japan, GPS, the personal handy-phone system (PHS), GPS-equipped mobile phones, and personal digital assistants (PDAs) with GPS have been tested (Ohmori et al. 1998, 2000, 2006b; Asakura and Hato 2004). As data can only be obtained if respondents carry the device when they travel, these technologies alleviate respondent burden. It helps to conduct longer-term surveys for weeks, months and a year to capture day-to-day variability in travel behavior.

Because travel is a derived demand from participating in activity, how activities are scheduled in decision making is also important. Advanced computer technology makes it possible to develop the software to collect this information. For example, CHASE (Doherty and Miller 2000) and React! (Lee and McNally 2001) record both the activity scheduled for a reporting week and that which is actually realized. Zhou and Golledge (2004) developed similar software on PDA with GPS. These are classified into computer-assisted retrospective surveys. Respondent burden is greater than for simple diary surveys, notwithstanding that the outcome would be most effective in understanding the complex mechanism of, and constraints to, activity-travel behavior.

Computer-assisted stated preference survey has been applied as a useful method because it can provide more realistic situations and customized questions replying to respondent answers. Recently, the Internet-based SP survey has shown itself to be a promising method. Aono et al. (2004, 2006) investigated the possibilities of Web-GIS technology in the Internet-based SP survey.

These computer-assisted survey methods can be applied only to those people to whom the technology is available. How to select a sample that is representative of the characteristics of the entire population is a problem to be solved. However, computer- and Internet-based survey is effective for special groups such as students. When trying to collect richer data, the respondent burden and the survey cost increase considerably. The balance between data quality and cost should be considered when choosing survey methods.

7.4 Analysis and Application of Information on Human Activity-Travel Behavior

This section describes what kind of analysis is needed using information on activity-travel behavior to evaluate policy measures for sustainable urban regeneration.

7.4.1 Demand Analysis

For basic transportation planning, trip information is used for developing travel demand forecasting models and evaluating a future plan with related policy measures. The traditional method is the trip-based four-step modeling approach of trip generation, distribution, modal split, and assignment, which is not behavioral in nature and ignores trip chaining behavior and time dimension. It cannot deal well with various space-time constraints and interactions between household members. Conventional trip-based modeling is not adequate for evaluating the effects of detailed and delicate measures such as TDM and ITS. Much research on activity-based travel forecasting models has been conducted during the past 30 years, e.g., CARLA (Jones et al. 1983), STARCHILD (Recker et al. 1986), SHEDULER (Gärling et al. 1989), AMOS (RDC Inc. 1995), SMASH (Ettema et al. 1996), daily schedule system (Bowman and Ben-Akiva 1997), PCATS (Kitamura 1997), and Albatross (Arentze and Timmermans 2000). Some models have been applied to practical travel demand forecasting.

7.4.2 Evaluation of Space-Time Accessibility

Providing individual mobility and accessibility to urban activity is an important goal for transportation planning (Meyer and Miller 2001). The simple measure of accessibility is travel time or travel cost (or generalized travel time/cost) between two locations. This measure reflects the spatial dimension of accessibility but does not explicitly reflect the temporal dimension of activity participation. In this context, the space-time prism is a very useful concept (Hägerstrand 1970). Based on the space-time prism, "space-time accessibility" has been proposed, which explicitly considers space-time constraints and activity duration at opportunities (Lenntorp 1978; Burns 1979).

GIS has recently become a powerful tool to measure space-time accessibility in real urban space. Much research on the operationalization of space-time accessibility measurement on a GIS platform has been conducted (Segawa and Sadahiro 1995; Kwan 1998; Miller 1999; Ohmori et al. 1999; Ohmori and Harata 2004). Applications of space-time accessibility in evaluating policy measures using a GIS are, for example, gender difference in accessibility (Kwan 1999), evaluation of location and service hours of childcare facilities (Segawa and Sadahiro 1995), accessibility of elderly people with and without a car (Ohmori et al. 1999; Ohmori and Harata 2004; Izumiyama et al. 2007), etc.

This space-time accessibility measure can be applied to evaluate the level of mobility-related "social exclusion" (Izumiyama et al. 2007). Kenyon et al. (2002) defined mobility-related "social exclusion" as "*the process by which people are prevented from participating in the economic, political and social life of the community because of reduced accessibility to opportunities, services and social networks, due in whole or in part to insufficient mobility in a society and environment built around the assumption of high mobility*." In an aging society, importance should be placed on the feasibility of activity participation by people with lower mobility and to the investigation of useful policy measures to apply.

As described in the previous section, accessibility to activities not only in real space but also in cyberspace should be considered in the information age. In addition, accessibility measures including activity while traveling would be useful. Appropriate methods should be developed. People would consider the activity possible while traveling when making decisions about residential and/or job location choice. Dijst (2004) proposes that actual, potential, and perceived action spaces will expand through the use of ICT. Harvey and Macnab (2000) propose interpersonal temporal accessibility in both real and cyberspace. Kenyon et al. (2002) discuss the possibility of promoting social inclusion through virtual mobility.

7.4.3 Simulation of Household Activity-Travel Patterns

Providing spatial and temporal information on activity-travel patterns is very useful to enable individuals to understand and investigate their current and alternative activity-travel patterns in urban space (e.g., Jones 1982; Jones et al. 1983; Ohmori et al. 2005). A gaming simulation technique developed by TSU is useful to better understand how household members adapt their activity-travel patterns to change in urban environment and constraints. The Household Activity-Travel Simulator (HATS) is a famous tool (Jones 1982; Jones et al. 1983). This was applied to understand household responses to changes in the levels of bus service, road pricing measures, and so forth. The author and his colleagues developed a GIS-based activity-travel simulator: Simulation Model for Activity Planning (SMAP) (Ohmori et al. 2003). The system represents the current activity-travel pattern in space and time dimensions using a GIS function, and generates alternative activity-travel patterns based on spatiotemporal constraints of the current activity-travel schedule. It was originally applied to understand travel behavior and constraints in households of the elderly. Two improved versions were developed and applied: SMAP for Education (SMAP-E) to enable graduate students to understand human travel behavior under spatiotemporal constraints, and SMAP for Leisure (SMAP-L) to understand the activity scheduling behavior of tourists (Ohmori et al. 2005).

