Data Integration For Urban Transport Planning

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Data integration for urban transport planning
Gegevensintegratie ten behoeve van stedelijke vervoersplanning
城市交通规划中的数据融合

Doctoral Dissertation (2003)

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ISBN 90-6164-211-6

ITC Dissertation number 98
This research was carried out at the International Institute for Geo-Information Science and Earth Observation (ITC), P.O. Box 6, 7500 AA, Enschede, The Netherlands.

Cover designed by Andries Menning and Zhengdong Huang
Printed by Febodruk BV, Enschede, The Netherlands

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Gegevensintegratie ten behoeve van stedelijke vervoersplanning
(met een samenvatting in het Nederlands)
(附中文摘要)

Proefschrift

ter verkrijging van de graad van doctor
aan de Universiteit Utrecht
op gezag van de Rector Magnificus, Prof. Dr. W.H. Gispen
ingevolge het besluit van het College voor Promoties
in het openbaar te verdedigen
op vrijdag 28 maart 2003
des namiddags te 14:30 uur

door

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Geboren op 14 oktober 1968 te Hubei, China

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To my wife and son
and
my mother

Acknowledgements

This PhD study is part of the five-year SUS-DSO project financed by the Dutch government. Many thanks to the former directorate of the School of Urban Studies (SUS) at the former Wuhan Technical University of Surveying and Mapping (WTUSM), and especially to Professor Yang Ren and Professor Lan Yunchao for nominating me as a PhD candidate and for their continuous help during the study period. Since the advent of the new Wuhan University (WU), the new directorate of SUS has also paid much concern on my work.

My PhD supervisor and promoter at ITC and Utrecht University, Professor Ian Masser, directed and encouraged me throughout the study. Although we could not meet every week due to his half-time contract at ITC, Professor Masser, with his broad vision, knowledge and critical comments, deepened my insight into the subject. My second promoter, Professor Henk Ottens of Utrecht University, was a constant source of help during the final stage of dissertation drafting. With a special mission, he had to travel between Enschede and Utrecht once or twice every week, and my draft chapters became his “entertainment” on many of his two-hour journeys. Henk also helped me by translating the summary into Dutch. During my first six months of proposal writing, Mark Brussel of ITC was involved in some discussions and made many useful suggestions.

One part of the research benefited from discussions with Klaus Spiekermann in Dortmund, as well as with Professor Michael Wegener and his colleagues at IRPUD of the University of Dortmund. It was also a pleasure to talk with Wang Donggen at the Hong Kong Baptist University. During the fieldwork in Wuhan, I enjoyed constructive conversations with Long Ning and her colleagues from the Institute of Urban Transport Planning, as well as with Li Zonghua, Hu Runzhou and Peng Mingjun from the Information Center of the Bureau of Urban Planning and Land Administration.

ITC has provided wonderful working environment including top infrastructure and friendly staff. My gratitude especially goes to those people at ITC who have followed my progress with interest. Paul Schoonackers and Marjan Kreijns helped a lot with the successful completion of the study. With his rich experience of cities in developing countries, Dr. Jan Turkstra helped to identify the importance of the local context. Their lasting friendship has not only been a factor in the implementation of previous projects, but is also a good basis for ongoing and future cooperation. Frans van den Bosch kindly helped in many issues related to equipment. Ayako Kagawa and Lorena Montoya shared many encouraging stories during the study period, including the successful interpretation of some of the professor’s handwriting that was once “impossible” for me. Secretary Petra Webber was always efficient in responding to my requests. With her kindness and

concern, Loes Colenbrander at the PhD helpdesk ensured things ran smoothly. Also, Richard Sliuzas and Sherif Amer gave much encouragement during the long period.

Staying with the PhD fellows at ITC is such a great opportunity. I have shared nice experiences with AbuBakr Mohamed, Rhodora Gonzalez, Mehdi Farapour, Jose Santos, Amon Murwira, Martin Yemefack, Karin Schmidt, Mohammed Said and Onisimo Mutanga while sharing offices, and with Uday Nidumolu and Pravesh Debba regarding some family issues.

Owing to the SUS-DSO project, there has been a “SUS group” at ITC for nearly four years. Zhan Qingming and Cheng Jianquan are the other two “permanent members” (PhDs) in this group, and we have participated in so many wonderful things together. He Wenyan, Xue Wenbo and Xiao Yinhui finished their MSc here. Du Ningrui, Huang Jingnan, Lan Yunchao, Song Jufang, Wu Min, Zhang Jun, Zhang Xia and Zhao Bing were short-stay visitors who brought us much happiness and encouragement during this period.

It is also a pleasure to have had the opportunity to meet some other Chinese PhDs and friends in Enschede. Cheng Tao, Yang Hong, Zheng Ding, Zhou Yueqin, Liu Xuehua, Liu Yaolin, Tang Xingming and Zhu Sicai provided much inspiration for my study. Sun Yuxian, Hans Gieszen and Wang Lichun were always ready to help. Each year I have had good times with all the Chinese students at ITC.

I can never get back those days when I was away from my wife Yuesheng (Pam) and son Daochi (Chongchong). Their understanding and love are great encouragement to me. Chongchong’s stories and self-invented words are the other topic that I have been exploring in parallel with my PhD study. I am also indebted to my parents-in-law for looking after Chongchong during my absence. My parents and other family members in my hometown are a source of support that I can always rely on.

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Chapter 1 Introduction

1.1 The changing context of urban transport planning

Human history is also the history of transport evolution. Every revolution in transport technology has dramatically extended the human ability to explore and use the Earth's surface. Ground transport technologies specifically, including rail and road transport, have greatly influenced the Western urban structure since the 19th century. However, whereas the development of rail transport has been growing or slowing down since the second half of the last century, road transport has been booming, owing to advances in motor vehicles and infrastructure construction materials in conjunction with economic growth. Transport development has increased people's mobility, benefited economic growth, stimulated changes in society, but also negatively impacted on the environment. Political debate on the value, goals and objectives of transport development has always been necessary, and transport planning has been credited as a necessary tool to assist policy making.

In the Western world, the increase in motor vehicles has stimulated vast road infrastructure developments since the 1950s. The improvement of transport infrastructures and services has made a major contribution to the suburbanisation process. For several decades the major concern of transport policies has been to build more infrastructures to meet the growing demand for mobility. But up till now different transport sectors have been working in isolation, data collection has been difficult, and planning has been regarded as a blueprint rather than a process – and these are just some of the problems. In Britain, the pressure on transport growth has facilitated an interest in transport planning as a distinct part of the urban and regional process (Starkie, 1973). Accompanying this interest is a call for a comprehensive and systematic approach to transport planning, which includes a distinct concern for formulating and appraising alternative transport strategies.

While the construction of highways continued to increase in the 1970s, it was realised that travel demand would never be satisfied with new infrastructure development. The relationship between supply and demand had to be redefined, with more attention being paid to the demand side. This recognition necessitated the forecasting of travel demand under various policy alternatives, which has since evolved to become an important part of transport planning. Also, the oil crisis and economic recession in the early 1970s encouraged the improvement of public transport. Frustrated by difficulties in data collection, land use and transport models were modified to consume less data.

Techniques for transport planning analysis have been improving in response to the need for demand forecasts. Land use and transport models have made use of theories on the economic base, spatial interaction and entropy. A comprehensive four-step model system has been developed to forecast aggregate flows at the strategic planning level. Although the model in its entirety has been used less in recent decades, the use of its individual step models, such as modal choice models and traffic assignment models, has increased. A call for individual analysis of travel choice was initiated from the perspective of time geography (Hagerstrand, 1970). In the mean time, behavioural models have been formulated to study individual choice of travel mode and location, derived from the micro-economic theory of consumer behaviour (e.g. McFadden, 1973). These developments laid the foundations for the activity-based approach and simulation with advanced computer technologies.

Zone-based transport planning has focused on the development of transport infrastructures at the strategic level. With the expansion of planning tasks from physical development to responding to more complex social, economic and environmental policies, travel demand needs to be forecast at a more detailed level. In the mean time, it has been realised that travel demand is derived from activity demand, and that activities should be the focus of modelling. The activity-based approach is based on household and individual choices of mobility and lifestyle, activity and travel scheduling, and implementation and rescheduling (Bowman & Ben-Akiva, 1997). Under these circumstances travel demand models have evolved from aggregated ones to disaggregated ones.

The shift from aggregate to disaggregate transport analysis indicates a reorientation of the planning profession away from engineering towards the social sciences, especially economics and psychology (Pipkin, 1995). As technological and demographic changes are essentially aspatial, modern transport planning has to focus on both the spatial representation of urban systems and non-spatial aspects such as culture and political economy (Banister, 2002). Accompanying this challenge is the integration of data from a wide range of sources.

With the continuous growth in mobility since the 1980s, the gap between supply and demand has become wider. Congestion, accidents and environmental impacts are the symptoms of this imbalance. Under these circumstances, transport demand management has become an important measure in transport policy to calm down traffic in congested areas. Rosenbloom (1978) proposed four basic categories of demand management: 1) to reduce the number of vehicles by increasing occupancy; 2) to reorient travel to off-peak periods; 3) to redirect travel to alternative routes; and 4) to reduce the total demand for travel. These strategies have been supplemented by various control techniques that are suitable for individual cities, such as parking control and ride sharing. Demand management belongs to a series of policy strategies. For transport demand management in Asian metropolises, for example, it is beneficial to set up a structured framework concerning the objectives and policy measures for land use and transport development (Black, 1992). The ultimate goal is to balance the supply and the demand so that the social, economic and environmental benefits can be maximised while a sustainable transport system is maintained. The analysis of users’ response to management measures became necessary in order to evaluate policy alternatives. Another issue is the multimodal integration of transport activities in order to respond to growing mobility and particularly to the need for efficiency. Equity is also a big problem under the new socio-economic and political requirements (Masser *et al*, 1992).

On the supply side, while the technologies for construction materials and vehicles have been under continuous improvement, the advent of information science and new detection devices has provided more efficient tools for guiding travellers. Such techniques as advanced information provision, real time bus location and automatic congestion detection are just a few examples under the general rubric of the intelligent transport system (ITS) (Mast, 1998). Advances in these technologies have expanded the capacity of highways, improved levels of service for public transport, and increased safety.

There have also been growing concerns about the negative impacts of transport on the environment and society. In general the transport industry consumes a lot of the Earth's resources. Highways are criticised as intrusions into the local landscape and way of life. The biggest problem with motor vehicles is the emission of pollutants such as carbon dioxide (CO_2) and nitrogen oxides (NO_x). Passenger cars account for more than 13 percent of the total carbon dioxide emitted from fossil fuels worldwide, which contributes directly and indirectly to global warming (Lowe, 1990). Noise is another severe pollutant in urbanised areas. Reducing the impact of transport requires concerted effort at the local, national and international levels. In the United States, the 1990 Clean Air Act Amendments requires state implementation plans (SIP) to include estimates of emissions and transport control measures so that the national standard of air quality is met (Karash & Schweiger, 1994). A series of emission models are available from the U.S. Environmental Protection Agency. The European Union has recognised the importance of transport impact and has outlined future development based on sustainable mobility in its new common transport policy (Haq, 1997).

Computer and information technologies have dramatically improved the capabilities of transport forecast and evaluation models. Transport software packages are available for various scales of application, ranging from strategic trend forecasts to detailed traffic assignment. Simulation models, particularly micro-simulation models, are applicable with the availability of advanced computing methods such as object-oriented programming and parallel processing (Algers *et al*, 1998). New data capture techniques such as Global Positioning Systems (GPS) provide a revolutionary means of data collection for transport planning and operations management. Data for transport planning are best managed by and retrieved from database management systems. More advanced techniques for data manipulation are available, including data warehousing, data mining and knowledge discovery. However, as data come from a variety of sources and in varying data formats, this presents a tremendous challenge in terms of linking and integrating the transport data.

Transport challenges in the developing world appeared later than in the developed world, but developing countries generally face more serious problems, due to the lack of control on transport and especially to the failure to learn from the lessons of the developed world.

The general conditions of transport in developing countries include the shortage of infrastructure supply, highly mixed usage of vehicles, low accessibility, high traffic incident rates, and severe environmental impact (Vasconcellos, 2001). In the developing countries, the need to control traffic demands is even more urgently required than in the developed countries (Tanaboriboon, 1992). However, the low availability of transport-related data is a serious drawback for transport planning in the developing world. These characteristics have to be taken into account when carrying out data integration studies in the developing cities.

The concerns regarding urban transport in China began in the 1980s, aroused by the nationwide economic development policies that dramatically stimulated mobility in cities. Bicycles and public transport are important modes of transport in Chinese cities, and public transport is especially encouraged by urban transport policies (Spencer, 1999). In general, however, the rapid increase in transport demand has not been met with sufficient transport infrastructures or efficient demand management. Motorisation is a powerful force in the economic growth, but one which also causes congestion and pollution in Chinese cities (Stares & Liu, 1996). Comprehensive transport surveys have been carried out for transport planning purposes in many cities, yet there is still a serious shortage of up-to-date data. Little effort has been put into integrating transport-related data from different sources.

The research into data integration has been inspired by the context of Wuhan, a metropolitan city in central China. Among cities with more than one million residents in China, Wuhan is typical in terms of transport pressure brought about by rapid socio-economic development since the 1980s. Transport planning in Wuhan has played an inadequate role in supporting decision making. One of the major reasons for this situation is the lack of reliable and cross-referenced data for transport modelling and policy evaluation. This study aims at improving the integration of transport-related data, with specific reference to local circumstances.

1.2 Issues of transport data integration

1.2.1 The need for data integration

The need for transport data integration can be justified from several perspectives. In general, transport planning and management consumes a large amount of data. These data have to be integrated in a way that satisfies the needs of transport planning, modelling, evaluation and policy making.

That transport data come from a variety of sources constitutes an important phenomenon. Examples of data sources include passenger surveys, traffic monitoring, land use, socio-economic records and so on. These broad categories of data again involve detailed data sets. For example, passenger surveys acquire data by using many different techniques, including cross-sectional surveys, panel surveys, activity surveys and stated preference surveys. On many occasions, transport data are collected on a project basis, which means the data sets are fragmented. No single data collection method can yield sufficient information to meet the requirements of transport models, and there is a need to integrate data from different sources (Lee-Gosselin & Polak, 1997). On the institutional side, transport stakeholders maintain data sets for their own purposes, but these data sets are also valuable sources for transport planning. Data sharing is necessary so that data sets from different agencies can be incorporated.

Transport entities are characterised by their spatial, non-spatial and temporal attributes. The linkage between these different attributes has to be created. Proper representations of these data are necessary to facilitate data integration, thereby providing fundamental support to transport modelling and evaluation. Transport research is a data-driven process, yet there is a remarkable lack of consistency, compatibility and comprehensiveness in data structures (McNally, 1998). The reasons for this include the complexity of transport-related data, the variety of data types and data sources, the theoretical preferences of modelling professionals, and the inconsistency of data models among commercial software packages.

Transport models require data at specific scales. These differences in scale imply disparate requirements in terms of data representation. For example, aggregate models require road networks be represented as links and nodes, while disaggregate micro-simulations demand details of the networks, even down to the lane level. For different applications, it may be necessary for a set of data to be aggregated to a higher level, or to be disaggregated to a lower level. These data must be vertically referenced and integrated.

The same sort of transport data may be supplied in different formats, by different data providers, or by the same provider in different time periods. For example, each modelling package usually has its own data structure, and requires data transformation for both data input and output. Also, transport institutions collect data to their own standards. When data from these institutions are shared, an immediate issue is to construct an interface to link the data.

Database Management Systems (DBMS) and Geographical Information Systems (GIS) are potentially effective tools for integrating these data. In general, transport data representation in GIS or DBMS has been implemented well in a segmented way, without much effort in building a comprehensive database framework (Goodchild, 2000). Although much has been achieved in GIS-T (GIS for Transportation) applications, some new challenges always emerge during the evolution of transport models. For example, Shaw and Wang (2000) pointed out that there has been little research on handling disaggregate transport data with GIS technology.

1.2.2 Methodological aspects

To integrate data means to coordinate or blend distinct data into a unified whole. There are many reasons justifying data integration, e.g. the data are from different sources, have different data types or different data formats, or are shared by different agencies.

As far as transport data are concerned, the integration tasks involve five types of operation, i.e. data standardising, interfacing and interoperability, spatial and temporal referencing, aggregating and disaggregating, as well as data warehousing. All these belong to the technical aspect of data integration.

Data standardising is a process of normalising data for easier representation in a database system and for data exchange between different systems so that interoperability can be achieved. Many industrial standards for spatial, temporal and attribute data have been developed or are under development. Only systematically represented data can be integrated properly for data processing. Data standardisation requires an in-depth understanding of the related field of study, i.e. in this case the transport enterprise. Transport-related data standards have been proposed at both the national and international level, e.g. the U.S. National Spatial Data Infrastructure (NSDI), the European Geographic Data Files (GDF), the Open GIS Consortium (OGC), as well as ISO/TC 211.

Interfacing refers to the nature of the data exchange between two application systems, or between computer and human operator. A typical instance of interfacing is transforming data from one data format to another. One such example is the data exchange protocol between EMME/2 (transport software) and Arc/Info (GIS software), in which the corresponding data items in both systems are identified and a data communication process is set up (Lussier & Wu, 1997). Interfacing is built on the standardisation of data, and is closely related to interoperability under the concept of system integration.

Spatial referencing links activity or event data to spatial locations so that spatial patterns can be revealed. Accordingly, temporal referencing attaches the time aspect to data so that chronological change can be detected. Temporal referencing can simply be seen as adding temporal stamps to entities or activities, and therefore may not be regarded as a big challenge in terms of data referencing. Because of the spatial characteristics of transport networks and the large socio-economic data requirements in transport planning, it is necessary to develop location referencing methods that link transport events and socio-economic data to geographical locations. A location referencing system is a system for describing the absolute or relative positions of entities and activities within a spatial framework. Examples of referencing bases include latitude and longitude, two- and three-dimensional coordinate systems, grid systems, linear reference systems, street name and address, and census tract (MDOT, 1994; Goodwin *et al*, 1995; Vogt *et al*, 1997).

Data aggregating or disaggregating is closely related to exploring information from databases where the unit of data storage is different from the unit of data processing.

Aggregating tools have been widely utilised for data summarising and have been improved during the last few decades. They are also being expanded to handle spatial and temporal data, but more analytical work is needed in order to answer practical questions. Spatial data aggregation in this research context means the transition of data from smaller zones to larger zones, in which the two sets of zones (units) are spatially compatible (no boundary intersection). Spatial disaggregation is the opposite process, e.g. the distribution of population from larger statistical zones into smaller land use parcels. Both aggregation and disaggregation are necessary in transport data preparation.

Data warehousing is a technology for assembling data from various operational, legacy and possibly heterogeneous data sources, to provide efficient information for decision making activities (Mohania *et al*, 1999). In addition to involving all the previous four techniques, the data warehousing process takes advantage of several key information technologies such as the database system, the Internet, On-Line Analytical Processing (OLAP) and GIS. By assembling data from various sources and synthesising operational and historical data, data warehousing acts as a facilitator for integrating enterprise-wide agency data into a comprehensive repository (O’Packi & Lewis, 1998). There have been many attempts at building spatial transport data warehouses (e.g. O'Packi *et al*, 2000).

1.2.3 Institutional aspects

From an institutional point of view, the need for data integration comes from the need for data sharing among institutions. To address this need, organisational profiles and their relationships have to be studied. It is argued that the treatment of organisational issues has to be embedded in a background of management and social science theory (Obermeyer & Pinto, 1994). In general, Oliver (1990) has suggested six determinants of inter-organisational relationships towards integration, i.e. necessity, asymmetry, reciprocity, efficiency, stability, and legitimacy. These factors have been used by Azad and Wiggins (1995) as fundamental reasons for geographical data sharing among organisations, whereby an intensity scale for inter-organisational relationships can be set up along three stages: collaboration, cooperation and coordination. It is concluded that each organisation will attempt to minimise its loss of autonomy and therefore its interdependency with other organisations.

Institutional topics appear in many GIS and GIS-T research projects. Nedovic-Budic (1995) has argued that, apart from the technological impediments to data sharing, it is important to understand sharing mechanisms and factors that affect the coordination of spatial database development and use. This understanding will even advance the efforts in building national spatial data infrastructures. In Europe between 1993 and 1996, data integration research was one of the major topics in the GISDATA programme, in which political and organisational issues were evaluated with respect to diffusion and deployment of GIS technology (Masser, 1997). Another large-scale project, the Transportation Case Studies in GIS, carried out under the Travel Model Improvement Program (TMIP) of the United States, brought together agencies from metropolitan planning organisations, state departments of transportation and other sectors (*http://tmip.fhwa.dot.gov/*). The project assists in formulating data management programmes and inter-agency partnerships for data collection and maintenance.

There are two implications for institutional analysis in transport planning. One is the need for clarifying and evaluating the functionality of urban transport agencies, through which the types of data produced and needed are acquired. The administrative and functional relationships among various agencies must also be made clear, so that data flows are understood and incorporated into a general framework. The other task is the definition of a data support framework within which the data requirements of transport planning projects can be fulfilled. The framework should be built on existing institutional structures, and make full use of information technology. This concerns such factors as data format standards, meta-data, the selection of centralised versus decentralised system structures, as well as the incorporation of different data systems.