Encouragement of travelers to become involved in environmentally friendly travel patterns has been recently recognized as a promisingly effective policy measure to reduce car use. Jones (2003) called such approaches soft measures in mobility management. The effectiveness of this method has been demonstrated by previous research in, for example, Individualized Marketing (Brög 1998), Travel Smart (Department of Transport, Western Australia 2000), Travel Blending (Rose and Ampt 2001) and the Travel Feedback Program (TFP) (Fujii and Taniguchi 2005, 2006). In these programs, the first step is obtaining information on travel diaries from participants to diagnose their travel patterns. The programs then provide the participants with information on the CO2 emissions they produced, and on public transport as an alternative mode, and/or advise how to reduce car-use based on their current travel patterns. The authors further developed the SMAP into the Web GIS-based system: Internet-based SMAP (iSMAP) (Nakazato et al. 2006), integrated with a Web-based SP survey system (Aono et al. 2004, 2006). The iSMAP was applied, as a communication and self-consultation tool, to TFP. Individual travel data were collected using a GPS mobile-phone-based survey system. Participants in the program were well able to understand their activity-travel patterns in a Web browser. They could compare alternative activity-travel patterns consulting the diagnostic indicators such as travel time, travel cost, CO2 emissions, and calorie consumption (see Figure 3). The iSMAP was further enhanced using Google Maps API and applied to a mobility management program on the Kashiwa campus of the University of Tokyo (Aono et al. 2007). This decision support system for activity-travel patterns could be a very promising tool, and has much possibility for its further application to public participation in community-based planning for sustainable urban regeneration.

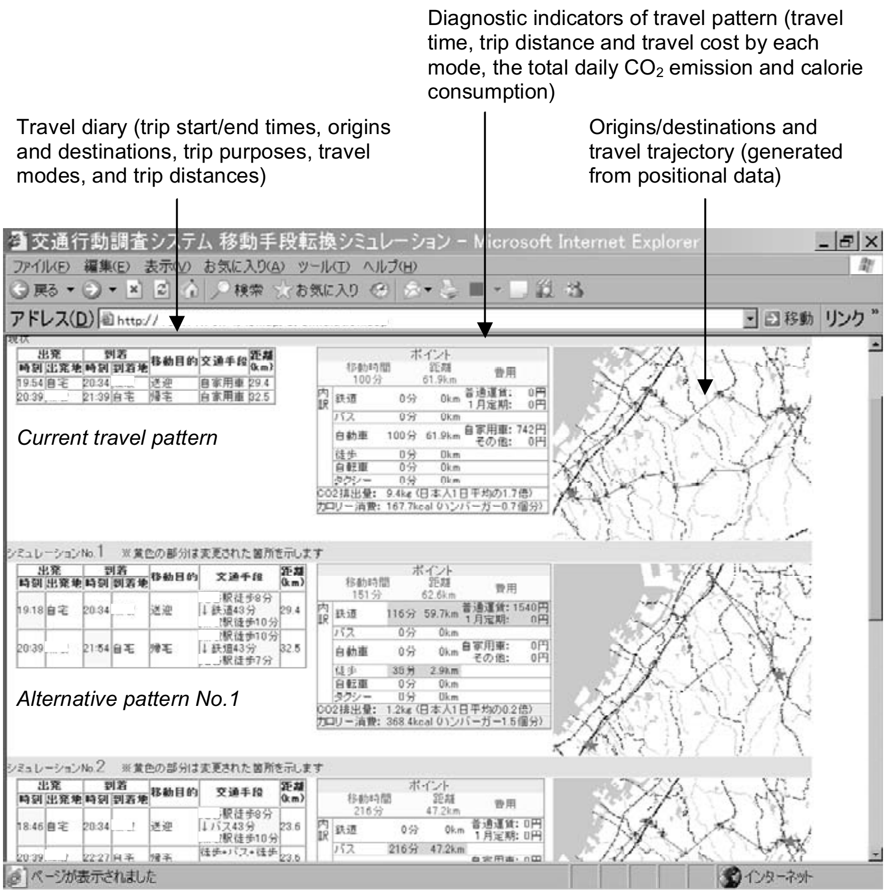


Fig.7.3. Snapshot of *i*SMAP (representation of current and alternative activity-travel patterns)

7.5 Conclusions

Human activity-travel patterns are the result of decision making about participation in activity in urban space and time under the space-time constraints of the urban environment (activity and transport system). Therefore, we cannot evaluate policy measures to attain sustainable urban regeneration without spatial information on human activity-travel behavior combined with information on the urban environment. Spatial data infrastructure should include the urban environment and activity-travel patterns of city dwellers.

Cities have recently been facing dramatic alterations to their society, economy, and environment. Rapid development and the prevalence of ICT are the most important elements that have caused this change. With the change in urban environment, individual activity-travel behavior has also been altered dramatically. In particular, individuals can participate in a variety of activities in real space, and also in cyberspace, using ICT, such as the Internet and mobile phones. Visions, goals and objectives in urban transportation planning and policy have also been changing. More detailed and delicate analyses are necessary to evaluate policy measures towards sustainable urban regeneration. In this context, new information technology, as represented by GIS, GPS, mobile phones, and the Internet can assist in collecting more detailed and accurate information on human activity-travel behavior and also in analyzing and presenting it.

New survey methods should be developed to collect the arising activity-travel behavior, such as the use of telecommunications, activity while traveling, multitasking, and the fragmentation of activity. Further applications of information on activity-travel behavior should be examined, for example the decision support and self-consultation system, and the provision of citizens with information on their activity-travel patterns for public involvement. Spatial data infrastructure, including human activity-travel behavior, offers many possibilities for further applications towards understanding sustainable urban regeneration.

References

Aono S, Ohmori N, Harata N (2004) Development of an Internet-based travel survey system. Proceedings of the International Symposium on City Planning 2004, pp 41–50

Aono S, Ohmori N, Harata N (2006) Development of a Web-GIS simulator for holiday non-work activities. Proceedings of the 5th International Conference on Traffic and Transportation Studies, pp 959–967

Aono S, Takahashi O, Seto Y, Ohmori N, Harata N (2007) Development and application of a Web based activity-travel simulator for travel feedback program. Proceedings of the 10th International Conference on Computers in Urban Planning and Urban Management, CD-ROM

Arentze TA, Timmermans HJP (2000) Albatross: A learning-based transportation oriented simulation system. European Institute of Retailing and Services Studies, Eindhoven, The Netherlands

Asakura Y, Hato E (2004) Tracking survey for individual travel behaviour using mobile communication instruments. Transportation Research C 12: pp 273–291

Bowman JL, Ben-Akiva ME (1997) Activity-based forecasting. In: Texas Transportation Institute (eds) Activity-based travel forecasting conference, June 2–5, 1996. Summary, recommendations, and compendium of papers. Travel Model Improvement Program. U.S. Department of Transportation and U.S. Environmental Protection Agency, Washington D.C.