1.3 Research objectives

To respond quickly to various planning requirements, integrated transport data should be readily available from accessible database management systems. The general objective is to explore methods of data representation and data integration, making use of information technology, to facilitate urban transport planning in both theory and practice. A GIS-based framework for transport data integration is to be designed through systematically investigating and evaluating data needs and data representation techniques in transport planning. Under this framework, three major aspects of data integration are to be explored, which include:

- To examine and evaluate the techniques of point-type data integration that are important to transport data collection and representation. In particular, to study how the spatial referencing methods for locating socio-economic activities can be improved.
- To enhance the methodology for linear data integration by exploring appropriate data models to facilitate the integration of public transport data.
- To improve the methodology of data transition between spatial zonal systems, so that the same set of data can be integrated into different sets of zones that are needed by different transport models.

To achieve these objectives, it is also necessary to illustrate the potential application of this framework with respect to transport planning in China in general and with particular reference to the city of Wuhan.

1.4 Research methodology

1.4.1 Approach

While some theoretical and institutional issues are addressed, the main focus of the research lies on the methodological innovations that are pertinent to both the local and more general circumstances. A comprehensive review of transport data needs and data handling in information science leads to a general framework for transport data integration. This framework provides a structure for the different aspects of technical solutions.

There are two implications in this methodological research. One is to investigate how the techniques of data integration can be adapted to fit the local circumstances, or how the local situation can be adapted to meet the requirements of the techniques. The other is to explore how the existing techniques of data integration can be improved so as to contribute not only to local needs but also to more general solutions.

Meanwhile, to set the context of study, a general review is made of the context for transport planning in China, and a brief case study of the institutional issue in Wuhan is implemented to justify the need and opportunity for local transport data integration.

1.4.2 The research framework

The research framework is shown in Figure 1.1. Theories of urban planning and modelling are examined to understand the data requirements. The state-of-the-art information technology is evaluated in terms of advanced methods of data representation and data integration, which serves as a starting point for the technical aspect of the research. Functional analysis is carried out on local transport institutions to disclose their relationships and data availability. The gaps in data representation and planning needs are identified.

Based on information technology, the research focuses on aspects that need to be improved, i.e. the referencing of socio-economic data, the representation of bus routes and stops, and the integration of zonal data. Location referencing methods are adapted to improve efficiency in locating socio-economic activities. GIS route data models are expanded to satisfy the needs of bus route representation. With regard to data disaggregation, methods of areal weighting and Monte Carlo simulation are implemented in a GIS context.

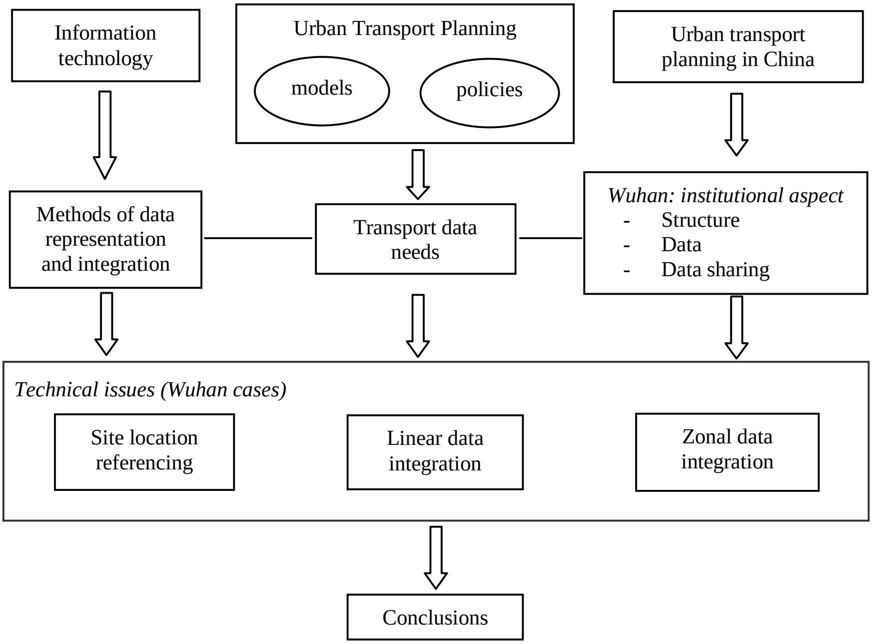


Figure 1.1 Research framework

1.5 Structure of the dissertation

There are seven chapters in this dissertation. This first chapter provides an introduction to the research background and poses the research questions. Some of the theoretical foundations of transport data integration are considered in Chapter 2. The local contexts for transport data integration are examined in Chapter 3. Technical solutions for integrating point, linear and areal entities are presented respectively in Chapters 4, 5 and 6. A number of conclusions are drawn from the research as a whole in the final chapter.

Chapter 2 presents an in-depth review on data needs and data representation in urban transport planning. The main features of transport planning models are summarised, followed by a data needs assessment and an introduction to transport data representation methodologies. These discussions lead to the need for transport data integration. A framework for data integration is proposed.

Chapter 3 deals with the local context of the research. Some basic characteristics of transport development, transport administration and transport planning in Chinese cities are described. Specifically, attention is given to the institutional issues of urban transport data integration in Wuhan, China. The local transport-related organisations are introduced and, after identifying their functions, the data they collect are examined. Some of the possibilities and restrictions in data sharing and data integration are highlighted.

In Chapter 4, attention is paid to locating socio-economic activities within the urban environment of Wuhan. The spatial referencing of discrete socio-economic activities is a topic for point-based data integration. The local address expressions are analysed, and possible referencing bases are identified. Two strategies for location referencing, i.e. name-based and street-based, are assessed in detail. A more general framework is put forward for locating socio-economic activities.

Linear transport data integration is the focus of Chapter 5. A typical case of linear relationship is bus routes and street networks. The chapter starts with the need for detailed bus representation by illustrating the real situation in heavily transit-oriented cities such as Wuhan. A bus route data model is developed with internal linkage to streets. The applications of the integrated model in transport planning and bus operations are demonstrated in the ArcGIS environment.

Chapter 6 presents some solutions to zone-based data integration. The phenomenon of zonal data transition for transport modelling is described. Some of the main techniques of areal interpolation are reviewed, and zone design practices are summarised. It is noted that the major issue in Wuhan (and other cities of China) is the disaggregation of data from statistical units to land use parcels. Two methods, the weighted area-weighting method and the Monte Carlo simulation, are used to demonstrate the disaggregation strategy. Transport Analysis Zones (TAZ), land use, and statistical units in Wuhan are utilised to demonstrate a disaggregation-aggregation transition approach.

The final chapter of the dissertation discusses the findings and draws some conclusions from the research. Some future research challenges are highlighted.

Chapter 2 Data For Urban Transport Planning

2.1 Introduction

Urban transport planning involves formulating and evaluating a set of scenarios for decision makers. The process starts with identifying existing transport problems or envisaged transport objectives, and continues with forecasting and evaluation. The goals and objectives of urban transport development have been changing with the improvements in transport systems, as well as with new insights into social and economic requirements. These changes necessitate modifications of existing models. Since different models usually have different data needs, model improvements imply possible requirements for new data.

To study the data needs for urban transport planning, a starting point is to explore the existing situation with respect to data needs, data usage and data processing techniques. This chapter deals with these issues by extensively reviewing the historical evolution and current practice in the field of urban transport. In the first place a general description is given of the aspects of urban transport planning, covering the planning process, transport models and transport policy evaluation. This introduction sets the context for analysing data needs in urban transport planning. The data needs assessment is systematically carried out by categorising transport data into demand data, supply data, operations data and impact data.

Past experiences have shown an isolated approach to data requirements, which has led to inefficiency and redundancy in data collection and storage. To bring data together, the principles of data representation and integration have to be applied. The last two sections of the chapter examine technologies of transport data representation and integration in information science. Data integrating issues that are specific to this research and that represent the current challenges are finally delivered, which lay a foundation for the rest of the chapters in this dissertation.

2.2 Urban transport planning

2.2.1 General planning process

Since the 1950s, transport planning in Western developed countries has been coping with increasing travel demand as a result of urban population increase, rapid growth in car ownership, and the movement to suburban areas. The influence of the car industry has been immense on a variety of aspects, such as travel pattern, land use pattern, urban form, environment and development policies. During the last few decades, the concept and process of urban transport planning have been gradually formulated and improved in response to social, economic and environmental changes. Authorities and research agencies responsible for transport have been set up. Legislation and guidelines have been developed and implemented through the years. In the United States, for example, several laws have marked the progressive emphasis on transport planning and research (Weiner, 1992). These include the Comprehensive, Co-operative and Continuing (3C) process of urban transport planning in 1962, the change of emphasis from long-range planning to short-term transport system management (TSM) in 1975, the Clean Air Act Amendments (CAAA) in 1990, and the Intermodal Surface Transport Efficiency Act (ISTEA) in 1991. More recently, the Transport Equity Act for the 21st century was passed (TEA-21: *http://www.fhwa.dot.gov/*).

Meyer and Miller (1984) regarded transport planning as a four-phase process that reflects the need for a decision-oriented approach (Figure 2.1: *Left*). This approach considered that technical analysis was only one component of the whole planning process, and that planners should also pay attention to the subsequent project implementation, operation and monitoring activities in the process chain. An important aspect of the process is the recognition of the different types of data needed for urban transport planning. In addition to the inventory of transport systems and the information on urban activities, it was recommended that policies, and the organisational and fiscal state of the transport programme were all necessary inputs into the planning process. These aspects could provide useful information for assessing the feasibility of alternative projects, understanding the organisational requirements of other agencies, as well as increasing awareness of likely competition for investment funds. The planning process also identified the importance of feedback, from the analysis and monitoring steps through to the diagnosis step, which could be utilised to adjust the problem definition, based either on preliminary analysis results or on real performance of the transport system.

Pas (1995) suggested a similar process of general urban transport planning (Figure 2.1: *right*). The framework identified three phases in a planning process: pre-analysis, technical analysis and post-analysis. While technical planners play an almost exclusive role in the analysis phase, decision makers and citizens should be involved in the other two phases. The technical analysis phase predicts the impacts of alternative scenarios, which include the quantity and quality of traffic flow on road networks, as well as capital and operating costs, energy usage, land requirements, air quality and accident rates. All these analyses necessitate the collection of a variety of data, such as system inventory, travel pattern, land use and so on. Similar to the process proposed by Meyer and Miller (1984), the planning framework also showed the importance of feedback among the different phases. Transport planning has different focuses from those of traffic planning or traffic engineering in terms of planning objectives, area of concern, and temporal ranges.

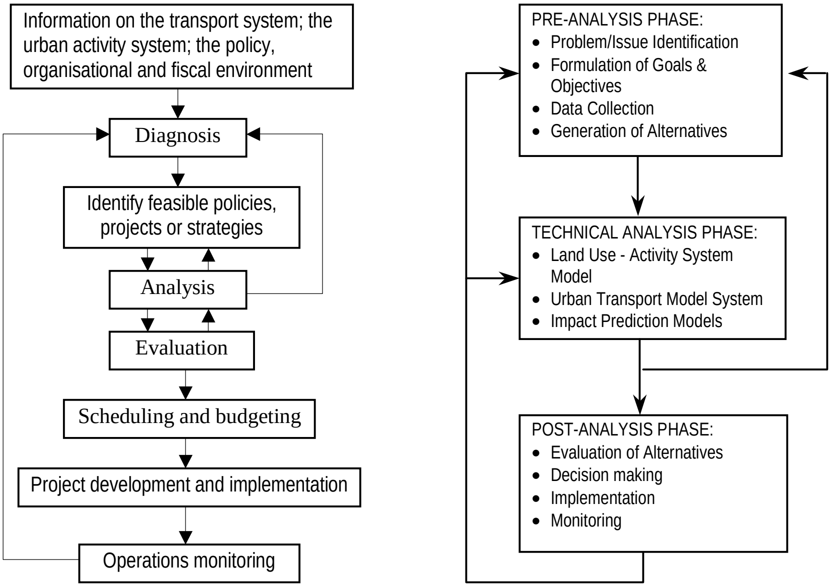


Figure 2.1 General urban transport planning process
(*left*: Meyer & Miller, 1984; *right*: Pas, 1995)

Transport planning has to reflect the requirements of a changing urban context as a result of economic development, concerns in social policy, the increase in affluence and leisure, technological advances, decentralisation, and the globalisation of economies. These challenges call for an improvement in planning methods, in terms of both quantitative and qualitative analysis. A wider view of the socio-economic context implies some new directions in transport planning – for example, moves away from trend-based extrapolation to richer social analysis based on linking transport to what people do and how industries operate, and from "objective" factors in analysis (e.g. cost and time) towards the acceptance of subjective valuation and political rationality (Banister, 2002).

One of the major challenges of transport planning is the evaluation of transport polices and projects. Basically, evaluation serves to identify the value of individual alternatives and to compare these alternatives with respect to their costs and benefits. The values of alternatives are expressed by measures of effectiveness (MOE), which may be specified for different socio-economic classes or for distributed geographical areas (Meyer & Miller, 1984). Transport policies involve a set of objectives, such as economic efficiency, environmental protection, safety, sustainability, equity, financial availability and practicability (May, 1997). Evaluation of these objectives requires measuring large sets of individual items, which implies a major challenge for data collection and processing.

2.2.2 Travel demand models

Various models have been developed to represent the whole or part of a real world system. Encapsulating only the important features of a system, models can estimate likely outcomes more quickly and at lower cost and risk than would be possible through implementation and monitoring (Bonsall, 1997). Models used in transport planning can vary from very simple (such as a trend curve) to very complex (such as dynamic simulation). To validate and evaluate a model, relevant data have to be collected.

Since the appearance of the first urban transport modelling system in the 1950s, many kinds of models have been developed utilising such theories as entropy, spatial interaction, micro-economy, random utility and time geography. These models have been used for trip production and attraction, trip distribution, mode choice and traffic assignment, as well as land use–transport integration. Depending on the level of detail, models can be characterised as either aggregate or disaggregate.

The four-step transport model system

Aggregate models work on a zonal basis, typically called the Transport Analysis Zone (TAZ), in which such data as households and their economic features are aggregated or summed up according to certain criteria. Examples of such models are those used for forecasting trip productions and trip distributions in the traditional four-step Urban Transport Model System (UTMS). The transport modelling process takes advantage of aggregate data on the TAZ to estimate travel demand and makes predictions of traffic flows on the urban transport network (Figure 2.2). This procedure is generally referred to as a sequential model, which is composed of four distinct steps: trip generation, trip distribution, modal split and trip assignment.

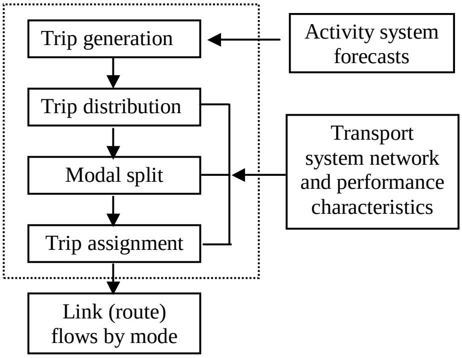


Figure 2.2 The four-step UTMS process (source: Meyer & Miller, 1984)

Trip generation estimates the total number of trips that are produced by (origin) or attracted to (destination) each TAZ. Generally, the amount of production for a zone is some function of its aggregated household and demographic characteristics, while the amount of attraction is concerned with the economic activities of the specific zone. Linear regression and category analysis (cross-classification) are the two basic approaches to trip generation. Linear regression analysis assumes that the number of trips is linearly related to the explanatory variables, and uses empirical data to predict the best-fit combination of those variables. The basis for category analysis is that the households or individuals are classified exclusively according to such categories as household size, age structure, car ownership and income. A trip generation rate is calculated for each category, and the total number of trips generated from a zone is estimated by summing the trips from all categories. Three broad types of information are used in trip generation models: land use type, intensity of land use, and socio-economic characteristics. These explanatory variables can be broken down according to the types of trips being modelled, and the prediction of different trip types needs different variables.

Trip distribution estimates how many trips are going from each zone to all other zones. In this phase, the linkages between origins and destinations are determined, based on some measurement of the attractiveness of the destinations and the cost of getting there. By pairing the origin and destination, the overall travel patterns of the study region can be produced. The three most popular types of models for trip distribution are the gravity models, the intervening opportunity models and the entropy models (Sheppard, 1995). The gravity models assume that the number of trips from zone i to j (interaction) is positively related to the number of trips leaving zone i (origin) and to the pull attributes of zone j (destination), but is inversely related to the distance or travel time between the two zones. The measure of distance factor might be physical distance, travel time or travel cost. The intervening opportunity models are derived from the gravity models. The trip distribution calculation in these models is based on the idea that a trip maker leaving a particular origin will consider each possible opportunity sequentially, starting with the closest. The probability of stopping at the closest zone is said to be proportional to the number of opportunities there (Schneider, 1960). The measure of probability depends on the number of opportunities of a zone, and on the probability that the trip maker did not stop at the previous destination. The entropy models are applied in a situation where insufficient data are available. The purpose of the models is to maximise the entropy, with some constraint functions (Wilson, 1970; Webber, 1984). Constraints are the information already available on such trip distribution characteristics as trip length, number of trips generated, and the number of trips at each destination.

The modal split (or mode choice) addresses the problem of how the various trips will be made. The origin-destination movements are split by travel mode, and the proportion of trips by each mode is predicted. The important factors influencing the mode selection are travel time and costs, based on which the diversion curves and choice models are utilised. Choice models estimate the probability of selecting one particular travel mode. Binomial or multinomial logit models are commonly used.

The task in traffic assignment is to predict the flows along road networks, from origins to destinations, for each travelling mode. The total volume of travel for each network link is calculated based on the aggregation of routes that pass through the link, so the required capacity of the existing or planned road network can be predicted. The simplest strategy for trip assignment is to assign all trips along the shortest path between origin and destination. Two other strategies are available: the incremental assignment approach and the multipath assignment approach. Both these strategies are based on Wardrop's first principle of network equilibrium (Sheppard, 1995).

The improvement of the UTMS

Although the four-step UTMS has been the major tool in travel forecasting for a long time, the process has also been criticised over the years. Some of the deficiencies of the planning process include the following:

- The structured sequential nature of the process imposes a decision sequence and does not allow feedback to previous steps (Miller & Storm, 1996).
- The problem of land use–transport system interaction is not addressed in the process, with the land use being used as an exogenous input to the travel forecasting model.
- While the aggregate approach in the process predicts trip generation from the socio-economic characteristics of people within a zone, it masks the causal relationships and differences of households in the zone. This results in an inability to analyse the influences of specific transport policy on travel behaviour.
- As regards analysis zones, it was realised that planning theory should focus on meaningful decision-making units instead of somewhat arbitrary spatial units, i.e. models should be disaggregate and behavioural (Webber, 1980).
- By predicting trip generation and distribution, the process envisages a travelling activity as a one-way trip, which would not reflect the complexity of the real situation (Stopher *et al*, 1996).

With these problems in mind, a number of attempts have been made to improve the conventional model system. One of the measures for improving the UTMS is to emphasise closer linkage between land use and transport models. Since the 1970s, attempts have been made to combine the two planning systems. In these models, the land use system not only generates exogenous variable input to transport models, but also receives some feedback, after a time lag, from the outcome of transport planning results. The linkages within the four steps of transport models are also strengthened. These lines of the attempts are viewed as linked land use–transport models, or the first generation of combined models (De la Barra, 1989).

The recognition of intricate connections between land use and transport systems since the 1980s has led to the second generation of combined models, i.e. integrated urban land use and transport models (Webster *et al*, 1988; Wegener, 1994; Southworth, 1995; BTE, 1998). There have been many integrated models for the interaction between land use and transport planning. Theories utilised for the integration include micro-economy, entropy, random utility, time geography, spatial interaction and so on. Based on theoretical paradigms, there are behavioural predictive models and mathematical optimising models, and based on model structure there are unified and composite models (Giuliano, 1995). Southworth (1995) has presented a general framework of the integrated land use and transport model, and Ben-Akiva and Bowman (1998) have integrated an activity-based model system with a residential location model.

One of the widely used integrated urban models has been the Integrated Transport Land Use Package (ITLUP), developed and improved by Putman (1983, 1991, 1998). The basic idea of the model is to predict transport and land use activities in an iterative way. Firstly, employment and household locations are forecast based on transport networks, using an employment allocation model (EMPAL) and a disaggregate residential allocation model (DRAM). Secondly, travel demand, trip origins, trip destinations, trip interchanges and mode splits are computed. Thirdly, traffic assignment is carried out, and travel time and / or cost are estimated. Finally, the estimated time of road networks is utilised for the next round of employment and residential locations. The whole process is repeated until an overall static equilibrium between transport, location and land use is achieved. The location forecasting models, EMPAL and DRAM, provide the linkage between land use and transport system. These models require information on the locations of employment and household (in the previous stage), cost of access (e.g. travel cost), and types of employment and household by TAZ.

The development of disaggregate models

Disaggregate models are built on the activities of households and individuals, which are meaningful decision-making units compared with arbitrary spatial zonal units (Webber, 1980). For travel behaviour modelling, there have generally been two paradigms (Pipkin, 1995). The first is the choice-oriented, highly segmented probabilistic behaviour models of the 1970s and early 1980s, which have been applied in mode choice, destination choice and route choice. Multinomial logit (MNL) models and hierarchical logit models have been the most influential types of choice models. Second come the activity-based models, or constraint-oriented approaches, which focus on the pattern of household travel as a whole and require more detailed activity data.

The impetus of activity-oriented research in the transport field stems, on the one hand, from criticism of the traditional aggregate method and, on the other hand, from advances in related disciplines. Ettema and Timmermans (1997) have given a complete list of theories and models of activity patterns arising from such disciplines as urban planning, economics, psychology and transport. The operational focus of the activity model facilitates the analysis of the impact of transport policy on an individual’s daily activities.

As disaggregate modelling requires a wide variety of data, information technology has been utilised as an important tool for managing these data and even for realising model computation directly. For example, Greaves and Stopher (1998) have put forward a GIS-based spatial decision support system for activity-based travel forecasting. Golledge (1998) has also concluded that GIS could have a significant capability for facilitating disaggregate behaviour travel modelling. Disaggregate models are widely used in the computer simulation of transport systems, for example, the SMART (Simulation Model for Activities, Resources and Travel) is an activity-based simulation system based on GIS (Stopher *et al*, 1996).

2.3 Data in urban transport planning

2.3.1 Data needs assessment

The objective of data needs assessment is to identify the data sets needed for a planning. Depending on the specific context, transport data needs may be assessed on the project basis, the business basis or the system basis. The purpose, content and extent of data needs are different for these three bases.

In many cases, data requirements have been listed or evaluated as a part of transport research projects, many of which are concerned with model improvements. Transport planning projects usually have clear objectives and a designated time range. Data in these projects are determined by the requirements of specific modelling, validation and evaluation. Data are organised in a way that best suits the needs of the projects. Because of the one-off characteristics of planning or research projects, the data reusability rate has been low. In this sense, there is a need to integrate data from various transport projects. When a comprehensive database system is available, less effort will be spent on data collection and more time on the planning analysis.

An alternative is to examine the transport stakeholders who are collecting and holding these data. Administrative agencies usually manage large quantities of data that are relevant to their function. To study the data availability in these agencies, it is necessary to investigate their missions, goals, objectives and development strategies. Each institution has a data system that serves its own business. Transport-related agencies manage data that are relevant to transport planning and policy making. The potential usage of these data in transport planning has to be analysed in detail.

A more comprehensive assessment on transport planning data is to regard the data as in a whole system and classify them into meaningful groups. One such attempt has been the assessment of multimodal transportation planning data, carried out as a response to the 1990 Clean Air Act Amendments (CAAA) and the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) in the United States (Jack Faucett Associates, 1997). The research proposed a data organisation framework that incorporates the data components of supply, demand, system performance and system impacts (Figure 2.3). There has also been a conference on information needs to support state and local transportation decision making into the 21st century (Pisarski, 1997). The conference addressed six data issues: socio-economic data, financial data, supply and system characteristics data, demand and use data, system operations data, and impact and performance data.

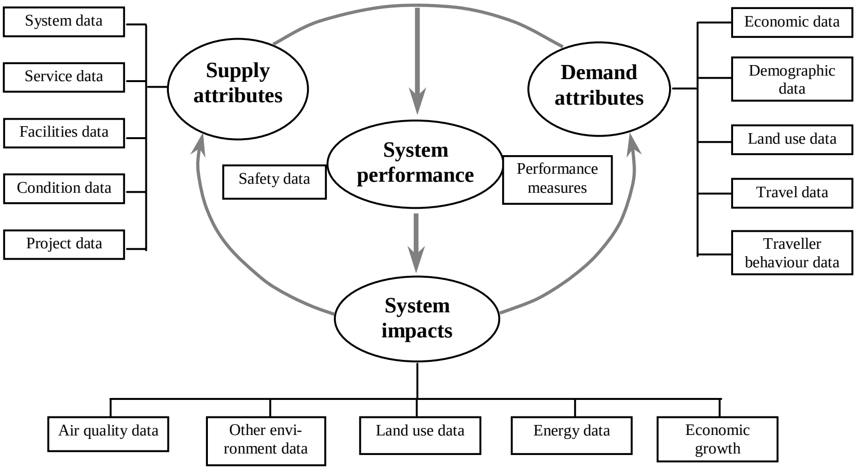


Figure 2.3 Data organisation framework (source: Jack Faucett Associates, 1997)

By making use of entity relationship analysis, data related to transport entities and transport activities can be identified, and the relationships among the entities established. For example, streets are spatial entities that possess such attributes as length, width, pavement material, construction year and number of lanes. These streets are also interconnected to form a topologically represented street network. The rest of this section makes use of the framework and discusses data needs within four groups, i.e. demand, supply, performance and impact.

2.3.2 Demand data

Transport demand data include demographic data, land use data, economic data and travel demand data. These data are consumed by transport demand models at both the aggregate and the disaggregate levels.

Demographic data

Demographic data are most commonly available from governmental statistical agencies (e.g. census bureau). Census data, generally collected on a decennial basis, are the most comprehensive and important sources for demographic research.

Statistical items of census are usually concerned with demographic, social, housing and economic aspects. Basic demographic items such as age, gender, relationship, marital status and race are important for analysing the mobility pattern of various population groups. In the United States, some transport items have also been included, e.g. place of work, journey time to work, and vehicle availability. Based on studies of the typical number of daily trips taken by households with different numbers of vehicles available, transport planning agencies can estimate total vehicle travel demand and its effect on the transport system. In China, the census has been conducted on both individual and household level, including items on age, employment, education, housing and migration (Lavely, 2001). There are no direct indicators on transport (e.g. number of bicycles per household), yet the census data can still provide valuable information for transport research.

Individual data has to be located and summed up geographically to describe spatial demographic characteristics. A fundamental issue in acquiring demographic information is to identify the geographical unit for statistical purposes. The Bureau of Census of the United States has been making efforts to define the geographical statistical unit since the 1970s. A Geographic Base File (GBF) is defined to link non-spatial data (e.g. demographic data) with spatial locations. DIME (Dual Independent Map Encoding) and TIGER (Topologically Integrated Geographic Encoding and Referencing) are two types of GBF utilised respectively in the 1980 and 1990/2000 census. Statistical units defined in these files are census tracts and blocks, encompassed by street segments with address ranges (Huxhold, 1991). With this structure, demographic and other information can be linked to road segments.

Transport planning models require such demographic data as age, income and occupation of individuals in a household, as well as car ownership, bicycle ownership, and expenditure structure of the household. For example, the categorical analysis for trip generation needs to classify trip rate for each type of household.

Land use data

Land use development is an effective indication of urban growth. Both land use planning and transport planning are indispensable in a comprehensive long-range urban planning. Urban land uses are normally classified into two or three hierarchical levels, with the highest level differentiating broad categories. For example, in China urban land use is grouped into the following 10 classes: residential, public facilities, industrial, warehousing, outward transport facilities, street and square, municipal utilities, green, special designated, and other uses (Ministry of Construction, 1990). In defining TAZs, the land use pattern is an important referencing factor. The zones should be as homogeneous as possible so that intra-zonal trips are minimised (Black, 1981; Ding, 1998). Moreover, transport decision making requires information on land value, land tax, land quality and land use policy (Pisarski, 1997).

Urban land use is among the most important inputs to transport demand modelling. Many kinds of models have been developed to describe the interaction between land use and transport. An empirical description of the mutual interaction is shown in Figure 2.4. The characteristics of the transport system determine the level of accessibility, which in turn affects the location of activities (land uses). The location of activities in space influences daily activity patterns, which bring about the need for travel.

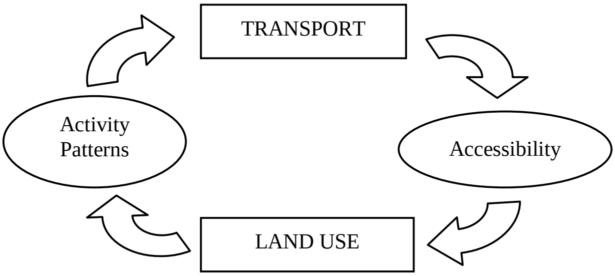


Figure 2.4 The transport–land use interaction (source: Giuliano, 1995)

Although the relationship has been recognised for many years, theories related to land use and transport systems have been individually developed in relative isolation (De la Barra, 1989). Early attempts were made to link land use with traditional four-step transport models, based on the perception that the transport model no longer treats land use variables as exogenous, and the feedback from transport to land use pattern is also made explicit (BTE, 1998). Spatial activity location models, which incorporate the concept of locational accessibility, are utilised to forecast the locations of housing, employment and other activities in transport zones. Data needed in the models, such as number of residents, number of jobs and transport costs, could be derived from land use and transport systems.

Economic data

Acting as an incentive factor, the transport system makes a special contribution to a city's or a nation's economy. The transport sector itself accounts for quite a significant share of the GDP of every country, for example, 11 percent in the United States in 1995 (USDOT & BTS, 1997) and 6.1 percent (including post and telecommunication) in China in 1997 (National Bureau of Statistics China, 1998). The expenditure of households or enterprises on transport is also an effective economic indicator. For example, about 20 percent of total expenditure was spent on various modes of transport in the United States in 1994 (USDOT & BTS, 1997).

On the demand side, both passenger and freight transport rely heavily on the relative costs for different kinds of uses. Information on the traveller's reaction to transport policy alternatives, such as price changes in petrol, is an important input to travel demand forecasting. In predicting trip generation, such economic factors as household income, car ownership, cost induced in various transport modes, and types of employment are all among the explanatory variables (Hensher, 1977; Black, 1981).

There has also been a very close relationship between transport and economic theory. Some of the most important theoretical concepts that form the basis of analysis and evaluation have come from economic theory, such as the theory of consumer travel behaviour, the supply curve, equilibrium and welfare measures (Meyer & Miller, 1984). In analysing traveller behaviour, utility functions make use of several economic variables, including transport services by various modes, monetary out-of-pocket costs on trip, and income.

Data on travel

Passenger travel demand modelling represents a major effort in transport demand analysis. In general, demand modelling takes account of three basic elements, i.e. people, their activities, and the space context within which the activities take place (Figure 2.5). Each element has a set of attributes describing the characteristics that are needed by demand models. The difficult and more important aspect of demand modelling, however, relates to the interactions among the three elements, i.e. perception of space, travel mode and constraints on movement. For example, modal split is one of the four steps in the urban transport model system, and is also a favourable application field for discrete choice models. The concept of time geography, one of the most original and influential ways of looking at complex behaviours, states that both space and time are scarce resources which will constrain people's daily activity patterns (Hagerstrand, 1970; Pipkin, 1995).

The traditional four-step model system takes land use and socio-economic data, together with road networks, to predict future travel demand. For example, in predicting the generation of the home-based work trip, the necessary variables include zonal population, income, car ownership, occupation, transit availability and so on. Among the criticisms of the four-step model is its lack of feedback between the sequential processes. Such feedback should include observed demand or use of transport systems by travellers. Trip information contains the following aspects (Hutchinson, 1974): place of origin and destination (zone-based), trip purpose (work, shopping, school), trip mode (car, bus, rail), vehicle type (number of seats), number of persons / size of load in vehicle, time of day (peak or non-peak), and trip duration.

The discrete choice approach is generally based on micro-economic theory, where certain kinds of utility are calculated and compared for individual choices. In making a choice, a user tends to maximise his or her utility (e.g. to minimise travel time and cost, and to maximise comfort and convenience). Compared with data requirements in aggregate demand models, individual choice models require fewer observations in the sample, but higher data quality in terms of the information obtained per observation (Meyer & Miller, 1984). Moreover, in data collection, stated / reported preference data on individual's choice are collected together with revealed / observed preference data. Travel-related choices include trip frequency, time of travel, destination, transport mode and routes (BTE, 1998).

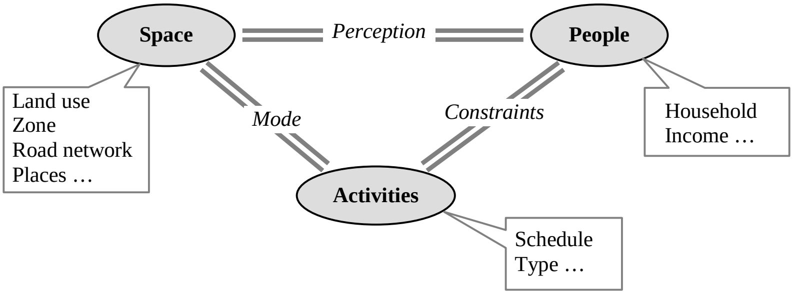


Figure 2.5 Data aspects in transport demand analysis

The assumption underlying the activity-based approach is that travel is a derived demand for accomplishing daily activities such as work, shopping, school and entertainment. The presumption implies that activities should be the focus of modelling and the information acquired about the activities of households or individuals should be as detailed as possible.

In general, apart from basic infrastructure and socio-economic aspects, data on trips or activity patterns are necessary to calibrate various kinds of travel demand models. Differences in data needs arise from differences in theoretical foundations. For example, the differences between the underlying principles of the UTMS and the activity-based approach also indicate variations in data requirements (Table 2.1). The activity-based approach requires more detailed information than the UTMS.

Table 2.1 Difference in data requirements of the two approaches

UTMS	Activity-based
Trip pattern (where and how to go)	Activity pattern (what, where and how)
TAZ as analysis unit	Individual/household as analysis unit
Travel flows between TAZs	Individual movements in space and time
Zonal socio-demographic and trip rates	Individual activities

(Adapted from Greaves & Stopher, 1998)

Another aspect in transport demand analysis is freight transport and logistics. The detailed operations of freight transport are the responsibility of the private sector but, in general, governments have intervened in the freight market through such policies as regulatory and control mechanisms, taxes and subsidies, and traffic management measures (Nash, 1997).

Freight demand is an important aspect in long-range metropolitan transport planning, yet it has been given insufficient attention in the planning process (Pisarski, 1997). The modelling of urban freight movements is usually adapted from techniques for passenger modelling, although there are some modelling challenges unique to the freight market (D'este, 2000). Data needs for freight demand forecasting include locations and types of business establishments, freight movement by mode, enhanced statistics on commodity flow, freight demand by time, O-D movement characteristics, goods content, and tonnage transported.

2.3.3 Supply data

Road networks and related facilities are components of urban infrastructure that are fundamental to mobility. The physical aspect of urban transport planning deals preliminarily with the layout and capacity of these transport facilities. The outcomes of both aggregate and disaggregate urban transport models are mainly the impacts on road networks under different alternatives. Road networks have been a self-evident input to the urban transport modelling process and a carrier of output from the modelling results.

The level of detail for road network representation depends on the scale of transport analysis. Conventional metropolitan transport planning makes use of a symbolised link-node structure (i.e. roads, intersections and zone centroids) for analyses on accessibility, shortest path and trip assignment. Information on roads concerns length, designed volume, maximum speed, pavement, flow direction and so on. For road intersections, information relates to type of crossing, turning rule, light control, and average waiting time. This simplified representation of spatial road networks has been widely accepted and applied in aggregate transport modelling packages. However, with the development of activity-based models as well as short-range local transport policy analysis, more details of road networks are required. To meet these needs, data have to be collected on the number of lanes, high occupancy vehicle lanes, elevated roads and flyovers.

Transport networks include not only roads for motor vehicles, but also pedestrian routes, bicycle routes, ferry routes and so on. These routes provide alternative transport modes which, together with public transit and cars, are to be included in mode choice models (such as the hierarchical logit model) in the modal split phase. Also, transport facilities are among the components of an integrated urban transport system. These facilities help to realise smooth traffic flow on transport networks. The location and capacity of the facilities, such as parking lots, tollgates and transferring centres, are identified in urban transport planning.

A comprehensive list of transport system data is given by Bonsall and O'Flaherty (1997), which includes highways, on-street / off-street parking facilities, public transport infrastructure, facilities for cyclists and pedestrians, canals and navigable rivers, freight interchange facilities and traveller facilities.

2.3.4 Performance data

The operations of urban transport infrastructure indicate the real performance over time. The information is needed to evaluate system performance or predict future trends, e.g. using regression analysis or trend analysis to forecast traffic volume of a road network in the near future. Variables detected or monitored for the operations include (Pisarski, 1997):

- Travelling speed, rate of flow, density and volume on various links
- Types of vehicles travelled through monitoring sites
- Incidents such as level of congestion and accidents
- Operating restrictions, e.g. vehicle speed, height and weight limits
- Tolls and other facility-specific charges
- Functional class of highway segment
- Frequently updated condition measures for bridges, arterial and street systems, and other facilities
- Inventory of materials used in construction and maintenance
- Information on agency or company responsible for maintenance and operation of the facilities so that data on supply and cost can be related

These data are important to system evaluation or performance measurements, which indicate the effectiveness of a transport system. The operational performance, measured by the ease of travel, the quality of service provided, and service reliability, is an important consideration in maintaining acceptable levels of mobility.

To measure public transport performance, seven factors have been identified under the categories of input, consumption and output (Fielding, 1987). The linkages among these factors indicate the performance level from three perspectives, i.e. service efficiency, cost effectiveness and service effectiveness (Figure 2.6).

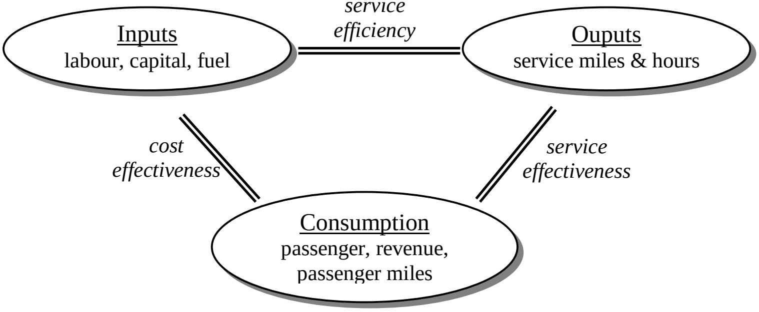


Figure 2.6 Dimensions of public transport performance

One important characteristic of system operational data is that these data must have a clear temporal imprint. Information on operations such as speed and volume are meaningful only when the times of observations are specified. The traffic condition in rush hours is very different from that at other periods of the day, and differences also exist during weekdays and weekends, as well as seasons of the year in some scenic or historical areas. From the perspective of data management and data analysis, the temporal aspect represents a complicated challenge that has aroused much research interest (e.g. Kitamura *et al*, 1997; Shaw & Wang, 2000).

2.3.5 Impact data

One of the most important characteristics of the urban transport system is that it has direct or indirect impacts on the urban activity system. These impacts can be classified into physical, economic and social aspects (Table 2.2).

Table 2.2 Transport facility impacts on the activity system

Physical impacts	*Economic impacts*
Aesthetics and historical value	Employment, income and business activity
Infrastructure	Residential activity
Terrestrial ecosystems	Effects on property
Aquatic ecosystems	Regional and community plans
Air quality	Resource consumption
Noise and vibration	*Social impacts*
Disruption or damage to adjacent properties	Displacement of people
Traffic circulation and parking	Accessibility of facilities and services
Public safety	Effects of terminals on neighbourhoods
Energy	Special user groups

(Source: Meyer & Miller, 1984)

The major concern of the physical impact analysis has been centred on environmental impacts, such as pollutant emissions, air quality and noise. An important variable for estimating the amount of pollutant emissions is called vehicle-miles-travelled (VMT). For detailed estimation, more variables are needed, such as travel time, travel speed and vehicle type, as well as number of trips taken in cold-start mode.

The objective of the 1970 Clean Air Act (CAA) of the United States was to control emissions and improve air quality. The act was amended in 1977 and in 1990, each time with new and stricter standards and guidelines. The 1990 CAAA recognises the important role that transport plays in determining the air quality, and provides for sanctions related to transport implementation programmes if schedules and requirements are not satisfied (Karash & Schweiger, 1994). The biggest achievement of the Act has been the large reduction in the amounts of lead in the atmosphere, which were reduced by 85 percent between 1970 and 1994 (Stutz, 1995). Levels of other pollutants (e.g. sulphur oxides, ozone, CO) have also declined. However, the accomplishment has been counteracted by increased VMT during the same period of time. Therefore, the environmental problem continues to be a significant concern.

As an example of data requirements for environmental impact evaluation, the transport-related inputs to the MOBILE model developed by the U.S. Environmental Protection Agency (EPA) are (*cited by* Karash & Schweiger, 1994):

- VMT by eight different vehicle types
- Annual mileage accumulation rate by vehicle type
- Vehicle registration distribution by vehicle type and 25 vehicle age categories
- Trip length distributions
- VMT by speed class
- VMT by time of day
- VMT by the above categories by grid square for photochemical modelling purposes
- Seasonal variation in VMT, vehicle mix, etc.

2.3.6 Summary

The grouping of data into classes of demand, supply, performance and impact is appropriate for transport planning. The data framework is not organised to fulfil the specific needs of a particular model, rather it is for analysis and evaluation throughout the whole process of transport planning. Table 2.3 gives some examples of data under the four groups that are important to several transport planning tasks. It can be seen from the examples that socio-economic activities, road network and land use are necessary data sources for most of the tasks. It is therefore important to link these data with other related data to support planning processes.