Brög W (1998) Individualized Marketing: implications for TDM. Proceedings of the 77th Annual Meeting of the Transportation Research Board, CD-ROM

Burns LD (1979) Transportation, temporal, and spatial components of accessibility. Lexington Books, Lexington

Department of Transport, Western Australia (2000) Travel Smart: a cost-effective contribution to transport infrastructure. Perth

Dijst MJ (2004) ICT and accessibility: an action space perspective on the impact of new information and communication technologies. In: Beuthe E, Himanen V, Reggiani A, Zamparini L (eds) Travel demand and organization in an evolving world. Springer, Berlin, pp 27–46

Doherty ST, Miller EJ (2000) A computerized household activity scheduling survey. Transportation 27: pp 75–97

Ettema D, Borgers A, Timmermans HJP (1996) SMASH (Simulation Model of Activity Scheduling Heuristics): some simulations. Transportation Research Record 1551: pp 88-94

Fujii S, Taniguchi A (2005) Reducing family car-use by providing travel advice or requesting behavioral plans: an experimental analysis of travel feedback programs. Transportation Research D 10: pp 385–393

Fujii S, Taniguchi A (2006) Determinants of the effectiveness of travel feedback programs—a review of communicative mobility management measures for changing travel behaviour in Japan. Transport Policy 13: pp 339–348

Gärling T, Brannas K, Garvill J, Golledge RG, Opal S, Holm E, Lindberg E (1989) Household activity scheduling. Selected proceedings of the 5th World Conference on Transport Research 4, pp 235–248

Golob TF (2001) Travel Behavior.Com: activity approaches to modeling the effects of information technology on personal travel behavior. In: Hensher DA (ed) Travel Behaviour Research: The Leading Edge. Pergamon, Oxford, pp 145–183

Harvey AS (2003) Time-space diaries: merging traditions. In: Stopher P, Jones P (eds) Transport Survey Quality and Innovation. Pergamon, Oxford, pp 151–180

Harvey AS, Macnab PA (2000) Who's up? global interpersonal temporal accessibility. In: Janelle DG, Hodge DC (eds) Information, Place, and Cyberspace: Issues in Accessibility. Springer, Berlin, pp 147–170

Hägerstrand T (1970) What about people in regional science? Papers of the Regional Science Association 24: pp 7–21

Izumiyama H, Ohmori N, Harata N (2007) Space-time accessibility measures for evaluating mobility-related social exclusion of the elderly. Proceedings of 11th International Conference on Mobility and Transport for Elderly and Disabled Persons, CD-ROM

Jones PM (1982) 'HATS' educational manual: studying travel in the context of household activity patterns. Transport Studies Unit, Oxford University, Ref.193/PR

Jones PM, Dix MC, Clarke MI, Heggie IG (1983) Understanding travel behavior. Gower, Aldershot

Jones PM (2003) Encouraging behavioural change through marketing and management: what can be achieved? Paper presented at the 10th International Conference on Travel Behavior Research, Lucerne, August 2003

Kenyon S, Lyons G, Rafferty J (2002) Transport and social exclusion: investigating the possibility of promoting inclusion through virtual mobility. Journal of Transport Geography 10: pp 207–219

Kenyon S (2006) The 'accessibility diary': discussing a new methodological approach to understand the impact of Internet use upon personal travel and activity participation. Transport Geography 14: pp 123–134

Kenyon S, Lyons G (2007) Introducing multitasking to the study of travel and ICT: examining its extent and assessing its potential importance. Transportation Research A 41: pp 161–175

Kitamura R (1997) Applications of models of activity behavior for activity-based demand forecasting. In: Texas Transportation Institute (eds) Activity-based travel forecasting conference, June 2–5, 1996. Summary, recommendations, and compendium of papers. Travel Model Improvement Program. U.S. Department of Transportation and U.S. Environmental Protection Agency, Washington D.C.

Kwan M-P (1998) Space-time and integral measures of individual accessibility: a comparative analysis using a point-based framework. Geographical Analysis 30: pp 191-216

Kwan M-P (1999) Gender and individual access to urban opportunities: a study using space-time measures. Professional Geographer 51: pp 210–227

Lee M, McNally MG (2001) Experiments with a computerized self-administered activity survey. Transportation Research Record 1752: pp 91–99

Lenntorp B (1978) A time-geographic simulation model of individual activity programmes. In: Carlstein T, Parks D, Thrift N (eds) Timing Space and Spacing Time 2, Human Activity and Time Geography. Arnold, London, pp 162-180

Lenz B, Nobis C (2007) The changing allocation of activities in space and time by the use of ICT—''fragmentation'' as a new concept and empirical results. Transportation Research A 41: pp 190–204

Lyons G, Urry J (2005) Travel time use in the information age. Transportation Research A 39: pp 257–276

Lyons G, Jain J, Holley D (2007) The use of travel time by rail passengers in Great Britain. Transportation Research A 41: pp 107–120

Meyer MD, Miller EJ (2001) Urban transportation planning: a decision-oriented approach, 2nd ed. McGraw-Hill, New York

Miller HJ (1999) Measuring space-time accessibility benefits within transportation networks: basic theory and computational procedures. Geographical Analysis, 31: pp 187–212

Mokhtarian PL, Salomon I (2001) How derived is the demand for travel? some conceptual and measurement considerations. Transportation Research A 35: pp 695–719

Mokhtarian PL, Salomon I, Handy SL (2006) The impact of ICT on leisure activities and travel: a conceptual exploration. Transportation 33: pp 263–289

Murakami E, Wagner DP (1999) Can using global positioning system (GPS) improve trip reporting? Transportation Research C 7: pp 149–165

Nakazato M, Ohmori N, Aono S, Maruyama T, Harata N (2006) Internet GIS-based activity-travel simulator for investigating alternative activity-travel patterns. Paper presented at the 11th International Conference on Travel Behaviour Research, Kyoto, August 2006