Table 2.3 Examples of categorised data for transport planning tasks

Planning tasks	Data source examples			
	Supply data	Demand data	Performance data	Impact data
Land use – transport	Road network	Land use; socio-economic		
UTMS	Road network; node; transit	Land use; socio-economic	Speed; volume	
Discrete choice	Distance	Socio-economic	Travel time	
Activity-based	Location	Socio-economic; travel diary	Time; volume; incidents	
Traffic assignment	Road network; node	O-D	Time; speed; volume	
Micro-simulation	Road network; lane; junction	Land use; socio-economic	Speed; volume	
Operations	Road network		Speed; volume; incidents	Noise
Impact analysis	Road network		Congestion	Noise; VMT; emissions

In addition to the complex data requirements in transport planning, data themselves are complicated in that they are represented differently and are collected and kept in different agencies. When evaluating institutional data, certain questions have to be answered: what kind of data is available in which agency, on what scale? what is the collecting phase? what is the quality of the data? For building an integrated transport information system, transport data have to be conceptually modelled in terms of representations and cross-references. The following two sections give some details on these aspects.

2.4 Transport data representation

2.4.1 Data representation principles

Objects in the real world can be defined or depicted in three ways: the verbal, the graphic and the pictorial symbolisation (Table 2.4). The three methods range from abstract to concrete. The abstract definition of an object is a verbal description of its name, type, function, property and so on. For example, a road can be defined as an open way for vehicles, persons, or animals. The graphic method depicts the objects on certain media (e.g. paper) so that its physical shape is visually observed. Depending on the degree of detail, this method may take the form of a brief sketch, delicate drawing or precise mapping. The pictorial one is a vivid representation based on photographs, images or 3-D models.

Table 2.4 Representation of spatial entities by levels of detail

Symbolisation	Type of illustration	Data model	Level of abstraction
Verbal	Name Definition / Description	Text / Table	Abstract
Graphic	Sketch Drawing Mapping	Vector	↓
Pictorial	Photograph / Image 3-D model	Raster Vector / Raster	Concrete

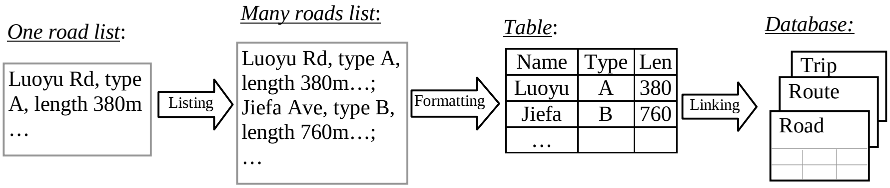
(Based on Hansen, 1999)

The advent of electronic computer technology has revolutionised the means of representation. Entities in the real world are abstracted and conceptualised in the mental world, and represented in the digital information world. The fundamental element of digital representation in the computer is the pair of binary code, i.e. 0 and 1. These two binary digits make up numbers, characters and instructions, which are used to represent such complex objects as graphics, images, sounds and databases. Information systems, particularly spatial information systems, are developed on the basis of these representations. The types of data models for this purpose determine how detailed the representation can be.

Both numbers and characters are the verbal (non-spatial) description of real world objects. Figure 2.7a shows how a road is conceptualised and represented in a computer system. This kind of representation forms the basis of information systems (Figure 2.7b). Information on an entity is stored in a formatted way. Many entities of the same type (e.g. road) can be represented in the same format and kept in one or more tables. Many tables having relevance for one another constitute a database. Database technology has revolutionised data representation and retrieval (O'Neill, 1994). Data are kept in a repository with normalised formats, making it efficient for searching, querying and statistical operations.

Realm	*Concept*	*Representation*
Real world	Road	
Conceptual world	Linear entity	Description: name, length, …
Computer world	Entity	Values: character; number

(a) from real to virtual



(b) from text to data

Figure 2.7 Non-spatial representations of entities

Spatial entities can be represented graphically in computer systems. The graphs of the entities are depicted by their coordinates, which are either geographically or non-geographically referenced. A non-geographical reference is a planar representation with an arbitrary coordinate system. A geographical reference is based on a map projection of the Earth, such as topographical maps with latitude and longitude. In an urban area, large-scale topographical maps are also referenced with planar coordinates.

Two kinds of data models are available to represent geographical phenomena: the raster model and the vector model. The two models are derived from two different ways of viewing spatial features: the field-oriented and the object-oriented (Worboys, 1995). The field-based approach partitions a region into finite tessellation that serves as a spatial location framework. This distribution is associated with continuous geographical phenomena such as elevation in topography. The object-based approach regards physical objects as discrete entities that are cross-referenced by topological descriptions within a certain spatial framework. Each entity may have four dimensions for representation: the geo-spatial coordinates or locations, the graphical generalisation in different scales, the temporal attributes and the textual attributes. Although the raster model was designed to represent spatial fields and the vector model was invented to represent spatial objects, the two models are interchangeable (Heywood *et al*, 1998). In transport planning models, spatial features are generally viewed as object-based and represented by a vector data model. However, the raster data model has been used in urban models such as micro-simulation (Batty, 2001).

2.4.2 Transport data from the perspective of geographical information science

In geo-information science, data are classified as spatial and non-spatial, both imprinted with a temporal sign. Depending on their shapes and scales of representation, spatial entities may be treated as points, lines, polygons or surfaces. Non-spatial or attribute data are linked to their spatial objects by means of object ID. Various data models have been proposed for representing these data in 3-D space and the temporal dimension. As a large proportion of transport data are referenced by location, GIS has been used in the transport field (known as GIS-T) extensively (Waters, 1999).

From the GIS perspective, spatial data in urban transport planning can be grouped as points, lines and polygons, as shown in the following:

- points: TAZ centroids, activity sites, intersections (nodes), surveying points
- lines: road segments (links), routes
- polygons: TAZs, land uses, statistical units, administrative units

The above entities do not exist in isolation. They are linked by spatial topology (Figure 2.8). In transport analysis, these spatial units have to be defined with reference to each other. The figure indicates the relationships among point entities, linear entities and areal entities. Among the spatial entities, the route is a logical entity that is normally defined by a set of interconnected road segments (links). More than one route connects two TAZs, as is also assumed in the traffic assignment processes.

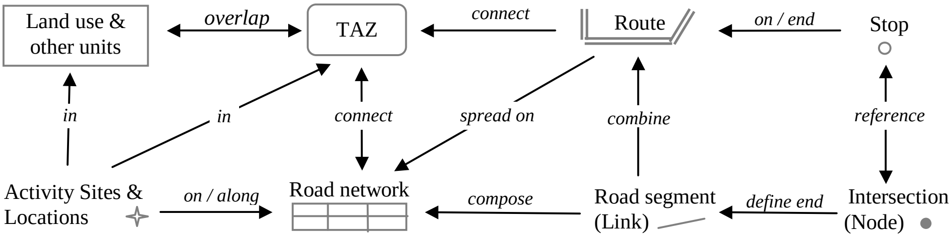


Figure 2.8 Links among spatial transport entities

Compared with spatial data, non-spatial data are those without geographical coordinates and geometrical shapes. In GIS, this type of data is referred to as attribute data, i.e. the attribute of a certain entity. The relationships of these data may be clarified by Entity-Relationship (E-R) analyses, which produce normalised tables. In fact, all these data are directly or indirectly relevant to spatial entities.

In urban transport planning, although the final objective is to improve the spatial flow of traffic, the process of achieving the objective includes a series of scenarios and modelling that require comprehensive non-spatial data. These data may appear as single values (total trip rate, model parameters), lists or tables (household information, activity diary, employment), and matrixes (O-D tables). Several examples are shown in Table 2.5.

Table 2.5 Examples of non-spatial data

Household table (list)	
Items	Value
ID	*420111*
Size	*3*
Age (father)	*32*
Age (mother)	*30*
Age (child 1)	*6*
Age (child …)	
Income (father)	*20000*
Income (mother)	*14000*
Car	*0*
Bicycle	*3*
Total trips a day	*3.8*
Home address	*Qi str. 20*

Activity diary (list)	
Items	Value
Day	*4-Nov-1996*
Time	*9:00*
Place	*Office*
Type	*Work*
Duration	*8 hrs*

O-D table (TAZ matrix)				
	1	2	…	n
1	500	130		95
2	83	800		62
…				
n	98	150		650

Attributes of spatial entities are kept in tables, using the unique IDs of the entities as the keys. For example, a street segment may have such attributes as pavement, width, length, maximum speed, address range, traffic volume and year of construction. These tables are put together with spatial entity maps so that queries on certain criteria can be easily carried out.

2.4.3 Approaches to transport data representation

As many types of spatial data are used in transport planning, the representation of these spatial data is a major challenge. Methods of transport data representation rely heavily on the purpose and scale of the transport analysis, as well as the type of model.

Traditional transport demand models represent networks and locations as non-geographical spatial data. In situations where a geographical framework is used, less attention has been paid to the precision of the representations (Sutton & Gillingwater, 1997). The gap between non-geographical model data and general-purpose geographical data can be filled by such techniques as network conflation in GIS (Sutton, 1997). With the widespread use of geo-spatial data in governmental organisations and commercial agencies, data in transport planning and operations will undoubtedly become geo-referenced.

GIS is an effective tool for managing spatial transport data, but data in GIS are not necessarily effective for transport models. This is due to the different data representation methods in GIS and transport models. Table 2.6 shows the differences in the approach to transport network data between GIS and conventional transport models. Due to these differences, the advocated GIS for Transportation (GIS-T) is therefore more than just one domain of transport application added to the GIS functionality (Thill, 2000).

Table 2.6 Different approaches to network data

Geographical Information System	Transportation model
Multi-purpose	Single purpose
Data-driven	Model-driven
Geographical context	Abstract context
Many topologies	Single topology (link-node)
Chain structures	Link-node structure
Spatially-indexed	Sort-indexed
Many fields	Few fields

(Source: Sutton, 1997)

The representation of transport data, either with GIS or in transport models, is dependent on the scale of the application. A long-term strategic planning model requires a simplified vision of the transport network, with a link-node structure in the UTMS or an arc-node structure in GIS. The details of the road network, such as the number of lanes and types of intersection, are omitted in such a representation. For traffic simulation and in-vehicle trip guidance, however, the transport system has to be represented in as much detail as possible. Such details include non-planar network, lanes, turning impedance, dynamic segments, routes, temporal flows and so on. The representations of these details have to combine spatial data models with non-spatial data models, using such concepts as turn-table, dynamic segmentation, linear referencing and matrix manipulation (Goodchild, 1998; Spear & Lakshmanan, 1998). A brief summary of techniques for representing transport features is shown in Table 2.7. Implementing these in GIS has the advantage of integrating with other transport data.

While the enterprise transport model systems represent transport data in a way that best suits their own needs, a GIS or a transport information system usually requires data be represented in such a way as to promote the integration of transport data. That is to say, the issue of data representation is more related to transport information system development, in which transport data are cross-referenced and the maximum utilisation of the information is achieved. The development of the Urban Transport Information System (UTIS) in Newcastle upon Tyne, for example, has the ambitious objective of satisfying the data demands of all transport decision makers (Wright *et al*, 2000). The research demonstrated the construction of a lowest-common-denominator database that allows all networks derived from it to be updated simultaneously. The model from the U.S. National Cooperative Highway Research Program project, 20-27(2), has also proposed a detailed representation of the transport network (Adams *et al*, 1999). Based on the concept of linear referencing system, a method with a slightly higher level of representation has been proposed for transport features by Dueker and Butler (1998, 2000). Transport features in this scheme are logical linear or point events based on geographical street networks. The implementation of the enterprise GIS-T model has also been demonstrated (Butler & Dueker, 2001). For aggregate traffic data applications such as travel time studies, an expansion of the traditional link to a bi-directional representation (without going down to the lane level) will be sufficient (You & Kim, 2000).

Table 2.7 Representing transport features with GIS

Transport features	Representation	Examples
Zone	Polygon	TAZ
Zonal interaction	Matrix	O-D table
Road link	Arc	Urban street
Road network	Network	Street network
Dynamic section	Dynamic segmentation	Pavement
Traversal	Route	Bus route
Lane	Arc + attribute	Lane
Intersection: simple	Simplified node	Equal intersection
Intersection: signalised	Node + turn-table	Signalised intersection
Intersection: non-planar	(no node)	Overpass
Intersection: multi-lane	Lane connection	Lane level street
Traffic incident	Linear referencing	Accident report
Stops	Points / route event	Bus stop inventory
Activity site	Street address	Trip stop

The time dimension of transport data is another complicated issue, usually referred to as spatio-temporal modelling. All transport features change in time with different frequencies, from fast-moving vehicles to slowly updated road networks. The representation of these spatio-temporal data in GIS are mainly based on three approaches: the snapshot model that records only the entities available at the time of surveying, the space-composite model that "stamps" spatial entities with the time attribute, and the object-oriented model that incorporates the thematic, temporal and spatial dimensions (Valsecchi *et al*, 1999). In other words, the representation of the spatio-temporal phenomenon in general depends on the way the time is viewed, i.e. a “discrete view” or a “continuous view” (Peuquet, 2001). Spatial entities with spatial, aspatial and temporal attributes may be represented with the object-oriented data model (Figure 2.9). This concept is utilised by Etches *et al* (1999) in an integrated temporal GIS model for traffic systems, in which a linked hierarchical scheme consisting of three sub-schemes (geographical, traffic and simulated) is defined. This representation makes the database work at both the microscopic simulation level and the macroscopic abstraction level. Another example of spatio-temporal application is the accessibility measurement that is based on the space-time concept, in which arcs are characterised by a set of temporally dependent velocities and nodes are characterised by a set of temporally dependent turn times (Miller, 1991).

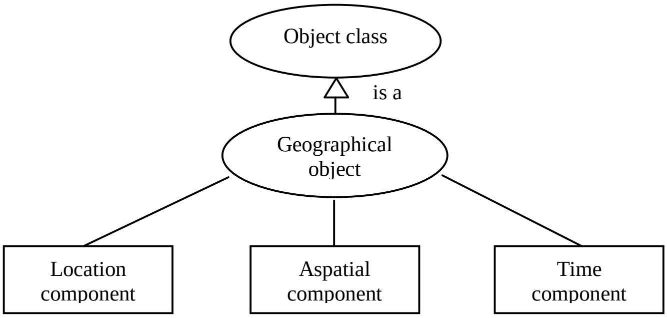


Figure 2.9 Conceptual scheme of spatio-temporal object (after Peuquet, 1999)

2.5 The technology of transport data integration

2.5.1 GIS-T

Geographical Information Systems (GIS) have been increasingly utilised to manipulate spatial information since the 1960s. GIS is a useful tool for addressing complex tasks in policy making, planning, design, management and evaluation. The popularity of GIS is due not only to its ability to manage spatial data, but more importantly to its ability to integrate spatial and non-spatial data, as well as its spatial analysis functionality. GIS plays an important role in supporting urban and regional planning (Ottens, 1990; Masser & Ottens, 1999). As transport networks and transport activities are spatially distributed, GIS may also contribute to transport analysis. The potentiality of spatial analysis (e.g. buffer, allocation, routing) for a specific transport analysis (e.g. impact analysis, accessibility analysis) has also been recognised.

The development and use of a GIS for transport (GIS-T) involves more than just implementing a technical tool, it broadens and deepens transport analysis (Nyerges, 1995). Generally, a GIS-T can be seen as a system of hardware, software, data, people, organisations and institutional arrangements for collecting, storing, analysing and disseminating information about areas of the Earth used for or affected by transport activities (Fletcher & Lewis, 1999). The system has benefited technologically from the development of management information systems and relational database techniques (Waters, 1999). Operational models such as shortest path algorithms, location-allocation models, dynamic segmentation and routing procedures have contributed to the development of GIS-T in transport agencies.

2.5.2 The state of the art

Many projects have demonstrated the application of GIS in transport planning. Wartian and Gandhi (1994) described a project undertaken by the GIS and Traffic Engineering (TE) departments of Orange County, Florida. A linkage was built up between the transport data model of the Florida Department of Transport (FDOT) and the county's street centreline network from the Geographic Index Database (GIX). Thong and Wong (1997) designed a traffic information database, using GIS for the realistic simulation of networks, for manipulating various transport-related information, and for supporting scenario comparison in urban transport planning. The prototype GIS-T database is beneficial for accessing network flow characteristics and evaluating future road-network assignments. Souleyrette and Anderson (1998) have reported the utilisation of desktop GIS for efficient urban transport model development. The desktop platform provides a means of incorporating existing data sources, integrating the data in a useful environment, creating a validated transport planning model for an urban area, and visualising the results. By incorporating a programming functionality, GIS-based tools can be developed for generating new transport models, modifying existing models and evaluating planning scenarios.

To demonstrate innovative approaches to using GIS-T for transport planning and programme development, several transport case studies in GIS have been carried out in the United States under the Travel Model Improvement Program (TMIP). TMIP is a multi-year, multi-agency programme to develop new travel demand modelling procedures that accurately and reliably forecast travel for a broad range of modes, policy actions and operational conditions (*http://tmip.fhwa.dot.gov/*). The series is entitled "Transportation Case Studies in GIS", and the cases are listed in Table 2.8.

Table 2.8 Transportation case studies in GIS within TMIP

1	Southern California Association of Governments – ACCESS Project
2	Portland Metro, Oregon – GIS Database for Urban Transportation Planning
3	North Carolina DOT – Use of GIS to Support Environmental Analysis
4	Maine DOT – Statewide Travel Demand Model
5	San Diego Association of Governments – Multiple Species / Habitat Conservation Programs and Transportation Planning
6	The Orange County Transportation Authority – GIS for Transit Planning at OCTA

One of the case studies, GIS database for urban transport planning, was carried out in Portland Metro jurisdiction, Oregon. As one of the leading users of GIS in transport planning, Metro has made use of GIS in a wide range of activities, including assembling data for the travel forecasting model, performing spatial analyses such as measuring job-housing balance, and displaying model outputs on base maps. This “geocentric” approach has resulted in many innovative applications of GIS to support modelling, including activity-based models and the TranSims Travel Model Improvement Project. The project demonstrated how GIS can enhance travel forecasting techniques utilised in transport and regional planning. Detailed descriptions of the applicability of GIS are:

- Geo-coding of survey data: household and activity locations, including employment sites, non-work activity centres and transit access and egress locations
- Analysis of demographic characteristics such as distribution of income, household size and age of household head
- Analysis of total and retail employment
- Measuring mixed land uses
- Analysis of pedestrian accessibility to transit services and of zonal accessibility by different modes
- Data aggregation to TAZ
- Mapping and display of model outputs, including results of traffic and transit network assignments

A recent GIS-T effort, the Unified NEtwork-TRANSportation data model (UNETRANS), was initiated in 2000. UNETRANS is a collaborative project to develop a generic data model for transport applications, using ESRI software. One of the outcomes of the project will be a comprehensive conceptual object model for transport features, incorporating multiple modes of travel, and accommodating multiple scales of interpretation of the real world (*http://www.ncgia.ucsb.edu/vital/unetrans/*).

2.6 Conclusions and discussions

Recent improvements in transport planning tools have given rise to a need for more detailed and complex data. These data are usually available from different sources, have multiple dimensions, and are represented in a way that fits the needs of specific planning tasks. The integration of these data is vital for a comprehensive planning application or the construction of a transport planning support system.

Information science has provided potential technologies for the integration of transport-related data. While there have been many achievements in the application of database systems and GIS to transport projects, the main challenges remain in the multiple representation and fusion of transport data. These challenges arise not only from such technical aspects as spatial-temporal representation and data warehousing, but also from non-technical aspects that relate to social, cultural and institutional traditions.

Transport entities and activities can be described from three perspectives: their spatial locations, their attributes, and the time period when they exist or happen. When creating an integrated database, data with these perspectives have to be properly linked. Table 2.9 gives a framework of interaction among the types of data, exemplified by some transport data that need to be considered during data integration. In this framework, spatial data are grouped as point, line and area data types, whereas non-spatial data are differentiated as value / table / matrix and time data types. Compared with the framework for transport data organisation shown in Figure 2.3, this framework classifies data from the perspective of information science. Each data type is related to the other types. For example, activity sites (point data) are associated with street networks, TAZs, activity attributes, as well as schedules. The integration of these data types involves a series of techniques from information science and is also closely linked to the specific context in which the transport data are utilised.

Table 2.9 Framework for transport data integration with some examples

		Spatial			Non-spatial	
		Point	Line	Area	Value / table / matrix	Time
Spatial	Point	Activity site & landmark	Activity site & street links	Activity site & TAZ	Activity & its attributes	Activity & schedule
	Line		Road network & bus route	Link & TAZ	Link & performance	Link & travel time
	Area			TAZ & land use	TAZ & attribute	Land use change
Non-spatial	Value / Table / Matrix				Origin-destination in TAZ matrix	Traffic flow & time
	Time					Volume in hours & days

The spatial-spatial issues within the framework represent big challenges to transport data integration and will be examined in three technical chapters of this dissertation. Based on the requirements of methodological improvement, as well as relevance to the local context, each chapter focuses on one major topic. The location referencing of socio-economic activities in Chapter 4 deals with the identification of point locations with reference to other point, line, and polygon entities. The detailed representation of bus lines in Chapter 5 is mainly a cross-reference between two linear entities, i.e. the bus routes and street networks, as well as a point-linear reference between stops and streets. In the same vein, Chapter 6 focuses on the interaction between two sets of areal entities. GIS is a major tool applied in all these attempts, in which the techniques of geo-coding, dynamic segmentation, aggregation and disaggregation are utilised or improved.

Before these technical analyses could be made, it is necessary to understand the local context in which the data integration is carried out. The next chapter introduces transport planning in China and examines the institutional structure for transport data integration in Wuhan.

Chapter 3 Urban Transport Planning In China: A Case Study Of Wuhan [*]

3.1 Introduction

According to their functional uses, transport data can be categorised into the four groups of supply, demand, performance and impact. From the perspective of information science, transport data can be classified as spatial and non-spatial types. These data are complex in terms of sources and scales of spatial and temporal changes. An important aspect is that these data are collected and managed by different transport agencies. Understanding the context for transport planning may facilitate the studies on transport data integration.

This chapter introduces the development of urban transport planning in China in general and in Wuhan in particular. The history, characteristics and institutions of modern transport development in Chinese cities are introduced in the first section. This is followed by a detailed study of Wuhan, including a description of transport development and the findings of a survey of the main stakeholders in transport planning and management in the city.

3.2 Urban transport growth and transport planning in China

3.2.1 The evolution of urban transport development in China

Before the 1980s

Before the 1980s, transport development in China was not a major concern. After several decades of political, social and economic turmoil, the challenge facing the new China founded in 1949 was to provide basic needs for living. In addition to nationwide rural restructuring to foster agricultural production, much effort went into industrial development in the cities (Wong & Han, 1999). Large-scale infrastructure was constructed in large cities to facilitate this industrial development. Goods transport was considered very important for agricultural and industrial products, while passenger transport was basically neglected because of the low demand for travel in that period.

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[*] Based on Huang, Masser & Hu (2001).

For practical reasons, little effort was spent on transport planning, development and management in this period. Firstly, under the planned economy, roads and road facilities were considered as “non-productive” and given low development priority. The planning of road networks was included in urban planning blueprints. Secondly, urban land was allocated to work units (*Dan Wei* in Chinese), such as governmental agencies, hospitals, universities and factories (Rose, 1999). There were no comprehensive housing development programmes. Each work unit had to develop its own offices and housing on the same piece of allocated land. This land use structure reduced the demand for travel to a minimum, because most activities happened within enclosed compounds. Finally, urban roads had a low level of service, which was disguised by the low traffic volumes of this period. There was inadequate recognition of speed, volume, and their implications for urban transport.

Economic growth inevitably put the inefficient transport system under pressure. By the late 1970s some big cities had already begun to experience such pressures, which stimulated serious thinking on transport problems among researchers and administrators. Some preliminary transport research was carried out, for example, surveys on traffic volume were implemented in several metropolitan areas, and Origin-Destination (O-D) investigations were used to predict traffic flow (Xu, 1992). However, these studies were generally primitive in nature.

Urban transport under the economic reform

After more than 10 years of economic and social stagnation during the 1960s and 1970s, economic reform and the open-door policy of the 1980s brought about drastic changes in both rural and urban areas. As a result, the demand for travel and the number of motor vehicles rapidly increased in this decade, generating much pressure on the insufficient road infrastructure, particularly in the large cities.

Over the years planners and administrative officers in China gained a deeper awareness of the urban transport issue (Xu, 1992). For example, urban transport was not non-productive but could bring great social and economic benefits. They also recognised that traffic management was indispensable for improving transport efficiency and that priority should be given to public transport.

Institutions were set up to promote the exchange of ideas and research activities (Xu, 1992). In 1979, the Academic Group for Metropolitan Transport Planning was founded in Beijing. The group worked under the Urban Planning Committee, a branch of the Society of Chinese Architects. Annual meetings, each with one main discussion topic, were organised by the group. These meetings played an important role in spreading transport concepts, experience, technologies and policies, and attracted participants from governmental agencies, such as the State Commission of Science and Technology, the Ministry of Public Security, the Ministry of Construction, the Ministry of Communications and the Ministry of Railways. Due to its successful work, in 1985 the group became the Chinese Academic Committee for Urban Transport Planning. At the local municipal level, some institutes for transport planning were set up under the administrative bureaus of urban planning and management.

Despite this progress, however, there were two dominant problems throughout this decade. Firstly, there was a marked emphasis on traffic engineering, without a broader view on the whole urban transport system and long-term transport planning. Secondly, insufficient infrastructure remained the bottleneck constraining development in large cities. The total amount of road space was far from sufficient. Nor were road networks developed in a systematic way.

The unprecedented challenge since 1990s

Since the 1990s, the Chinese economy has been growing very fast, accompanied by a corresponding increase in travel demand. As a result of the economic boom, urban development has taken place at an unprecedented speed, including the expansion of built-up areas into suburbs and redevelopment within historical central areas. Urban economic development has attracted a lot of surplus manpower from rural areas, giving rise to a dramatic population increase in most cities. Apart from population increase and economic growth, the increase in travel demand is also a result of several other factors. Urban expansion and land use reconfiguration have broken the traditional balance between jobs and housing, i.e. the *Dan Wei* system, where people live near their work places (Shen, 1997). Encouragement of the auto industry by central and local government has provided further impetus to the travel increase, and the number of automobiles has been mounting dramatically in urban areas.

On the supply side the shortage of road infrastructure has continued. The increasing travel demand brought about by economic and social development has placed great pressure on the already inadequate road infrastructure. Most of the newly built roads are in the fringe areas around the city and little has been done within the city centre. Another problem is the decline in public transport. Due to such factors as the implementation of the market economy and the shortage of funding and management skills, public transport has continued to operate inefficiently and has become a financial burden on local municipalities. In 1994, for example, 70 percent of the urban public transport enterprises were in the red, necessitating compensation from central and local government (Zhou, 1996).

Large-scale construction has taken place in every large city in China. It was realised that these types of developments would generate an increase in traffic on the road networks nearby. Consequently, traffic impact analysis of large-scale construction became necessary. In 1995, the Urban Planning Bureau under the Ministry of Construction issued a meeting synopsis advocating that traffic impact analysis should be carried out. Environmental problems caused by motor vehicles were not a real concern until the second half of the decade, when the atmospheric pollution in several of the largest cities became serious. In 1997, Beijing issued a traffic management regulation stipulating that all vehicles should install equipment for purifying exhaust gas. As a result environmental impact research became an important task.

At the national level, the bottleneck in transport development in Chinese cities during the 1990s was still the insufficiency of road infrastructure, and transport policies were in favour of road construction. The major task of transport planning was quite similar to that of Western cities about 30 to 40 years ago. It was increasingly recognised that physical extension and improvement of road infrastructures would never fully meet the growing transport demand. With this in mind and more information on the experiences of developed cities, transport professionals introduced some policy measures such as the demand management.

3.2.2 Characteristics of urban transport in China

Urban transport in China revolves around the imbalance between demand and supply, i.e. the supply of transport services falls behind the increasing demand for travel. The challenge facing transport supply is not simply the shortage of transport infrastructures, but the inadequacy of the whole framework of transport services, ranging from policy, planning and implementation to management. While the modes of transport in Chinese cities are basically the same as those in Western cities, the composition and characteristics of these modes are very different. This section gives a concise description of some of the important components of urban transport in China.

Passenger travel modes

A short list of the structure of several selected cities reveals some of the trip characteristics in China (Table 3.1). All the cities in the list have more than one million people. Although a direct comparison of the cities is less practical because of the different years of survey, it is still realistic to extract some basic features from this list. One such feature is that the bicycle plays an important role in passenger travel, accounting for more than 30 percent of all trips and over 60 percent of trips in some cities. In most cities walking is a popular mode, with a trip rate of over 30 percent in some cities. Public transport is also quite important in some cities, with trip rates of over 20 percent in some of the larger ones. Another interesting characteristic is that, due to a low ownership, there is no indication of the use of private cars. However, it has been estimated that, as the car industry is envisaged to be the industrial backbone of the country, private cars will become more and more important in urban transport (Stares & Liu, 1996).

One important mode of transport that is not reflected in Table 3.1 is the use of corporate vehicles. The word “corporation” here refers to any kind of employer (work unit or *Dan Wei* in Chinese terms) that has employment activities. Corporate vehicles may include cars, coaches, and trucks. Of these vehicles, only the use of the corporate bus was counted during the travel surveys. Actually, vehicles from these public or private corporations constitute a large proportion of urban vehicles. Unfortunately, there has been no detailed research on the use of corporate vehicles for the purpose of transport planning.

Table 3.1 Trip patterns in selected cities

City (year)	Public transit	Bicycle	Walk	Corpo-rate bus	Taxi	Motor-cycle	Other
Beijing (1986)	24.3	54.0	13.8	4.4	0.3		3.2
Shanghai (1986)	24.0	34.2	38.2	2.2	0.2	0.2	1.0
Tianjin (1993)	4.1	60.5	28.0	3.1		2.0	2.3
Guangzhou (1984)	21.7	33.8	30.6		6.1	6.4	1.4
Chengdu (1987)	5.8	54.6	36.0				3.6
Jinan (1988)	6.7	63.8	23.3	3.8		0.8	1.6
Wuhan (1993)	24.5	32.6	32.6	4.7	0.1	0.2	5.3

(Source: Li, Y., 1997)

Bicycles

The bicycle is one of the major modes of transport in Chinese cities. Bicycles are widely used when trip distance is within six kilometres of the house. Bicycle utilisation also depends on the scale of the city. Several studies have shown a difference in bicycle trip rates between three groups of cities, i.e. smaller cities have higher bicycle trip rates than larger cities (Table 3.2). Bicycles are affordable, flexible, energy saving, pollution-free, and beneficial to health. However, too many bicycles may also have a negative impact on urban traffic, including the influence on motor vehicles at crossroads, the lack of parking facilities, the safety aspect, and challenges to public transport. In response to both the advantages and disadvantages, there have been advocates for maintaining a moderate rate of bicycle trips in large cities (Miao & Zhao, 1995). One measure towards achieving this end is to build transfer points to link bicycle and public transport.

Table 3.2 Characteristics of bicycle trip in three city groups

Cities (population in millions)	Range of bicycle trip ratio	Average bicycle trip ratio	Trip ratio between public transport and bicycle
> 2	25%~55%	36.21	38 : 62
1 ~ 2	23%~63%	42.40	28 : 72
< 1	40%~75%	55.04	7 : 93
Average	-	44.55	24 : 76

(Source: Xu, 1997)

Walking

Walking is a “primitive” transport mode. Statistics in the second half of the 1980s in China showed that the walking trip rate in large cities was around 40 percent, in mediumsized cities about 45 percent, and in small cities more than 50 percent (Xu, 1997). There have been very few researches on the walking mode, and no standard for designing and constructing pedestrian roads. Pedestrian road systems in most cities are not complete, which has led to many traffic problems. It is difficult to cross a busy street, and sidewalks are often occupied by commercial uses. These factors have created an unfavourable walking environment on Chinese urban streets.

Public transport

According to the classification standard for the national economy and trade, urban public transport in China belongs to the social services industry rather than to the communications and transport industry. Similar to such trades as sewage and water supply, roads and bridges, and gas and heat supply, public transport has been regarded as one component of municipal public utilities. Financial support for public transport comes from local government, and a major part of this has been collected as a tax on urban construction and maintenance.

Table 3.3 shows the percentage shares of total passenger transport by various public transport modes at the 1994 national level. It is clear that buses are the dominating mode, carrying more than 75 percent of all passengers. However, it should be noted that the total number of passengers transported by buses has fluctuated since 1988, although the number of buses has been increasing. In fact, the shrinkage of bus transport has been very clear in large cities (e.g. Zhou, 1990, 1996, 1997; Zhao & Kong, 1999). Li (1997) also declared that bus transport in Shanghai had been in constant decline between 1988 and 1995. Actually, the trend continued until 1998, when a slight rebound occurred (*http://www.scctpi.gov.cn/*).

Table 3.3 Share of public transport modes in 1994

	Number of passenger trips (100 million)	Percentage
Bus	235.16	75.89
Tram	29.50	9.52
Trolley bus	2.30	0.74
Subway	5.42	1.75
Taxi	29.48	9.51
Ferry	8.01	2.59
Total	309.87	100.00

(Source: Wang *et al*, 1997*)*

Reasons for the shrinkage of bus transport include the low-price policy, inadequate finance, inefficient operations management, road congestion, the increase in motor vehicles, and the increase in other public transport modes. Despite the intractable situation, public transport has been identified as the critical means to meet the travel demand of urban passengers in China. With economic development, conventional buses and trolley buses can no longer cope with the rapid increase in transport demand, and alternative ways have to be explored. As early as 1985, the State Council concluded that rapid rail transport had to be developed gradually in the large cities, and that multi-dimensional transport systems had to be created (Wang *et al*, 1997).

Rapid rail transport in China can be classified into two categories, i.e. the mass subway or metro system (large capacity) and the light rail system (medium capacity). To alleviate the ongoing trend of transport deterioration, more than 20 cities have made plans for urban rapid rail systems (Allport, 1996). Currently, only four cities (Beijing, Shanghai, Guangzhou and Tianjin) have completed some subway lines. A light rail has been under construction since 2000 in Wuhan.

The taxi is a mode that has to be mentioned in regard to Chinese cities. During the last two decades the number of taxis has been increasing at a faster pace than that of buses (Figure 3.1). This phenomenon can be explained by factors such as the increase in income, business activity demand, and the door-to-door service. The problem with too many taxis is that they transport relatively few passengers but account for a large share of road traffic.

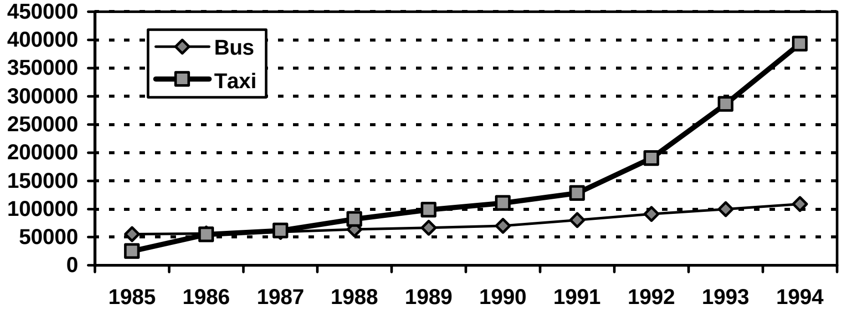


Figure 3.1 Increase in number of taxis and buses in cities of China
(source: Zhou, 1997)

Goods transport

Before the economic reform of the 1980s, goods transport dominated road traffic due to the low demand for passenger transport. Economic development brought about the expansion of goods transport, yet the proportion of goods vehicles has been reduced due to the increase in other types of vehicles. According to the statistical yearbooks of Wuhan, for example, in 1980 Wuhan had about 35,000 motor vehicles, of which 49 percent were goods vehicles; in 1998, with a total number of nearly 284,000 motor vehicles, the proportion of goods vehicles was only 20 percent (Wuhan Statistical Bureau, 1999b).

The expansion of goods transport has been accompanied by the internal restructuring of the sector since the 1980s. While state-owned transport enterprises were the only means of goods transport for several decades, these enterprises have become economically inefficient under the market economy. In the meantime, private goods transport has mushroomed and dominated the goods transport market.

3.2.3 Transport planning and management

Administration

Urban transport planning and management concerns aspects of infrastructure planning and construction, traffic management, safety, public transport and license registration. The administrative system for planning and management in Chinese cities has been set up according to these operational functions (Figure 3.2). Administrative agencies exist at three levels of government, i.e. central, provincial and municipal.

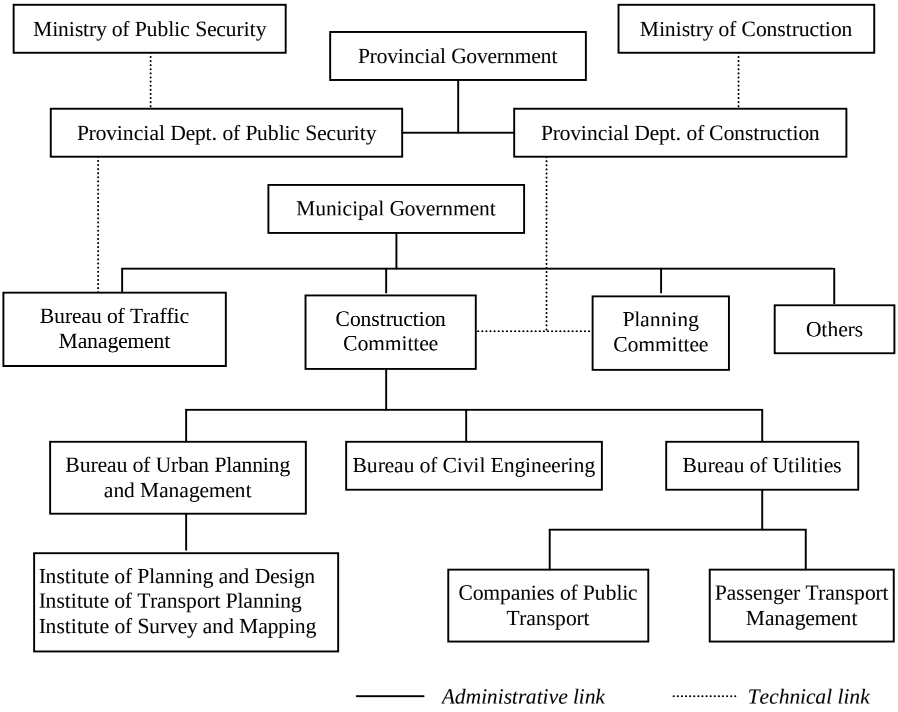


Figure 3.2 Urban transport administrative structure in China
(based on Wu *et al*, 1997)

These agencies are streamlined into two groups, i.e. the urban construction group and the public security group. In addition, other governmental agencies, such as the Financial Department and Planning Committee, also play a role in urban transport in terms of taxes, price policies, examining and approving large construction projects, and so on. Details of these institutions will be examined later with respect to Wuhan.

The transport planning framework

The Urban Planning Act became effective in 1990. According to the Act, urban transport planning is one of the components of master planning. However, the planning of transport systems places emphasis only on road networks and the location of transport facilities, and therefore represents only a part of the general meaning of transport planning (Li & Yu, 1997). This situation has improved as experiences from overseas have been acquired. Lam and Huang (1992) observed that, by absorbing successful experiences from more advanced countries, China had tried to make more effective transport planning and traffic management interventions. Techniques adopted for this purpose include land use and transport planning, travel demand forecasting, signalised junction design, and area traffic control systems.

It has been argued that transport planning should have hierarchies and time limits. Yang (1989) proposed three types of transport planning in terms of content and time range. Table 3.4 shows the three levels of transport planning, their ranges, and the corresponding stages of urban planning. In general, comprehensive transport planning involves a similar process to that presented in Figure 2.1, including stages of data collection, diagnosis, analysis and forecasting, scenario generation, evaluation, system planning and designing (Li & Yu, 1997).

Table 3.4 Transport planning and urban planning

Level of transport planning	Range (years)	Level of urban planning
Strategic transport planning	Far (20-30)	Master planning
Comprehensive transport and road networks planning	Long (10-15)	Zoning / control planning
Detailed improvement programme	Short (0-5)	Design / detailed planning

Comprehensive transport planning efforts have been made in some of the large cities (e.g. Chen, 1990; Chen, 1993; Pan *et al*, 1995; Li & Yu, 1997). Among these cities, Shanghai has played a leading role in transport research. In 1985, Shanghai initiated comprehensive transport planning (SICUTP, 1994). Five years later, the Institute of Comprehensive Urban Transport Planning was set up. This institute is responsible for mid- and long-term transport planning, for predicting future transport development, and for providing research results to policy makers. Transport strategies that have been identified as important to

Chinese cities include linking land use and transport development, improving road system and capacity, giving priority to public transport, controlling vehicle increase and use, and improving traffic management (*http://www.scctpi.gov.cn/*).

One of the major problems in transport planning has been data collection. By 1995, about 40 cities in China had conducted large-scale comprehensive passenger transport surveys (Wang, 1997). Such surveys usually require a large budget as well as close cooperation among various municipal departments. The advantages of these surveys have not been fully exploited owing to several limitations. Firstly, the lack of standard forms and definitions for transport surveys makes the comparison of cities difficult or impossible. Secondly, in many cases, comprehensive database systems have not been constructed for the surveys, which results in an inefficient utilisation of the data generated. Many data were lost after the research projects had finished, leaving nothing for the next planning effort or other uses. Also, there is a lack of standards for database structures. Finally, in addition to the data problem itself, there has been a shortage of qualified professionals to make full use of the findings of the surveys.

3.3 Transport development in Wuhan

3.3.1 Wuhan

Richly endowed by nature, Wuhan has been an important hub connecting the north and south, and the east and west of China for more than 400 years (Figure 3.3a). The Yangtze River, the third longest river in the world, which converges with the Han River in the city, has served as a thoroughfare from the east to the west in historical and modern ages. Railways and state highways have made the city a busy place for passenger and goods transfer, which also contributes much to the local traffic problems.