Nishii K, Sasaki K, Kitamura R, Kondo K (2005) Recent Developments in activity diary-based surveys and analysis: some Japanese case studies, In: Timmermans H (ed) Progress in Activity-Based Analysis. Elsevier, Oxford, pp 335-354

Niwa Y, Ohmori N (2006) Communications behavior of young couples: through four-week activity-telecommunications diary and depth interview surveys (in Japanese). Papers on City Planning 41: CD-ROM

Ohmori N, Muromachi Y, Harata N, Ohta K (1998) Possibility of GPS to travel behavior survey (in Japanese). Proceedings of the 18th Traffic Engineering Conference, pp 5–8

Ohmori N, Muromachi Y, Harata N, Ohta K (1999) A study on accessibility and going-out behavior of aged people considering daily activity pattern. Journal of the Eastern Asia Society for Transportation Studies 3: pp 139–153

Ohmori N, Muromachi Y, Harata N, Ohta K (2000) Travel behavior data collected using GPS and PHS. Proceedings of the 2nd International Conference on Traffic and Transportation Studies, pp 851–858

Ohmori N, Harata N, Ohta K (2001) The effects of using telecommunications on individual activity schedule (in Japanese). Infrastracture Planning Review 18: pp 587-594

Ohmori N, Muromachi Y, Harata N, Ohta K (2003) Simulation Model for Activity Planning (SMAP): GIS-based gaming simulation. In: Park C-H, Cho JR, Oh J, Hayashi Y, Viegas J (eds) Selected Proceedings from the 9th World Conference on Transport Research. Elsevier, Oxford, CD-ROM

Ohmori N, Harata N (2004) Evaluation of space-time accessibility considering daily activity engagement of the elderly. Proceedings of the 10th International Conference on Mobility and Transport for Elderly and Disabled Persons, CD-ROM

Ohmori N, Hirano T, Harata N (2004) Passengers' waiting behavior at bus stop. Proceedings of the 4th International Conference on Traffic and Transportation Studies, pp 157–164

Ohmori N, Harata N, Ohta K (2005) Two applications of GIS-based activity-travel simulators. In: Timmermans H (ed) Progress in Activity-Based Analysis. Elsevier, Oxford, pp 415-435

Ohmori N (2006) Connected anytime: telecommunications and activity-travel behavior from Asian perspectives. Paper presented at the 11th International Conference on Travel Behaviour Research, Kyoto, August 2006

Ohmori N, Harata N (2006) Activities while commuting by train: a case in Tokyo. Paper presented at the 2nd International Specialist Meeting on ICT, Everyday Life and Urban Change, Bergen, November 2006

Ohmori N, Hirano T, Harata N (2006a) Meeting appointment and waiting behavior with mobile communications. Transportation Research Record 1977: pp 250–257

Ohmori N, Nakazato M, Harata N, Sasaki K, Nishii K (2006b) Activity diary surveys using GPS mobile phones and PDA. Compendium of Papers of the 85th Annual Meeting of the Transportation Research Board, CD-ROM

Recker WW, McNally MG, Root GS (1986) A model of complex travel behavior: Part I: theoretical development. Transportation Research B 20: pp 307–318

RDC, Inc. (1995) Activity-based modeling system for travel demand forecasting. Report DOT-T-96-2. Washington, D.C.: U.S. Department of Transportation

Redmond LS, Mokhtarian PL (2001) The positive utility of the commute: modeling ideal commute time and relative desired commute amount. Transportation 28: pp 179–205

Rose G, Ampt E (2001) Travel Blending: an Australian travel awareness initiative. Transportation Research D 6: pp 95–110

Salomon I (1985) Telecommunications and travel: substitution or modified mobility? Journal of Transport Economics and Policy 19: pp 219–235

Segawa S, Sadahiro Y (1995) A policy making support system for child care facilities using GIS (in Japanese). Papers and Proceedings of the Geographic Information Systems Association 4: pp 59–64

Wermuth M, Sommer C, Kreitz M (2003) Impact of new technologies in travel surveys. In: Stopher P, Jones PM (eds) Transport Survey Quality and Innovation. Pergamon, Oxford, pp 151–180

Zhang M, Marchau V, van Wee B, van der Hoorn T (2006) Wireless internet on trains: the impacts on the performance of business travelers. Compendium of Papers of the 85th Annual Meeting of the Transportation Research Board, CD-ROM

Zhou J, Golledge R (2004) Real-time tracking of activity scheduling/schedule execution within unified data collection framework. Compendium of Papers of the 83rd Annual Meeting of the Transportation Research Board, CD-ROM

8. The Behavioral Basis of Environmental Design for Human Beings

Kazuhiko Nishide

Department of Architecture, The University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

8.1 Introduction

Can sustainable urban regeneration make people rich?

Do sustainable urban regenerated spaces really make people rich?

Could hard space respond to the diverse and ever-changing needs of people? Doesn't it force people to moderation? People do not change according to the environment. People adapt the environment according to themselves.

Can a space that fills people's needs over a long period of time be created under the conditions of sustainable urban regeneration?

Is there a good method of using existing space, and converting it to some other purpose effectively? Can't conversions be considered as a discovery of how to use new space positively? It is not a space that receives a specific use and a specific function that we should strive for, but rather a space that can contain the varying human behavior of diverse human beings, or their coexistence within it. Therefore, it will be necessary for us to examine what possibilities there are in using space to enhance the life of people.

8.2 What Is Human Environment?

Modern architecture often lacks the human touch. A modern new town is not human, especially when built in the age of high economic growth in Japan. Fig.8.1 is an aerial photograph of the Kodan Soka Matsubara Danchi housing development of 1963. This new town suddenly appeared in a rice field. A lot of buildings have been built in an orderly manner.

Fig.8.1. The Kodan Soka Matsubara Danchi housing development

How do people feel about the environment here?

Where is your apartment? Perhaps someone will enter someone else's apartment by mistake.

House number?

Building number?

Room number?

All are necessary here. We cannot help but rely on numbers in such an environment.

8.3 How Do People Perceive This Environment?

Fig.8.2 is a sketch map drawn by a schoolgirl who lives in this housing compound. She drew more buildings than the actual number. She recognized this town to be a place with a lot of buildings. This is not a human environment. Many buildings have been built that are efficient and functional. However, people need not only efficiency, but also a human point of view.

Fig.8.2. A sketch map drawn by a schoolgirl

Fig.8.3 is Roji alley in Kikusaka. We feel a human touch in these alleys: Roji houses open on both sides. Here is the well, which everyone used and formerly chatted around. This alley has an appropriate human-scale width. If a visitor meets a person living here, they can certainly greet or speak to each other. The number of housing units is also appropriate. There are a lot of pot plants here. The person who tends them might come out. We feel peoples' presence here. Also, strangers will feel excluded. This is semi-private space, defensible by the inhabitants. Such an environment is human, although it is not modern.

Fig.8.3. Roji alley in Kikusaka

If it is understood that the scale and the form of space are important for human beings, then we should consider what the scale and form of the built environment should be. First of all, we should understand humans and their surroundings. Human behavior in an environment and the perception of that environment should be examined.

8.4 What Is an Environment for Human Beings?

Our environment includes all of our natural and artificial surroundings. In real life, our behavior also occurs in the context of an environment that is constantly changing and is rich in information.

A sensory deprivation experiment suggests to us the meaning and significance of environment. In this experiment, a simulation deprived the subject of sense (Fig.8.4). Sound and temperature were controlled in this room. The subject put on a blindfold and soft gloves. No light, no sound, no touch…he was in this room for a long time.

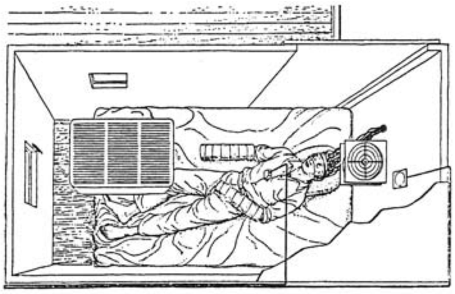


Fig.8.4. A sensory deprivation experiment

How long could he endure this?

The subject slept for several hours. Afterwards, he awoke, and his mental status become disordered, but there was still no stimulation, no senses, and before long he gave up. The sensory deprivation experiment suggests that depriving an individual of all sensory stimulation can lead to severe anxiety and other psychological anomalies.

This experiment indicates that it is necessary to derive stimulation from the environment so that a person may feel alive. People can live only in this environment, our environment. Depriving someone of stimulation is equivalent to depriving them of their environment.

Our environment also provides us with the basic needs for life, including food, water, and air to breathe. No living thing is separable from environment. All plants need water and light. The leaf receives light, and the root absorbs water in the soil. Therefore, the tree grows into shape.

Animals?

Fish live in water. Fish take in oxygen and food from water.

Human beings?

A person needs space around the body. Also, space between the person and the walls is necessary. In this space we find the basic needs for life: food, water, air to breathe, information, and much more.

8.5 Human Dimension and Hidden Dimension

Space is the fundamental environment around a person. An experiment was carried out on how many people can be crowded into a telephone box. The experiment was conducted twice. The same number of people that had first entered was not reached in the case of the second experiment. Why? The subjects took a rest after the first experiment, and they mutually introduced themselves. They became friends for the second experiment although they were strangers during the first attempt. They became human by the time of the second experiment yet they were mere things during the first one, so they could not be crowded into a telephone box because they are human beings.

Space is necessary between one person and another. A human needs space around the body. We have visible physical dimensions, height, weight, and other attributes. It is necessary to design a chair and the other furniture we use according to the dimensions of the human body. We also have invisible dimensions that are extensions of the body through our senses of sight, hearing, smell, etc.

It is necessary to design space according to the invisible measure of the human body. This is personal space.

8.6 Personal Space

Personal space is defined as "an area surrounding a person's body into which intruders may not come" (Sommer, 1969). The purpose of this study is to consider the individual cognition of personal space and meaning in relation to room space. Personal space is a fundamental concept in designing architectural space. Although it is an invisible psychological territory around a person, it may also be defined as a territory that has a physical area.

The two-dimensional shape and size of personal space in the built environment have been extensively investigated through experiments and field observations. Experimental investigations have been made into many aspects of personal space. Observations were made of people, for example, during conversation and while waiting in line in public spaces, to clarify how and why space formation between people typically materialized in these cases.

8.7 Meaning of Distance

Human behavior has a close relation to the environment. Fig.8.5 shows two women sitting on buffer stop blocks and chatting. Each of them uses the block, a buffer stop, as a substitute for a stool. They are sitting and chatting on objects that are sufficiently separated for conversation. If the seats were wider apart or closer together, they could not converse easily.
This block affords sitting, and invisible distance also permits chatting.

Fig.8.5. Two women sitting on buffer stop blocks and chatting

Fig.8.6 shows that a different distance between two chairs affords different human relations. The distance allows conversation. Different seat arrangements create different human relations. Side-by-side differs from face-to-face (Fig.8.7).

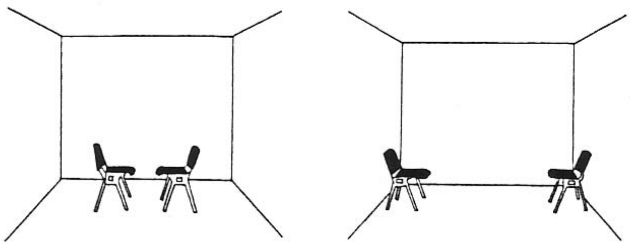


Fig.8.6. A different distance between two chairs affords different human relations

Fig.8.7. Side-by-side differs from face-to-face

What is he doing in Fig. 8.8? Is he waiting or not? Where do you stand to wait for this telephone? I wonder why? What is the reason for this doubt? The reason may be the ambiguous distance he requires. This shows one phase of the meaning of distance.

Fig.8.8. What is he doing?

Fig.8.9 shows the typical waiting distance in a Tokyo railway station. While waiting in line in a public space, a certain distance is constantly maintained between people. Invisible distance has a meaning like body language. A person indicates "waiting" by invisible distance. Invisible space around a person also has meaning.

Fig.8.9. Typical waiting distance

Fig.8.10 is a daily scene in Ueno Park with people sitting along the pond. Everyone maintains personal space around themselves. A certain distance is maintained between people. The distances between people reflect their relationships. They may be friends, or they may be strangers.