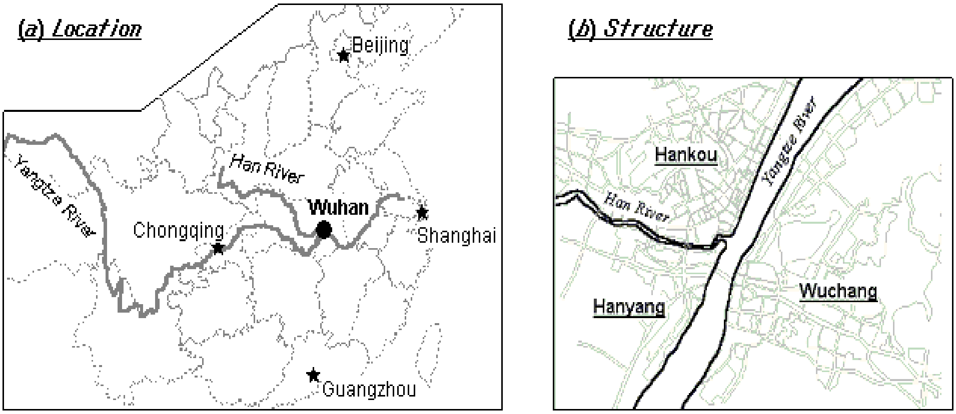
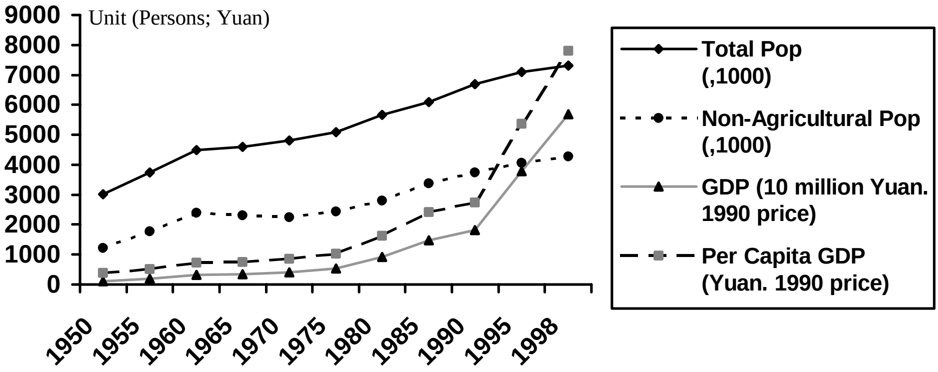


Figure 3.3 Location of Wuhan in China and its structure

The two rivers divide the city into three parts, generally known as the "three towns", i.e. Hankou, Wuchang and Hangyang (Figure 3.3b). Hankou is historically one of the "four well-known towns in China", and is now attracting a lot of commercial activities. The Hubei provincial government and many academic institutions reside in Wuchang. These three "towns" form the "core" of the city, with seven urban districts. Wuhan is administratively larger, with another five rural districts, in total covering more than 8,400 km^2. Restricted by many lakes and flood-prone areas, the city could not expand evenly in all directions. The built-up area in 1998 was 204 km^2 (Wuhan Statistical Bureau, 1999a).

Population in Wuhan has been increasing steadily. In 1998 the total population reached 7.32 million, with 4.28 million of non-agricultural population (Figure 3.4). Economic growth before 1980 was slow. In the early 1980s, the "open door" policy was introduced and the economic structure reform took place. Since 1990, the economy has been soaring.



(Note: the values are adjusted to have the same scale on the Y-axis – see the legend)

Figure 3.4 Changing population and GDP of Wuhan since 1950
(source: Wuhan Statistical Bureau, 1999b)

3.3.2 Transport development

In Wuhan, the physical structure as presented in Figure 3.3b indicates that the two rivers form a bottleneck for urban traffic. During the last two decades, enormous efforts have been made on restructuring and widening existing streets. Road density has changed little, from 6.10 km/km^2 in 1987 to 6.46 km/km^2 in 1997 (Wuhan Statistical Bureau, 1999b). Pressures on the Wuhan transport system have been caused by rapidly increasing travel and freight demands as a result of the economic boom since the 1980s, as well as by a failure to respond to these demands.

The increases in the number of motor vehicles may explain the challenges facing Wuhan. During the last two decades, the total number of vehicles has grown fourfold, i.e. from

35,000 in 1980 to 284,000 in 1998 (Wuhan Statistical Bureau, 1999b). While buses and trolley buses have been expanding gradually, taxis have grown dramatically from almost nothing in 1980 to 12,290 in 1998 (Figure 3.5). Surprisingly, the expansion of public transport in terms of the number of vehicles has not always been accompanied by an increase in passenger trips. Apart from the two exceptional years of 1991 and 1994, the general trend in passenger volume from 1988 to 1998 has been a steady decline (Figure 3.6). Many travellers have shifted to such modes as private cars, company coaches, informal transport, walking and bicycling.

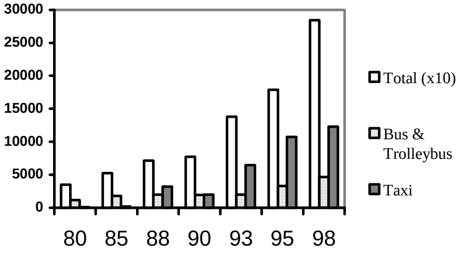


Figure 3.5 Increases in motor vehicles

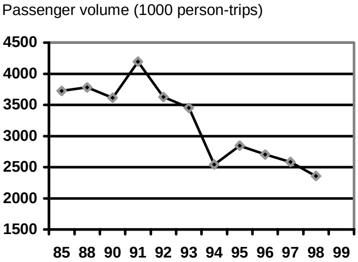


Figure 3.6 Public transport service

To ease the traffic pressure in the central built-up area, a comprehensive highway network has been proposed by the Institute of Urban Planning and Design (IUPD). The plan takes advantage of the national motorway scheme in which Wuhan is considered as a junction for distributing transport between the north-south (Beijing-Guangzhou/Zhuhai) and east-west (Shanghai-Chengdu/Chongqing) transport lines. As depicted in Figure 3.7, the two lines meet in the southwestern part of the region. A ring-road system has been proposed for making the connections. This will require two more bridges and two tunnels across the rivers. According to the IUPD, the four rings will have the following functionalities respectively:

- First inner ring: business, shopping and historical
- Second inner ring: 54 km, residential
- Third inner ring: 88 km, connecting economic development zones and bypass, and collecting traffic into the city
- Outer ring: 188 km, regional traffic bypass

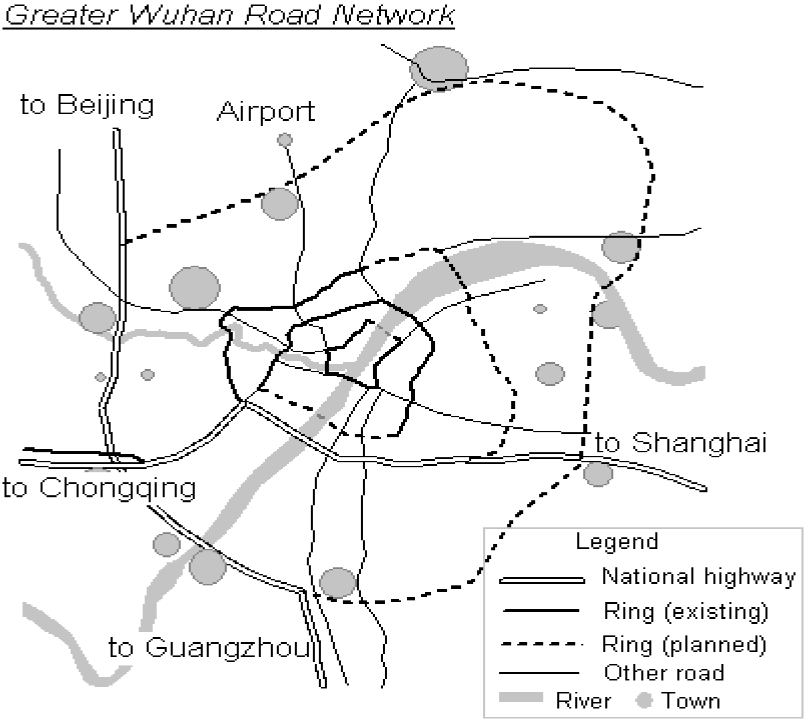


Figure 3.7 The planned road network of Wuhan

3.4 Institutional context for transport planning and management in Wuhan

3.4.1 An overview of institutional structure in Wuhan

Several groups of transport agencies play important roles in shaping urban transport in Wuhan (Figure 3.8). The municipal government administers and coordinates municipal committees and bureaus. The Construction Committee is responsible for infrastructure and the transport service. The Bureau of Public Security (BPS) is in charge of traffic management within the urban area and may provide data on social activities. The Transport Committee handles regional transport, including long-distance bus, railway, water and air transport. The Planning Committee exerts strategic influence on the transport system. The Statistical Bureau provides information necessary for planning and decision making.

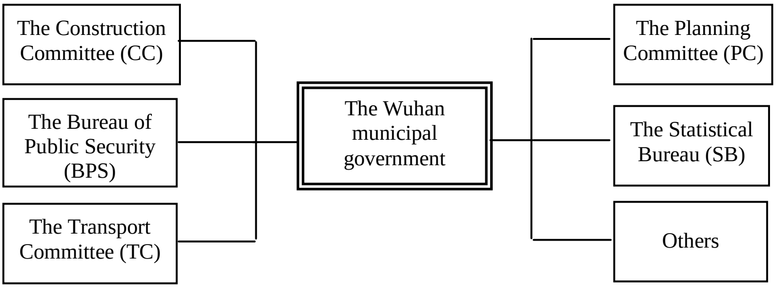


Figure 3.8 Groups shaping the urban transport system of Wuhan

3.4.2 Missions of transport institutions

The Construction Committee (CC)

Under the Chinese municipal system, all physical developments are directed and coordinated by the Construction Committee (CC). The Construction Committee of Wuhan is responsible for making strategic policies relating to urban expansion and for coordinating the work of its bureau. The major agencies within the committee are shown in Figure 3.9. The committee is technically directed by the provincial Department of Construction, above which is the Ministry of Construction in the central government (Figure 3.2).

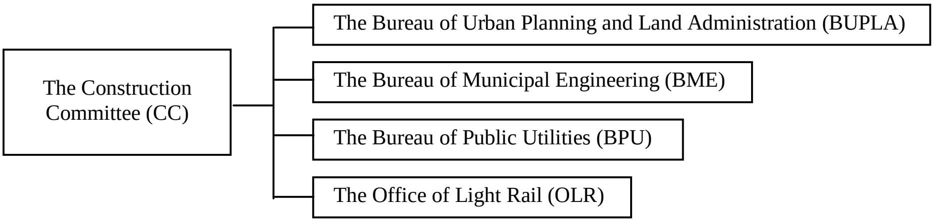


Figure 3.9 Agencies under the Construction Committee, Wuhan

The Bureau of Urban Planning and Land Administration (BUPLA) controls the physical development of the city, from the strategic to the operational levels and by administering land use changes and land registration. Apart from the management of physical development, the BUPLA has several technical institutes and an information centre that serve the purposes of data collection, data management, planning and design. A functional description of these technical units is listed in Table 3.5.

Table 3.5 Technical units under BUPLA and their functions

Unit	Functions
Institute of Urban Transport Planning (IUTP)	Comprehensive transport survey Strategic transport planning Road network planning Local transport improvement Road design
Information Centre (IC)	Management system for construction application Database development System development and maintenance
Institute of Urban Planning and Design (IUPD)	Master planning District planning Detailed planning / urban designing
Institute of Survey and Design (ISD)	Urban map surveying Urban remote sensing Engineering surveying

The Institute of Urban Transport Planning (IUTP) was founded in 1993 in response to the growing mobility since the 1980s. Traditionally urban road and transport facilities were regarded as "non-productive" and the municipality failed to react effectively to the requirements of transport. Since its foundation, the IUTP has been in a difficult situation. It has inadequate finance for developing travel and freight demand models, and has evolved like a consulting unit working on a less strategic level. In 1998 a comprehensive transport survey was carried out. Coordinated by the municipal government, the project involved agencies from public security, public utilities, traffic management, research institutes and universities. The survey covered a wide range of aspects needed for transport research, including:

- Resident trip survey
- Vehicle trip survey
- Vehicle trips to and from Wuhan
- Vehicle parking survey
- Traffic flow survey
- Traffic attraction point survey
- Public transport survey
- Outward traffic survey (passenger and freight flows)
- Socio-economic, land use and employment survey

Actually, prior to the foundation of the IUTP, similar transport surveys were carried out in 1982 and 1986. Due to changes in social, economic and political circumstances, parts of the survey (particularly the resident trip survey) in 1998 could not be carried out as effectively as in the two previous surveys.

The Institute of Urban Planning and Design (IUPD) is a technical agency that has information on the outcomes from various levels of planning, as well as some city design products. During the planning process, the institute collects data on urban land use, population, economy, geology, history, landscape and so on. The results are presented on the basis of the following three levels:

- Strategic master planning products (blueprints, reports), which are made or revised every 5 to 20 years. The major road network plan is one of the blueprints.
- District plans that designate land use, plot ratio, population density and so on. The boundaries and engineering parameters of main and secondary roads are identified, as well as crossroads, parking places and squares.
- Detailed planning blueprints which serve as engineering guidance for land (re-) development. Access roads are included in the drawings.

The Institute of Survey and Design (ISD) carries out surveying (including remote sensing) and exploration of engineering geology. It keeps geographically precise data, including topographical maps at different scales, land uses, road networks, aerial photographs and images.

The Information Centre of the BUPLA is formally responsible for maintaining the digital version of all data available at the bureau. As these data have different scales and formats, and are stored on different media, much work is needed to integrate them into an effective integrated information system.

The Bureau of Municipal Engineering (BME) makes and implements plans for road construction and road improvements. Information on every road segment of the city is collected and kept by the bureau, and a yearly statistical report is presented. It holds detailed records on urban road conditions, construction and maintenance. The bureau also has an institute for technical issues.

The Bureau of Public Utilities (BPU) is mainly concerned with public transport and gas supply. Policies and plans for public transport are made by its managerial office and implemented by corresponding companies. The bureau administers the Bus Company, the Trolley Bus Company, the Taxi Company, the Ferry Company and a research institute.

The Office of Light Rail (OLR) is a new agency specifically set up for the planning and management of light rail in Wuhan. Recent years have seen the initiation of mass public passenger transport. The OLR is responsible for initiating, coordinating and managing projects related to light rail development programmes.

The Bureau of Public Security (BPS)

The Bureau of Public Security (BPS) administers traffic operations, domicile registration, social security, passports and fire prevention. The first two functions are related to urban transport. The Bureau of Traffic Management (BTM) is functionally independent and administratively supervised by the BPS. The BTM is responsible for traffic development policies, traffic rules and regulations, motor vehicle registration, designing and implementing traffic signs, traffic operation control, driving licences, as well as monitoring and recording traffic flows.

The major objective of the BTM is to provide a safe and efficient traffic environment for travellers. Although it is a big organisation, it still lacks staff resources to respond to traffic incidents. This is due partly to the inefficient traffic control mechanism, and partly to the negative behaviour of travellers and drivers. It has been felt that advanced technologies have to be applied to improve management efficiency, and the BTM has already initiated a traffic management information system project.

The Section of Domicile Administration (SDA) of the BPS is responsible for registering urban residents and allocating street addresses. The Chinese domicile registration system is very strict and contains detailed data about individuals, households and work units. This information is quite useful for trip surveys and address geo-coding. The agency structure of the SDA follows the administrative structure down to the lowest unit – the residents committee. An enormous team (about 18,000 staff) works on the household registration and population statistics. Many social investigations are the responsibility of this team, such as the national census and the comprehensive transport survey. In addition to household registration, the section is also entitled to assign street numbers to spatial entities, i.e. houses legally owned by households and pieces of land used by work units. Due to these huge efforts, the domicile records represent the most complete and accessible social data among those of governmental agencies. However, the section has not yet employed a geographical system to geo-reference the registration data. Also, it is very difficult to update registration data in areas with fast development or areas with large amounts of floating population.

The Transport Committee (TC)

The Transport Committee (TC) deals with all modes of transport, post and telecommunications. The committee can be viewed as the counterpart of the Construction Committee (CC) in that the TC manages outward transport while the CC confines its extent to built-up districts. Thus the TC is regionally oriented. In the Chinese urban planning system, there are two types of transport: city transport and outward transport. Facilities such as railway stations, centres for regional passenger and goods transport, harbours and airports are classified as outward transport. Apart from these outward transport facilities, the TC also administrates road and water transport in the rural areas of Wuhan, which indicates a functional overlap with both the CC and the BTM. The TC maintains a traffic police team to ensure the control of transport operations. With regard to road transport, the TC is responsible for policies and regulations for regional transport, regional transport planning, administering outward transport within the city, administering road and water transport in rural districts, initiating and supervising road and transport facility projects, and administering toll roads and toll bridges.

Other agencies

The Planning Committee (PC) is a powerful agency within the planned economy of China. Its major role has been to make strategic plans for social, economic and infrastructural development, and to allocate financial resources to different sectors of the government. The strategic plans have been made in accordance with the series of national five-year plans. In recent years the main focus has been the 10th five-year plan, covering the period 2001 to 2005 (*http://www.whjw.gov.cn/*). The introduction of the market economy in the mid-1980s, triggered a decentralisation process that has somewhat weakened the role of the PC, particularly in the economic sectors. In spite of this shift, the committee continues to be the key agency for strategic urban development. Its function has not changed much. The work of the PC includes making strategic plans for land development and conservation, initiating large construction projects, and making five-year plans for social, economic and physical development.

The Statistical Bureau (SB) is the major source of information on the status and development of the population, economy, built environment and science. Information is collected periodically from organisations such as the Bureau of Public Security, the Bureau of Municipal Engineering, enterprises and commerce. In Chinese statistical terms, urban transport means the regional transport, i.e. the carrying of passengers and goods to and from the city, as well as the facilities used for this purpose. no information on travel demand or travel choice is collected routinely in the statistical system. The geographical basis for socio-economic statistics is the administrative hierarchy, including the municipality, the districts, the streets and the residents committee. In transport research, the Transport Analysis Zones (TAZs) are generally delineated along the boundaries of these units, which ensures cross-referencing between TAZs and statistical units.

Some other governmental institutions are also important to urban transport planning. For example, the Bureau of Commodity Price regulates the ticket prices for public transport, the Environment Protection Bureau keeps regular records on noise and emissions from motor vehicles, and the Commerce Committee holds data on large-scale commercial activity sites that attract a large amount of traffic flow. Besides the municipal government, the provincial government is also located inside the city and has some influence on strategic transport development.

3.4.3 Relationships among transport institutions

All institutions discussed above contribute to the development of the transport system in Wuhan. Several factors characterise the existing practice in these transport-related agencies.

Firstly, these institutions are independent in terms of mission and goal. For a transport system to operate properly, the administrative structure has to identify clearly the functional scope of each unit. In Wuhan, municipal institutions are respectively responsible for transport planning, traffic management, regional transport, transport infrastructure and transport facilities. Each sector has its own set of rules, regulations and laws as the basis for administration. Figure 3.10 shows the major business of each transport agency and their relationships. Based on the degree of influence on the urban transport system, the agencies can be divided into two general groups, i.e. those having direct impact, and those having less immediate impact. Institutions under the Bureau of Public Security (BTM) and the Construction Committee (BUPLA, BPU and BME) have direct and immediate impact on the transport system. They have close relationships and more frequently cooperate in terms of urban transport planning and management.

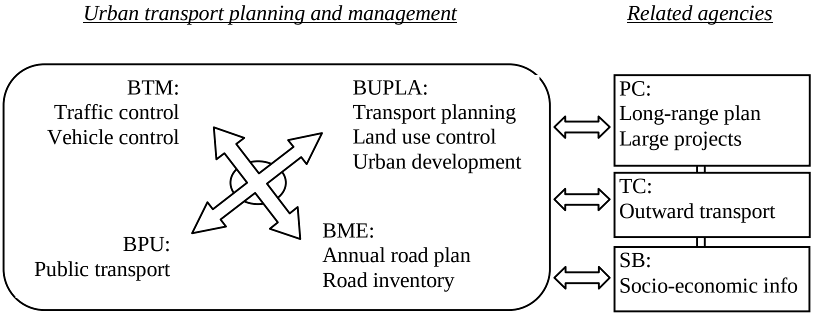


Figure 3.10 Institutional relationships on transport

Secondly, inter-institutional cooperation exists. On many occasions the organisations have to rely on one another in finding solutions to transport planning and management problems. For example, the comprehensive transport survey initiated by the Institute of Urban Transport Planning (IUTP) cannot be carried out without the assistance of the Bureau of Traffic Management (BTM), the Bureau of Public Security (BPS) and the Bureau of Municipal Engineering (BME). Also, traffic management schemes proposed by the BTM necessitate concerted efforts – by the BME as regards road administration, by the BPU as regards public transport administration, and by others. For purposes of transport planning and system performance evaluation, data from different agencies have to be integrated in such a way as to be referenced by common transport spatial entities (e.g. road, TAZ).

Wang *et al* (1999) have illustrated the items of travel demand forecast in Chinese cities, in which passenger travel is composed of resident travel, floating population travel, and outward or through passenger travel. By considering the general data requirements of passenger travel demand models, as well as the institutional structure of Wuhan, a data flow diagram can be made showing the possible contributions that various agencies could make (Figure 3.11). Basically the figure consists of three columns. The left column shows some procedures for travel modelling, the central column is a set of classified data necessary for the modelling process, and the right column indicates those agencies of Wuhan that may contribute to the data requirements. The arrows between the columns suggest which kinds of data are needed for the modelling purpose and which agencies may possibly provide these data. This diagram demonstrates both the importance of and the possibilities for data sharing and integration among these agencies.