Fig.8.10. People sitting along the pond

Hall (1966) pointed out the relation between communication and distance, and classified interpersonal distance. "The Hidden Dimension" is Hall's great work. The hidden dimension means an invisible human dimension.

8.8 The Distance and the Angle of Orientation Between People

Fig.8.11 shows two persons having a conversation whilst standing. Many examples of people conversing in public spaces such as railway stations were observed. There are typical distances and angles of orientation between people during conversation. Between individuals conversing in public spaces, a certain distance of 60–70 cm in standing mode is constantly maintained, and the angle of orientation is mostly one of three types: those of face-to-face, side-by-side, and angled-face-to-face.

Fig.8.11. Two persons having a conversation

How about a small group? Fig.8.12 shows several persons talking. We observed them and measured the group diameter during conversation. The individuals in the group arranged themselves in a circle or part of a circle, and the greatest distance between members was less than 3 m.

Fig.8.12. Several persons talking

But people are not always in communication. Most are strangers. People tend to step back from strangers unless there is a conversation. Fig.8.13 shows that the subjects share a table, but one of them steps back. Invisible personal space exists between them.

Fig.8.13. Step back from strangers

8.9 Experiment on Personal Space

An experimental investigation was made to identify personal space by the degree of the subject's inclination to move away from the object person standing at various distances and angles, and to investigate the effect of the object person's angle of orientation, subject's postures, and architectural variants.

In this experiment, subjects were asked to stand at a pre-determined position and the amount of adjustment movement away from the object person, the extent of 'fleeing' from each other, was measured. Fig.8.14 represents personal space as illustrated by contours drawn from the angle of inclination. The nearer the object person came, the more the subject inclined their body to move away.

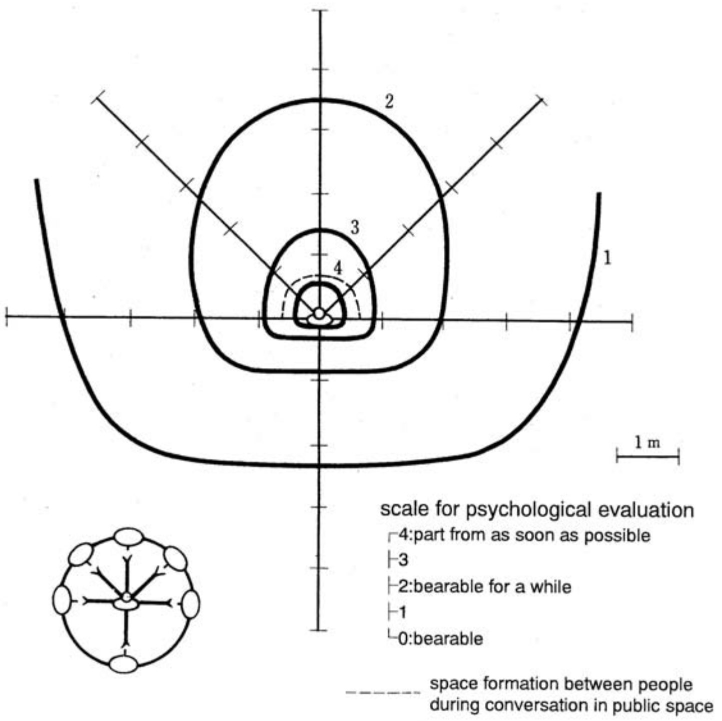


Fig.8.14. Personal space

Personal space is elongated forward, and when the object person turns their back upon the subject the personal space becomes less.

Personal space is smaller when enclosed by walls rather than in an open place. In a corner, personal space becomes less. Also, the sex of a person influences the preferred amount of personal space.

8.10 Interpersonal Distance

It is possible to conclude that interpersonal distance is classified characteristically into six grades based on an absolute scale (Fig.8.15). These are: Exclusive, Conversational, Space common, Mutual recognition (near and far phases), and Discriminating. In this scale, 1.5 m, and 3 m are turning points of relationship between people. In a box of 1.5 m, only conversation is afforded (Fig.8.16), whereas in a 3 m space, they can talk and also be strangers (Fig.8.17). Architects should be conscious of these turning points of scale.

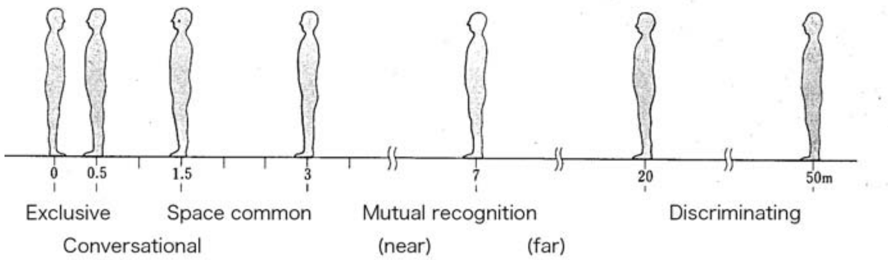


Fig.8.15. Interpersonal distance

Fig.8.16. In a box of 1.5 m

Fig.8.17. In a 3 m spacce

8.11 Space Formation of People

Orientation angles also have a meaning. Fig.8.18 shows the positions and orientation angles of people in a crowded train on the Yamanote line. People cannot keep personal space in a crowded train, but tend to turn away from others. The angles of orientation between friends are face-to-face, whereas those between strangers are never face-to-face. In Fig.8.19, they are at a very close distance, but they are looking aside. They are probably not friends. Alternatively, front and back as seen in Fig.8.20, they are probably strangers.

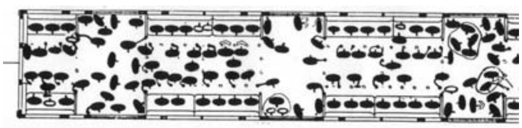


Fig.8.18. People in a crowded train

Fig.8.19. Looking aside

Fig.8.20. Alternatively, front and back

Space formation can be classified into sociofugal and sociopetal types. Sociopetal is the tendency to face each other to communicate. Sociofugal is turning aside to avoid others. Osmond (1957) considered these concepts with regard to furniture layout. Fig.8.21 shows a sociopetal setting: space for communication. Fig.8.22 shows a sociofugal setting.

Fig.8.21. Sociopetal setting

Fig.8.22. Sociofugal setting

Up to now, the topics have been two-dimensional studies in relation to planning. However, space has three dimensions.

8.12 Reference Domains of Demonstrative Pronouns as an Aspect of Personal Space

The Japanese language contains three demonstrative pronouns*, 'KORE'*, *'SORE'*, and *'ARE'.*

In everyday conversation in Japan, we use these according to the relative positions of, and the distance between, speakers who are the demonstrative object and the listener. The differences in the application of the three pronouns indicate that the space surrounding a person can be classified into three reference domains.

A demonstrative object placed in the domain nearest to the speaker, and which includes the speaker's standing point, is called *'KORE'* by the speaker. A demonstrative object placed in the next-nearest domain which surrounds the first one is called *'SORE'*. When placed in the third and farthest domain from the speaker beyond the two other domains, an object is called 'ARE'.

It is expected that the research examining the three-dimensionality of this territorial distinction recognized by these demonstrative pronouns will lead to an understanding of the way by which a person subjectively recognizes their surrounding environment as personal territory, as well as perhaps the nature of personal territoriality itself. Clarification of this territorial distinction of personal space in both a qualitative and quantitative way should provide a psychological and behavioral basis for evaluating the scale and form of the built environment.

An investigation was made to identify the reference domains of demonstrative pronouns three-dimensionally around a person. The experiment was carried out in a gymnasium to provide ample room (Fig.8.23). Subjects were located standing at a particular spot, whilst an object represented by a 7 cm diameter ball was adjusted to a range of pre-determined heights on vertical lines arranged, on a pre-determined three-dimensional grid, of possible positions. Subjects were asked to voice *KORE/SORE/ARE* while pointing to the ball as it was adjusted from one position to the next.

Fig.8.23. Experiment on reference domains of demonstrative pronouns

Fig.8.24 shows the reference domains of demonstrative pronouns. The reference domain of *'ARE'* encloses the domain of *'SORE',* which encloses the domain of *'KORE',* and *'ARE'* obviously extends to infinity. *'SORE'* and *'KORE'* approximately shape the division of near and mid-range personal space as concentric egg shapes.

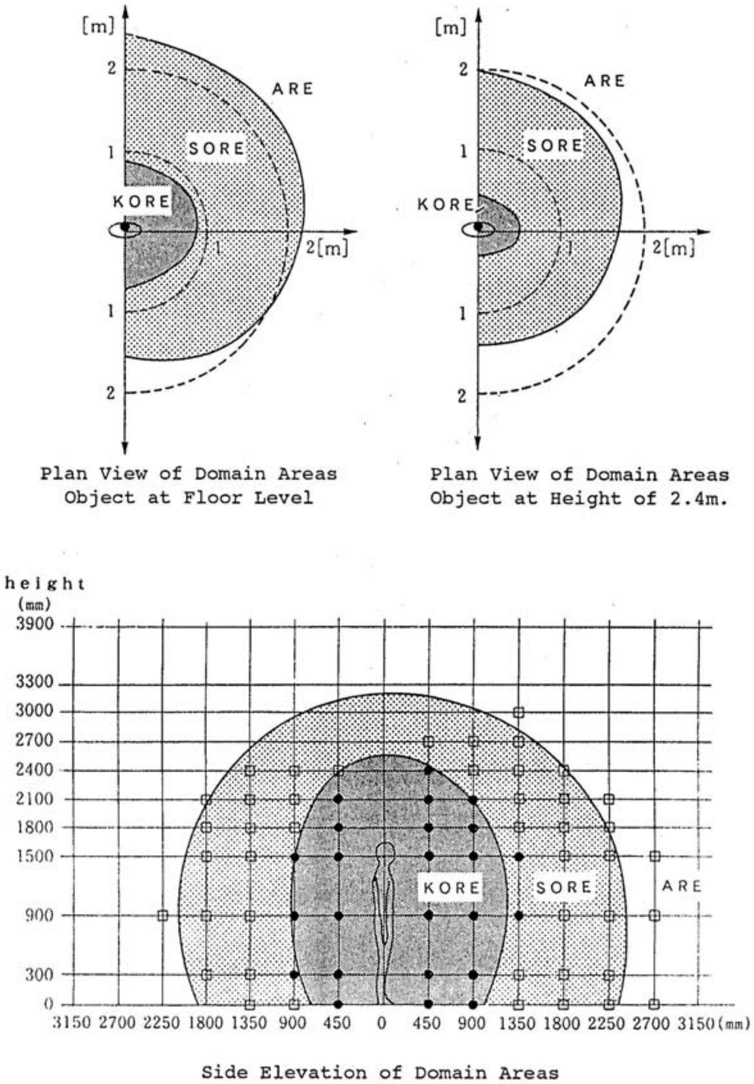


Fig.8.24. Reference domains of demonstrative pronouns

The domain of *'KORE'* corresponds to the intimate and personal, or protective zone where the approach of an unsuspected person is perceived as an intrusion and where both persons feel like fleeing from each other. Moreover, the characteristic of the domain of *'KORE'* is that its size and shape tend to be unaffected by different constraints, which is also an essential characteristic of the intimate and personal zone. As is the case with the intimate personal zone in personal space, the domain of *'KORE'* is more important to the speaker than the other domains. The next domain of *'SORE'* corresponds to the social zone.

It has been clarified that the spatial boundaries between the three reference domains of Japanese demonstrative pronouns can be clearly drawn, and divide personal space into zones, each with different cognitive and territorial values. This usage of demonstrative pronouns reflects on the cognitive change of one's surrounding space. For example, if the size of a room is too small to contain the external boundary of the domain of 'SORE', such a room gives people a cramped or claustrophobic impression. Thus, the reference domains of demonstrative pronouns can be an effective measure of the spaciousness of a room. As a result of this experiment, the shape, size, and volume of three-dimensional reference domains were introduced.

Fig.8.25 shows the reference domains of demonstrative pronouns from reclining postures.

They are different from the reference domains of demonstrative pronouns derived from standing. The reference domain of *'KORE'* encloses the region from head to knee, and has relationship to the motion area of the arm. Space at one's foot is perceived as not so close, and thus the reference domains of demonstrative pronouns can be an effective measure in thinking about postures.