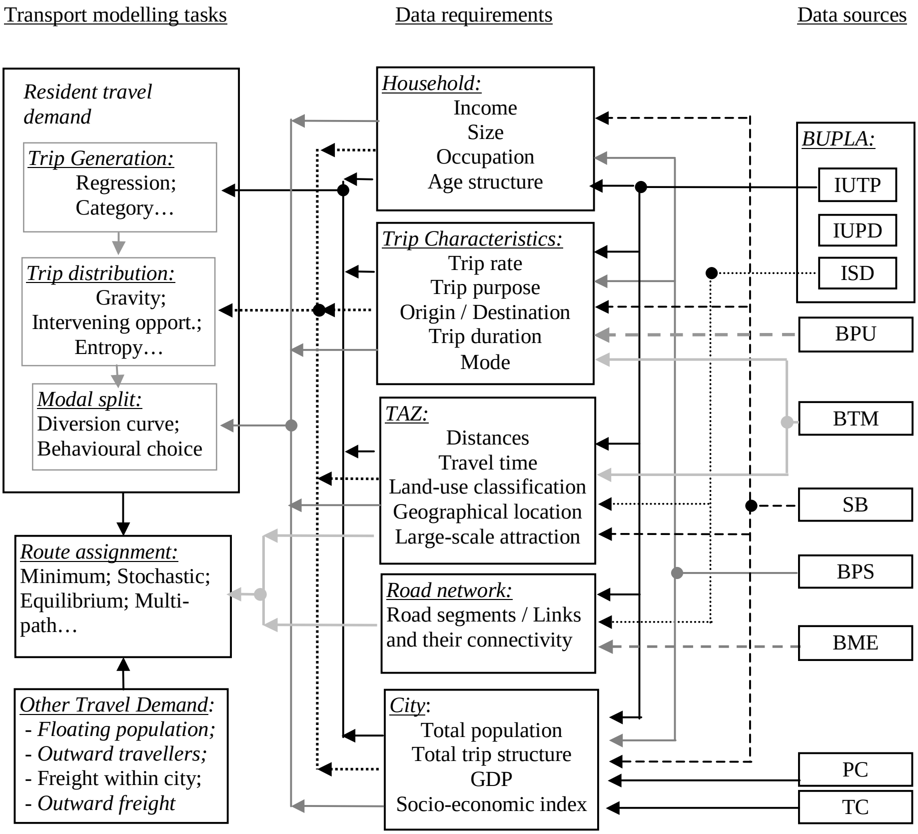


Figure 3.11 Institutional contributions to resident travel modelling

The third factor relates to the functional overlaps, conflicts and gaps among these institutions. One example of an overlap comes from road administration, which is to ensure the proper usage of road space. Both the BME and the BTM are responsible for curbing the violations of road usage, which may cause either avoidance (gaps) or duplicated pressure (conflicts) if there is no coordination. Although this factor is not a major problem area in institutional relationships, careful consideration is necessary.

Another example is the functional overlaps in strategic transport infrastructure planning. Firstly, the PC in Wuhan may launch transport consulting projects for the long term or for the five-year plan for socio-economic development. Project outcomes also serve as a basis for allocating financial investment during the relevant years. Secondly, the BUPLA has to include transport planning as an important aspect in its master planning. The IUPD under the BUPLA is responsible for the master planning, while the IUTP can hardly find a place in the process. Planning efforts by the PC and UPLA consider transport development inside and outside the built-up area. On the other hand, the TC is largely concerned with outward and regional transport planning. Overlaps happen especially in the fringe areas of the city.

Due to the above situation, negotiation is necessary among the agencies. Generally there are three types of coordination: involving upper agencies, involving the municipal government, and arising from joint projects. As each agency belongs to a hierarchy, from the national and the provincial down to the municipal level, many notifications, rules and regulations are jointly issued by the upper agencies. The joint guidance from the upper agencies also requires a united effort from municipal agencies, which is normally accomplished under the supervision of the municipal government. In most cases, a comprehensive improvement in urban road transport, e.g. the 1998 comprehensive transport survey, has also to be coordinated by local government. Apart from the two levels of coordination, some agencies also develop joint projects on road planning and traffic management. According to the Ordinance of Urban Road Administration, an urban road development plan should be formulated together by the departments of municipal engineering, urban planning and traffic management, under the supervision of the municipality (Ministry of Construction, 1997). The process of cooperation among the municipal agencies requires the sharing of, among other things, information.

3.5 Evaluation

At the Chinese national level there are no recommended general transport planning methods and models. Techniques of travel forecasting and planning evaluation have to be developed or adapted to fit the specific situation. One of the challenges for such techniques is the lack of integrated data. Although many cities have carried out comprehensive transport surveys, the exploitation of the survey results has been inadequate and slow. Also, the institutional study in Wuhan indicates that data for transport planning are spread over many transport-related agencies, and that these institutional data sets are not yet fully utilised. An important reason for this phenomenon is the lack of a data sharing framework among transport institutions, as well as the shortage of techniques for data processing and data integration.

An early investigation of urban transport management in 12 developed cities showed that the institutional context was an important factor in the successful formulation and implementation of transport policies (OECD, 1979). It was observed that the fragmentation of authority complicated and hindered the coordination of planning and implementation, that the consolidation of the authorities might achieve more efficient management, and that ad hoc coordination existed in the absence of any formal procedures. Compared with these findings, the investigation in this research shows a similar institutional context between Wuhan and Western cities in the 1970s, which implies ample space for improving the institutional relationships. To improve the situation, the diffusion of technology to the organisations is a necessary step (Ottens, 1993; Masser & Craglia, 1996). Another important aspect is the development of a data sharing policy among governmental agencies.

Obstacles to information sharing exist in every cultural context. For example, research on British local government has shown that only half of these organisations are in favour of cooperative information sharing (Masser & Campbell, 1995). Institutional aspects are regarded as the most difficult factor in data sharing among governmental agencies, which is especially true in the Third World (Batty, 1992). In Wuhan (and other cities in China), transport-related agencies have been separated and supervised by different provincial and national sectors, which encourages data exchange vertically rather than horizontally. Although the situation has been much improved by the widespread use of information technology, information exchanges among municipal units remain difficult. Given this institutional context, a point has to be found to balance the benefits to the agencies and the requirements of information technology, which, as Alfelor (1995) has pointed out, is a challenge to make every one better off as a result of adjustment brought about by information sharing.

The discussion of institutional missions in Wuhan helps to identify data needs or data availability within organisations. Assessment of institutional data needs may make use of methodologies from information science. Early information systems design methodologies concentrated either on data analysis or on process analysis, or on a combination of the two (Olle, 1982). The methodologies evolved into a system approach called information engineering, which involves an integrated and evolving set of tasks and techniques for business planning, data modelling, process modelling, systems design and systems implementation (Finkelstein, 1989; Martin, 1990). Using information engineering models, the data needs of an organisation may be acquired by identifying its mission, goals and objectives (Reeve & Petch, 1999). In this regard, the detailed description of institutional structure and missions in this chapter provides a starting point for further institutional data assessment.

The distinct characteristics of Wuhan, as well as other cities in China, must be taken into account when compared with the rest of the world, especially with the Western cities. These characteristics, as presented in this chapter, include a less organised urban structure, huge population size, high-density, mixed land uses, heavy dependence on the bicycle and public transport, and limited use of information technology for transport planning and management, as well as a mismatch between fast-growing travel demand and inadequate transport supply. These features provide a local context that has reference to the search for general methodologies for urban transport data integration.

Wuhan municipality implemented an institutional reform in the year 2001, which indicates a change in the organisational structure introduced in this chapter. As the fieldwork had already been carried out in 2000, there was no chance to get back to Wuhan and discover the details of this restructuring. However, it looks as though the fundamental functionalities for transport planning, construction, and operations management will not change as a result of the institutional reform. Rather, restructuring will most probably remove some of the old institutional barriers and achieve higher efficiency. Therefore, the underlying missions of transport agencies discussed here still give a good indication of the context for transport data sharing and integration in Wuhan.

3.6 Conclusions

To cope with the enormous increase in travel demand, urban transport planning in China is in the process of seeking appropriate technologies for evaluation and decision making. As demonstrated in the last chapter, manipulating a sustainable transport system involves huge amounts of data from a variety of sources. Without exception, transport planners in Chinese cities have also to face this data challenge.

The detailed investigation in Wuhan indicates that an entire institutional structure exists and that generally transport organisations are implementing their duties efficiently within their own administrative scope. To achieve greater efficiency, most organisations are attempting to build their own information systems. Given the complexity of the urban transport system, there is a growing awareness among these organisations of the importance of cooperation, which includes the exchange and sharing of institutional data.

While the functional categorisation of transport data contributes to studies of data integration from an institutional perspective, using information science techniques to classify these data may benefit the studies from a technical perspective. A major obstacle in the acquisition and sharing of transport data is the incongruence among different data sets. Integrating these data presents a series of technical barriers that have to be overcome during the building of an applicable transport information system. Breaking these barriers requires agreed standards for data representation as well as methodologies for linking and merging these data. The coming chapters will address the major methodological issues of transport data integration in the sequence presented in Table 2.9.

Chapter 4 Discrete Site Location Referencing [*]

4.1 Introduction

Transport planning is concerned with supply and demand analysis in a spatial context. Transport demand models require data not only on the types of socio-economic activities but also on the places or sites where these activities happen. Depending on the types and levels of transport models, the spatial locations of the activities are expressed in different resolutions. While traditional zone-based models require only aggregated attributes of activities in transport analysis zones (TAZs), the more advocated disaggregate models rely heavily on precisely located activities. In both cases the spatial locations serve as a key to integrating activity attributes with the transport model network.

Location referencing in this context of transport planning refers to the identification of spatial locations of socio-economic activities. Many location referencing methods have been developed and implemented in different fields. The TIGER/line files developed by the Census Bureau of the United States contain line, landmark and polygon features that provide location references for field staff and map users (Bureau of the Census, 1997). In urban areas the street address has been widely applied for address matching. The postcode system of the postal service is another important referencing base that has been utilised for location referencing in travel and activity surveys. From a geographical point of view, postcodes are becoming a widely used and a general method of describing the position or location of places, areas or objects on the Earth (Raper *et al*, 1992). A postcode may be designed to indicate a very small area or even an individual property, for example the Postal Address File (PAF) in the UK and the ZIP+4 in the United States. At a detailed level, postcodes and street addresses are linked with the properties they represent, which can provide a more flexible means of location referencing.

For most Western cities, although there are still some uncertainties in location referencing, referencing systems such as street address and postcode have been set up in a comprehensive way with relatively complete data. These systems can generally satisfy the needs of transport data processing. In most developing cities, however, there have been no consistent referencing frameworks, and the data in these referencing bases are incomplete. For example, postcodes in Chinese cities represent spatial areas that are too large to make any sense in location referencing. The street numbering scheme is theoretically systematic but in reality contains many errors. Moreover, even if these referencing data are available, the techniques of location referencing have to be adapted to meet local requirements. The

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[*] Based on Huang, Masser (2001; 2002c).

address expression in China is very different from the Western style and this frustrates the direct application of the address matching process that is readily available in most GIS packages.

This chapter discusses these problems and proposes solutions within the context of China. The importance of location referencing in transport planning is emphasised. Existing referencing methods that are possibly useful for transport data processes are explored with two schemes, i.e. the road-based scheme and the name-based scheme. An experimental implementation of these methods is presented based on data from Wuhan.

4.2 Location as a key factor in transport data integration

4.2.1 The context for location

According to Merriam-Webster's Collegiate Dictionary, a location is "a position or site occupied or available for occupancy or marked by some distinguishing feature". Two implications can be derived from this definition: one is that locations occupy space and therefore are spatial, the other is that locations are places associated with either human activities or natural phenomena, or with both. In geographical science, a location is a position on the Earth's surface or in geographical space definable by coordinates or some other referencing system, such as a street address or space indexing system (Clarke, 1999).

Human activities take place in space within which the relevant locations can be precisely identified by techniques of spatial surveying or observation. In urban areas, activities such as residing and working are linked with their address locations, which are referenced by street networks with address information. Activity locations are important data sources for locational optimising or simulation models. When all activities of the same type or different types are located in a spatial context, the spatial distribution patterns can be revealed. The patterns are useful for generating valuable information in spatial analysis. For example, the locations of bus stops can be utilised to evaluate the service quality of a city's public transport by combining them with land use and population data.

Another important factor is that each activity also happens at a certain point or period in time. By linking them with spatial locations, the spatio-temporal patterns of activities are available. For example, the traffic volume along a street or a motorway may change dramatically during a day, a week or a season. Also, the real time location of a bus is needed to provide passengers with estimated arrival times at a bus stop. In transport modelling such as travel demand forecasting, spatial and temporal aspects cannot be separated. Shaw and Wang (2000) have presented a framework from which disaggregate travel data can be retrieved by spatial and temporal criteria.

4.2.2 Location in travel demand forecasting

Travel demand forecasting is basically a modelling process that provides information for transport planning and dynamic traffic management. The spatial aspect of the process concerns the locations of origins and destinations, as well as routes of all kinds of movements. Identifying locations of trip ends or activities is the first step in data preparation, which relies on a consistent location referencing system. McCormack (1999) makes use of an address matching process to locate about 15,000 trip ends from a travel survey database. It is concluded that the value of the travel diaries is greatly enhanced by efficiently exploring the spatial information inherent in them. Using the same referencing method, Shaw and Wang (2000) have explored a travel survey data set and successfully matched about 6,000 trip ends to the locations in the streets of the study area. Compared with the traditional zone-based location method, the GIS-based discrete geo-coding improves the accuracy of transport model data and the modelling process (GIS/Trans, 1998). Street intersections are suitable referencing units for traffic accident reporting in urban areas. Levine and Kim (1999) describe a methodology of intersection matching for locating motor vehicle crashes. The Global Positioning System (GPS) has also been increasingly applied for collecting road data, e.g. Kim *et al* (2000) demonstrate a method of geo-referencing moving images based on locations from a GPS survey.

In an aggregate modelling approach such as the four-step forecasting model, the basic spatial unit is the TAZ. Origin and destination sites are aggregated in zones. Apparently if these sites are located incorrectly they may fall into the wrong zone, which will bias trip forecasts in subsequent steps. There are serious drawbacks to geo-coding to areas rather than points (Cambridge Systems, 1996). Using GIS, point data can be aggregated to different kinds of zones when necessary. This feature requires clear positional information such as street address, cross points or directly measured coordinates when a travel survey is carried out. A GIS-based geo-coding process is an optimal automatic method for locating trip ends. Yet depending on the availability of reference bases, the situation may be quite different from city to city. In Wuhan, for example, the residential trip surveys have been implemented manually and the locations of activities have been assigned the codes of TAZs directly during survey. This method simplifies the process of geo-coding at the expense of lowering the reliability of surveyed locations. Moreover, often the zone-based data set is not very suitable for other applications. Sometimes transport planners have to change the delineation of TAZs, and the former data set has to be abandoned if a point-based geo-coding is not possible.

The activity-based travel demand forecasting models are based on disaggregate data in which activity sites are identified, together with other data on activities. The smallest unit in this case is the point of location instead of the zone. Apart from sophisticated modelling approaches that might be utilised in the demand forecast, the preliminary aim is to identify locations of activities and to assign optimal routes to link these locations.

4.2.3 Location in traffic management

Identifying the locations of vehicles is valuable for traffic management and traffic information services. Two types of technology are applicable in this field, one is monitor-based and the other is navigation-based. The monitor-based method is to fix vehicle detectors at a stationary site to record passing vehicles. These detecting locations serve as keys to traffic data integration at any time intervals. The navigation-based method is to mount signal receivers on vehicles so that the location of the vehicles can be identified continuously. The trajectory of individual vehicles can be traced for navigation and other online information services. Both methods are applied in the field of Intelligent Transport Systems (ITS).

A preliminary solution for monitoring traffic conditions is to install detectors at important fixed sites. Detectors mounted along major roads and motorways can provide traffic flow and volume data. Information from these sensors at different locations is kept in a traffic management centre, where a panoramic picture of traffic flow in the city can be seen. This traffic flow information is an important data source for urban transport forecasting and evaluation. To implement certain transport policies, vehicle detection is a significant factor. For example, the electric road pricing system in Singapore defines a restricted zone, and vehicle detectors are installed at the points where streets cross the zone (Foo, 2000). These detectors collect data of vehicles passing by, and provide information relevant for demand management. Another example is the detection of bus locations in order to predict the arrival time at subsequent stops. To provide accurate information on arrival and departure times of buses, the first step is to continuously track and monitor vehicles and their performance. Nielsen (2001) described an Automatic Vehicle Location (AVL) system in Denmark that supports traffic flow control, passenger information provision, as well as dynamic fleet management at bus terminals. The ultimate purpose of such a system is to improve public transport services so that car traffic can be reduced.

While the monitor-based solution acquires vehicle and traffic data at stationary sites, the navigation-based method allows each individual vehicle to record its own spatial location in real time with or without interaction with a control centre. A prominent example is the use of GPS for vehicle navigation. GPS can provide real time coordinates, so the locations of vehicles can be identified at any time and recorded in spatial databases. As a highly dynamic tool, GPS has been applied in various aspects of transport research. The collection of road line data has been proposed and used. Integrated with GIS, GPS may be used to study travel time along road networks (Quiroga & Bullock, 1998). GPS is also increasingly applied in travellers' activity surveys, in which the locations of activities are recorded automatically and linked with other details of the activities. Perhaps the most promising implementation of GPS is the real time vehicle navigation in the field of ITS, including car navigation systems, emergency and rescue services, incident response and so on. This implementation, also referred to as transport telematics, is closely related to technologies of telecommunication and GIS (Xu, 2000). An even wider application concept, Location-Based Services (LBS), has been promoted to provide all kinds of information for ordinary users through such devices as mobile phones. However, the full potential of LBS will not be disclosed before an accurate location determination technology is in place (Beinat, 2001).

4.2.4 Location as an integrator: location referencing

Transport data can be categorised into demand, supply, performance and impact data. The key point in understanding transport data and their relationships is that these data are spatial or spatially referenced. A common spatial base brings these data together. Based on analyses of different groups on using location-referenced data, Ries (1995) concludes that location is a suitable integrating concept for data integration using GIS, and that the different forms and scales of data have to be incorporated.

Identifying the locations of transport activities is the first step in transport research. By anchoring socio-economic activities to locations, integrated data processing becomes possible in transport analysis. With more and more spatial databases constructed using geographical information technology, a geocentric approach has been the favourite of transport planners.

Location referencing is a process of identifying the spatial locations of activities within a predefined referencing base (Figure 4.1). The process is generally referred to as geo-referencing or geo-coding (e.g. Martin, 1999b). The geo-referenced approach provides a framework for information exchange and data integration. Data can be more easily incorporated as input into transport models, and the modelling results can be integrated into the original spatial database for further evaluation.

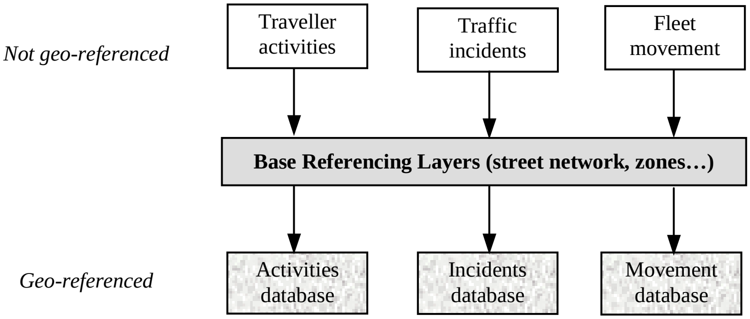

Figure 4.1 The concept of location referencing

4.3 Approaches to the treatment of location

4.3.1 General principle

The methodologies of location referencing have been discussed from different perspectives. The GIS itself is built upon a spatial referencing system for geographical phenomena. Laurini and Thompson (1992) declare that positioning objects in spatial referencing systems involves several considerations, such as the geometric character of the reference system, the measurement metrics, the nature of the origin, and discrete or continuous references. The referencing bases in GIS generally refer to either a coordinate or grid system. In surveying and mapping, professional apparatus is applied to determine positions with reference to a certain coordinate system. The GPS in particular allows positioning by directly acquiring coordinates and has great potential in transport applications (Quiroga & Bullock, 1998).

Goodwin *et al* (1995) have summarised several location referencing methods for transport applications, i.e. link ID, linear referencing system, coordinate system, street addresses, cross-street matching, and their combinations. In transport survey or socio-economic applications, it is generally difficult to get the coordinates of the positions of respondents directly. A practical method is to identify approximate positions of activities by referencing to existing spatial bases. Street networks and postcode zones are usually applied to serve as such referencing bases. The geo-coding process makes use of semantic linkage between site descriptions and referencing bases such as street names and zone codes.

Discrete site referencing is generally carried out in a location reference system, in which the discrete activity sites are identified with reference to geo-spatial bases (Figure 4.2). Referencing entities in geo-spatial base maps are assigned identifiers, such as street names and address numbers, which serve as linkages between socio-economic activities and the base maps during a location referencing process.