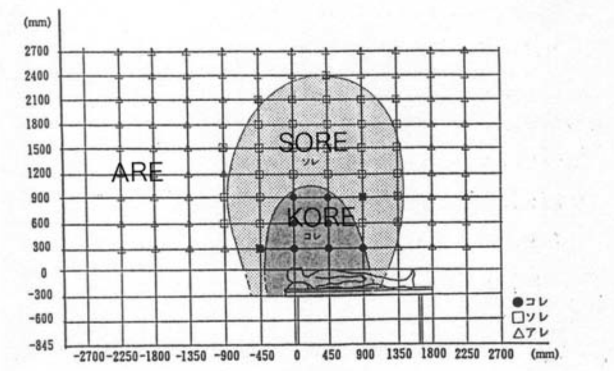


Fig.8.25. Reference domains of demonstrative pronouns from reclining postures

However, this method is valid only in the Japanese context. The Korean language also has three demonstrative pronouns, but some other languages have only two.

As Hall (1966) has described, one's personal space depends upon culture or lifestyle. Language also reflects these, and the way people consider and perceive the environment.

8.13 Three-Dimensional Human Scale

Most modern architectural design incorporates a building process that appears as the 'Domino system' (Fig.8.26). Floors are laid down first, and the partitions are made afterwards. It is possible to respond to various requirements, and in this sense, this is a good system. However, the ceiling height remains uniformly the same. Furthermore, the ceiling is kept low, maintaining the viewpoint of economy. It has very low limit regulations. In Japan, the ceiling height of a house is the same, 2.4 m everywhere, whereas a school classroom ceiling height is a universal 3 m. Alexander (1977) insisted that the height of a ceiling had to vary according to the purpose and use of the room (Fig.8.27).

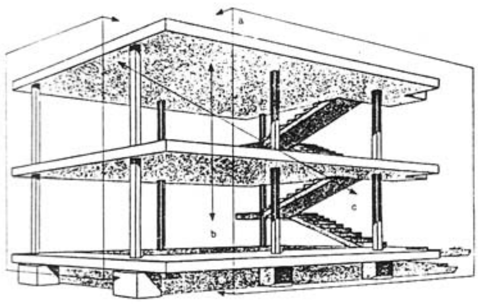


Fig.8.26. Domino (Le Corbusier)

Fig.8.27. Complete range of ceiling heights（Alexander）

In recent years, a resident's lifestyle has diversified. People are beginning to recognize the worth of three-dimensional space. Space came to be planned when a high-ceilinged room was considered in three dimensions (Fig.8.28).

Fig.8.28. High-ceilinged room

Therefore, we must pay attention not only to a plan, but also to the ceiling height or volume of a room. It is necessary to advance research into the perception of space from a comprehensive viewpoint. Moreover, in the future, there will be a change into the sustainable urban regeneration age. A space should fulfill people's needs over a long period of time and should satisfactorily contain the wide variety of human behavior shown by diverse human beings, or their coexistence with it.

This study aims to understand how three-dimensional space influences the living environment from the perspective of a psychological approach. We carried out the experimental research in an existing living space that has cubic features. A series of experiments were conducted using a full-scale adjustable room. The perception of space and the sense of volume were examined, to consider what the scale and form of the built environment should be.

8.14 Perception of Dimensions and Room Volume in the Room

The purpose of this study was to compare perceived room dimensions and volume to actual dimensions. In the analysis, the effect of the height of the space was examined. The perceptions of subjects are reported from the survey in a full-scale room with adjustable wall and ceiling-surfaces. Fig. 8.29 shows two full-scale adjustable rooms. The subjects could actually experience and compare these rooms.

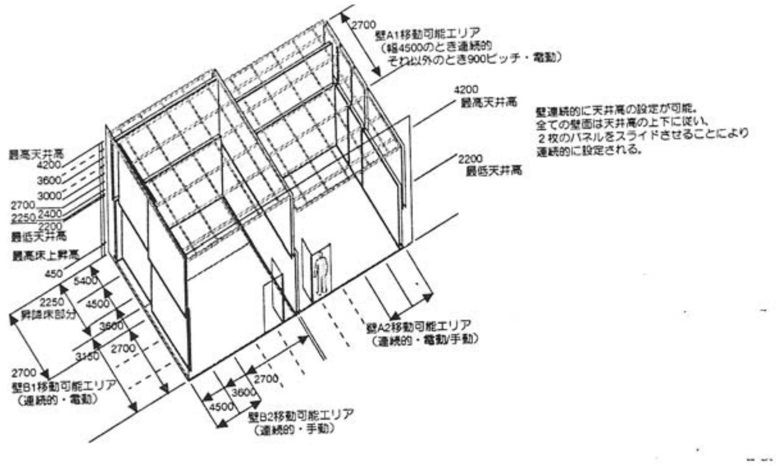


Fig.8.29. Two full-scale adjustable rooms

One important result is the relation between the ceiling height and the sense of volume in a room. The two rooms were adjusted to be the same volume. However, the dimension ratio was different. One had a small floor with a high ceiling, and the other had a large floor with a low ceiling. Whilst both rooms were equal in volume, the small-floored, high-ceilinged room volume was perceived as being greater than that of the large-floored, low-ceilinged room (Fig.8.30). This experiment shows the importance of the ceiling height in perception.

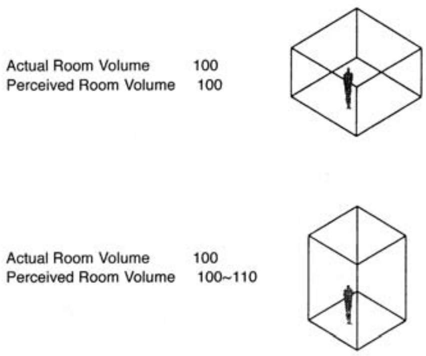


Fig.8.30. Perceived room volume

These are basic studies of spatial planning and design in terms of a three-dimensional approach to inner space living from a human point of view. These will become human measurements relevant to thinking about, and designing space. A proposal for a design theory for space, based on the perception of three-dimensional space should be advanced.

References

Sommer R (1969) Personal Space, The Behavioral Basis of Design. Prentice-Hall Inc., Englewood Cliffs, New Jersey

Hall ET (1966) The Hidden Dimension. Doubleday, New York.

Osmond H (1957) Function as the basis of psychiatric ward design. Mental Hospitals: 23–30

Alexander, C. et. al.: A pattern language. Oxford University Press, Inc., New York, 1977