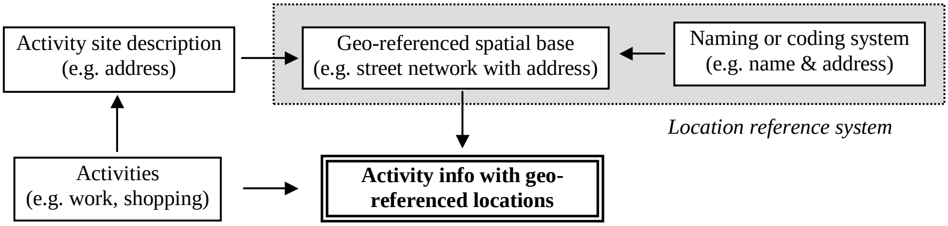

Figure 4.2 The process of location referencing

4.3.2 Three schemes of location referencing

People usually express a location in quite different ways. In a trip survey, for example, some may provide the street address as required, some may have no idea of the street number but may give their institution names, and some may only be willing to give a general description of the place where they are from. A location reference system should be able to cope with these situations and correctly find the activity sites.

Based on their spatial characteristics, existing referencing methods can be categorised into three types of location referencing schemes: the name-based scheme, the road-based scheme and the coordinate-based scheme. The name-based scheme matches candidates with referencing entities according to their semantic similarities. This process does not include graphical operations. The road-based scheme is basically a linear matching method in which the relative distance from an origin is needed to determine a location. The coordinate-based scheme surveys the coordinates of a location with reference to a coordinate system. Examples of the three schemes are:

- Name-based: building, place name, large or popular site, street intersection, street, administrative unit, telecom zone, postcode zone
- Road-based: street address, linear reference
- Coordinate-based: grid system, GPS, ground and aerial survey

Using the geo-coding function most GIS packages can generally handle the above three types of referencing schemes. For example, in ArcView, several address styles are defined, including streets, streets with zones, zip codes, single house, single value and so on.

4.3.3 Name-based location referencing

This scheme provides direct linkage between activities and base maps, using names as keywords. The referencing base is a set of geographical place points with which names are associated. Thus the geo-coding process is to match candidate names with those in referencing maps.

The name matching process can make use of a look-up table in a GIS environment (Figure 4.3). The table contains IDs of spatial objects on the one hand, and names of objects on the other. Preferably a place name is supplemented with an alias. The matching process is to search for names or aliases in the look-up table that have the same spelling as a candidate name. In the absence of correct matching, a remedial process can be started to search for possible candidates and to call for human interactions.

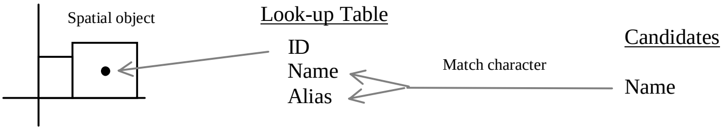

Figure 4.3 Name-based location referencing

While the semantic exactness influences name matching rate, the actual spatial area that a name represents determines the preciseness on the referencing base. Typical referencing bases that may be utilised in name matching are briefly described below.

Buildings / properties. The most accurate way of identifying locations is to designate the building in which activities happen. These buildings are available from topographical maps or cadastral maps. Yet without detailed numbering or naming records, it is also impossible to take the buildings as activity references. That is to say, semantic information has to be combined with these maps in order to fulfill the needs of location reference. The biggest problem lies in the possibility of generating and maintaining such a huge data set.

Street crossing. An intersection marks a more precise location than that of a street alone. Moreover, because of their spatial distributions, street intersections can be identified more easily than street addresses. Due to these characteristics, street intersections are important locations used in traffic management, navigation, and incident management. For example, road accidents are usually attached to or referenced by the nearest intersections (Levine & Kim, 1999).

Postcode. Postcodes are tightly associated with mail delivery. The formulation of postcodes is a systematic scheme that takes a hierarchical allocation. The ways of designating the hierarchy differ from country to country; some are only numeric digits and some may include alphabetic characters. Due to its systematic nature and frequent use, the postcode has been widely recognised by the general public. Furthermore, from a geographical point of view, postcodes are even becoming a widely used and general method of describing the position or location of places, areas or objects on the Earth (Raper *et al*, 1992).

Place names. From a geographical point of view, a conventional place represents an area that may relate to a legend or an event in history. In a survey on trips or activities, respondents may well report conventional names as their activity sites. One of the characteristics of places is that their areas may vary dramatically and they do not have clear boundaries. Another feature of places is that their spatial relationships are quite complex. A city itself is a place composed of many smaller places. It would be a good solution to categorise places in a city into different hierarchical groups according to their spatial extent. Although the spatial preciseness of place reference is not very high, the collection of these data is not demanding. This means the reference base can be set up with relatively less input but can still satisfy the needs of some applications.

4.3.4 Road-based location referencing

The road-based scheme includes street address matching and other linear referencing methods. The scheme is applied to road networks to locate traffic events and road conditions, based on a set of referencing points and distances to these points. The main feature of this location reference is that the process includes linear interpolation to identify a location along a road.

Street address matching. The street address has been the most popular and important means of locating socio-economic activities in space in well-developed cities (Figure 4.4). Due to the structured standard, the address matching function has been incorporated in GIS. The ends of each street segment are assigned address numbers so that a number range is specified for the segment. The process of address matching is a linear interpolation in which the place of an intermediate number is identified by its position with respect to the numbers at the two ends. As a major component of geo-coding in GIS, street address matching has been utilised in all kinds of applications that require locating activity sites. In transport research, it is important to identify the locations of residence, employment and other activities. Travel surveys usually require recording the street address of each activity or trip, which are geo-referenced in data processing. These activity locations, displayed together on screen, may reveal the spatial pattern of certain activities (GIS/Trans, 1998).

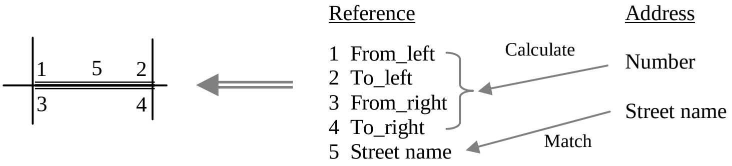

Figure 4.4 Street address matching

The address matching process, by its very nature of linear interpolation, cannot tell the accurate locations of addresses. If the addresses on a street segment are not distributed evenly, the address matching results will be different from the reality. The quality of the database with street names and street numbers has direct influence on the quality of the address matching process. Also, the correctness of an address to be matched will determine the precision of its geo-coded location. Normally the address matching processes are programmed to allow a certain degree of vagueness in expression and to give a level of confidence. In Western urban applications, the ordinary matching rates of street addresses are very high because of accurate base maps with street addresses (e.g. McCormack, 1999; Shaw & Wang, 2000). The rate of correct matches depends mainly on the completeness of address information.

Linear referencing. Linear referencing methods have been extensively applied in locating events on highways. In general, the methods identify the locations of events by using a name (e.g. route number or road name), direction, and a distance measurement (e.g. offset) from a known location. Street address matching is a linear referencing method that is widely applied in built-up urban areas. Concerning location referencing on highways, Nyerges (1990) concluded that the combination of three basic methods can be used, i.e. road name and milepoint, control section, and chain (link) and node. The problem with linear referencing is that each transport interest group has its own system. These systems usually have different anchor points on the same road network, and have to be unified for efficient applications (Fletcher *et al*, 1998).

4.3.5 Coordinate-based location referencing

This scheme requires surveying apparatus to acquire coordinates referenced by certain coordinate systems. The national grid system, such as the one in the UK, provides detailed reference to localities. The numbering of the grid squares is regarded as regular coordinates, and is mostly used in postal addresses. Coordinate surveying is a professional task and requires trained personnel. This indicates the limitation of coordinate-based references. However, the introduction of GPS technology has changed all of this dramatically. Nowadays, GPS can be easily utilised by casual users.

GPS is supposed to be an ideal method for locating socio-economic activities with reference to base maps. Because of its fast and efficient surveying, the system is being incorporated into ITS for such applications as in-vehicle driving guidance and road data collection. In activity-based research, it is also possible to put the system into a respondent's car for recording activity sites. A likely prospect, the system has to go through some technological and institutional barriers before it will be widely utilised.

4.3.6 Evaluation

Of the three schemes of location references, the road-based scheme has been extensively utilised in transport field. While street address matching is an effective method of locating socio-economic activities in urban areas, the linear referencing method is exclusively applied in pinpointing locations along streets and highways. As regards the name-based and coordinate-based schemes, a number of geo-referencing methods have gained importance, e.g. address point, postcode and GPS.

The reliability and preciseness of the reference bases are dependent on how much effort an agency will put into the generation of its database. The amount of effort (both in quantitative and qualitative terms) differs from country to country and even from city to city. It is also necessary to mention that the accuracy of matching results depends on both the reference entities and the candidates to be referenced.

The three schemes have different characteristics with respect to spatial referencing entities, matching methods and dimensions (Table 4.1). Concerning the type of spatial entities in a reference base, the name-based scheme may use point entity, linear entity, polygon, or their combinations, while the road-based and coordinate-based schemes use linear entity and projected plane respectively. The dimensions of the reference bases may be regarded as 0-D (no axes), 1-D (1 axes) or 2-D / 3-D (2 / 3 axes). Although the name-based approach may involve many kinds of entities, its matching principle determines that it is only a 0-D site match.

Table 4.1 Characteristics of the three location referencing schemes

Scheme	Reference entity	Matching method	Dimension
Name-based	Point/line/polygon	Semantic match	0-D
Road-based	Line	Linear interpolation	1-D
Coordinate-based	Plane/Earth	Survey	2-D/3-D

4.4 Elements for location referencing in Chinese cities

Location referencing involves the referencing base, the address / location expression and the matching method. This section examines the first two elements in Chinese cities.

4.4.1 The referencing bases

There has been no complete location referencing system in Chinese cities, and there has been little recognition of the use of information systems in effective and efficient site locating. Conventionally, the following referencing bases exist in various municipal sectors: administrative units, street names, street intersections, street addresses, postcodes, place names, large or popular sites, precise building locations and telecom zones.

Administrative unit

The official administrative hierarchy in an urban area is: the city – districts – streets – residents committees. The system has been used for resident registration and socio-economic statistics. Due to its strong structure, the administrative hierarchy is frequently applied in referencing activity locations. However, the level of residents committee rarely appears, as the geographical boundaries of this smallest unit have not been well defined. In address expressions the administrative units are usually used to supplement street addresses. Figure 4.5 shows the administrative districts and streets in Wuhan.

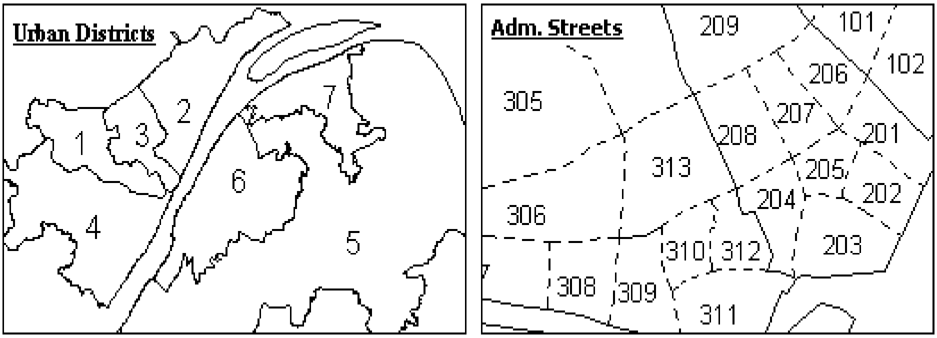

Figure 4.5 Administrative districts and administrative streets in Wuhan city

Street or road names

The naming of urban streets is the task of a designated office under a municipal government. Since the street network forms the spatial structure of a city, streets can be effective in indicating location. The problem with street names lies in the variable geographical precision. A long street is less accurate than a short one in terms of location referencing. In Wuhan, for example, roads parallel with the river are generally long (called *Dadao*), while streets perpendicular to the river are generally short (called *Lu* or *Jie*). The length of a road depends also on its function, i.e. main roads are generally longer.

It is important to differentiate the term “street” as an administrative unit from a road indication. The term is used in both ways and it is sometimes difficult to distinguish what is meant. Normally with local experience this problem can be easily solved, but in automatic address matching a delicate searching method is necessary.

Street intersections

A crossing occurs when two streets meet. The intersection indicates a point location that is precise and can be easily identified. This advantage is offset by the fact that most social activities do not take place near the crossroads. In transport incident analysis, street intersections may be very useful for locating traffic incidents.

Postcode

The postcode in China is a national 7-digit system. Within an urban area, there is no clear evidence of the relationship between the postcode zones and administrative districts. If used for location reference in a city for transport modelling, the postcode zones are too large in terms of geographical area. For example, the built-up area of Wuhan is about 230 km^2 and is divided into about 25 postcode zones. The shapes and sizes differ considerably from one zone to another. Useful integration with other spatial units is difficult to establish. No effort has been spent on a more detailed allocation.

Telecom zones

For the fixed line telephone service, telecom companies can tell where a telephone number is approximately located. The telephone service has a geographically hierarchical structure in which numbers are allocated regularly and based on which telecom zones can be delineated. Since the telephone number is sometimes recorded in traffic surveys or other customer surveys, it is useful to know the distribution of telecom zones in a city. There has been no case study on the performance of the type of zone.

Conventional places

The Office of Place Names under the municipality of Wuhan keeps records of all conventional place names in the city. An important fact is that bus stops are mostly named after the conventional names of the places. Considering the importance of public transport in Chinese urban systems, the names of transit stops are well known by travellers. More importantly, the stops cover a large proportion of the build-up area. Therefore, these stops could possibly serve as location references when other precise location systems are lacking.

Employment sites

This sort of reference could be an institution, a business park, a factory or a shopping centre where the employment takes place. Because of their popularity, these sites are frequently referred to by local travellers. These sites themselves could be precise in geographical location and cover a moderate area. They are also frequently utilised to reference other nearby sites. As the semantics and mental recognition of space differ from person to person, the relative locating task needs careful attention to spatial reasoning. In Wuhan, such sites range from a small building to a heavy industrial area that covers several square kilometres.

Buildings

Buildings are possibly available from maps of such agencies as planning and land administration, cadastral management and domicile registration. The Bureau of Urban Planning and Land Administration of Wuhan maintains complete and precise topographical maps that have no such information as address or building number. Large-scale, cadastral maps are either incomplete or unavailable. Interestingly, the domicile section of Public Security maintains a detailed draft map of buildings that is neither geo-referenced nor accurate in shape or location.

Street addresses

The street address system has been created and maintained by the public security sector, and has been widely used in mail delivery systems in Chinese cities. The basic rule for property numbering along a street is the same as that in most other countries, i.e. odd and even numbers are assigned to two sides of a street respectively. This potentially affords the possibility of address matching with a GIS software package.

As with the Western system, the Chinese urban roads are also named according to street type (Huang, 1998). For example, a "*Dadao*" indicates a major road or boulevard, a "*Jie*" means a street, a "*Lu*" denotes a road, and a "*Xiang*" or "*Hutong*" or "*Linong*" signifies an alley in a traditional residential area. These identities serve as indicators in automatic address matching.

While the street numbering method is systematic, numbering along some streets may not be complete. Wuhan, like other cities in China, has experienced dramatic changes in spatial structure due especially to social and economic development during the last 20 years. The changes in land uses along the streets have been happening fast and consecutively. Several address units (parcels) may be merged into one, or one address unit may be split into several units. These phenomena make it difficult to allocate street numbers in a comprehensive way. Figure 4.6 presents an example: at cross A the address number jumps from 833/834 to 853/854, implying that 20 numbers have been lost. The updating of street numbers has not been able to keep pace with the changing reality, causing mistakes to happen. In Wuhan, a re-numbering effort was undertaken to facilitate the fifth census in 2000, which initiated the first step towards a structured and systematic street addressing system.

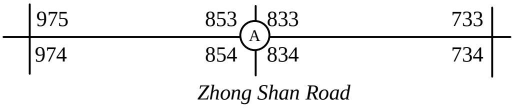

Figure 4.6 Non-continuous address numbering

Summary

The referencing bases described in this section vary in spatial preciseness, i.e. they cover different sizes and shapes in space. Ideally, the building location would be a good referencing base if each building could be named or coded in a proper way. However, with a fast-changing real estate market, it is less practical to maintain such a data set for location referencing. Comparatively, street and street address have been used as references for quite a long time and could also be accurate in spatial locations. Although address numbering may continue to be a problem in the near future, the whole structure is systematic and general application is achievable.

Figure 4.7 shows the relative positions of the referencing bases in terms of spatial preciseness and spatial dimension. Street intersections and buildings are most precise in spatial locations, whereas postcode zones and places cover large areas and have no clear boundaries. Also, a place could be either a linear entity or an areal entity. The quality of all these entities is primarily dependent on the method used for data collection and the frequency of data updating.

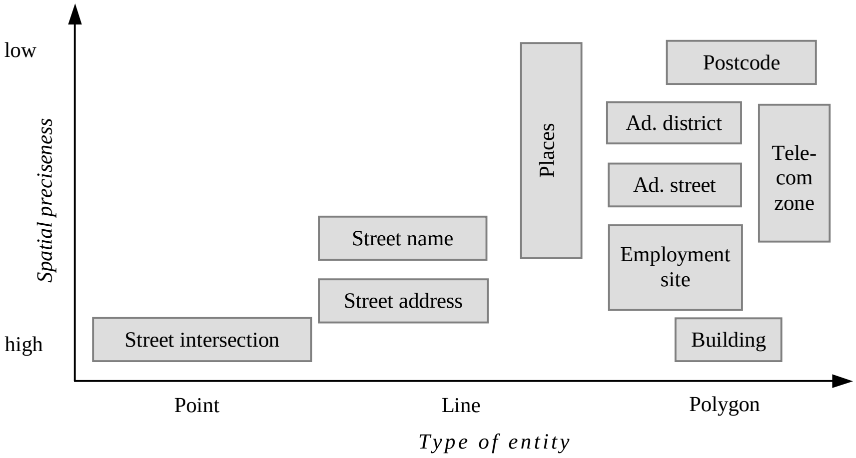

Figure 4.7 Relative preciseness of referencing bases

Despite the different sizes of area and the vagueness of entity boundaries, the location referencing processes only need to search for the names of these objects and to match the names to the candidates. That is to say, the referencing principle is the same for all the name-based entities.

Sometimes there is no direct address information available for an activity site and nearby referencing entities have to be applied. This relative positioning is an ordinary expression in a location investigation where information is incomplete.

4.4.2 The address expressions

The standard postal address contains street address and postcode. In Wuhan, as the postcode areas are large and do not correspond with any other spatial units, they alone cannot fulfil the needs of location referencing. Street address has been recommended by post offices and has been used more and more frequently. In the absence of street addresses, names of companies or institutions are usually used as substitutes by the postal service. In practice, various methods may be used together when stating an address. The following is an example:

Wuhan University -> *name of institution*
129 Luoyu Road -> *street address*
Hongshan District -> *administrative unit*
430070 -> *postcode*
Wuhan -> *city name*

The way of address expression in China makes it difficult to use the standard address matching process, which has been designed based on the Western style of address expression. The following shows an example of the Western and Chinese address style:

Western style: 340 Brelay Street / Brelay Street 340
Chinese style: 珞瑜路 129 号 (LuoyuLu129Hao i.e. Luoyu Rd 129)

The major difference is that in a Chinese address expression there is no space between the road name and the number, making it difficult to separate them. It is apparent that a conversion is necessary if the standard address matching process is to be applied to Chinese addresses.

This poses the problem of identifying the different parts in an address expression. The normal appearance of an address will not be in such a clear format as presented above. There are no spaces and commas used to separate the different parts. In traveller or customer surveys, it is common practice to design special forms that sort the different parts into predefined fields. There are still many cases in which addresses are reported as “one sentence”, and an extracting algorithm is necessary to differentiate various components.

A list of addresses was set up to explore patterns of address expression. The addresses were from two major sources: one was an address list of real estate companies available from a yearbook of the real estate authority in Wuhan, the other was a list downloaded directly from a less formal yellow page on the Internet. The addresses from the first source were formally structured on several printed pages. These pages were scanned as two-bit images, which were transformed back into Chinese characters by a software package specialised in Chinese character recognition. The addresses from the Internet were expressed in a casual way, as they had been input by Internet users themselves. The addresses from both sources referred only to work units. A manual filtering process was carried out to remove apparently inappropriate addresses, e.g. addresses from other cities. The list contained about 1,430 addresses, and a brief skim through them revealed tremendous variations in expressing style. The phenomenon confirms that no widely applied standard in address expressions exists.

Address units

The addresses can be broken down into several parts or items that can be classified into different types of units. These units have been discussed in the previous section and are referred to as *address items* or *address units* in this context. The address items include:

- Administrative city (AC) – the administrative city. The tag is “*shi*”.
- Administrative district (AD) – the administrative district. The tag is “*qu*”.
- Administrative street (AS) – the administrative street. The tag is “*jie*”.
- Place name (PN) – conventional place name. No obvious tag.
- Street name (SN) – street name, including road intersection. There are many tags used in street names: “*dadao*”, “*lu*”, “*jie*”, “*xiang*”, “*li*”, “*di*”, etc.
- Street number (SNR) – street number, including range number (e.g. 18-24) and also a special prefix character “*te*”. The tag is “*hao*”.
- Work unit (WU) – enterprise, agency, school, hospital, etc. Many tags are possible, e.g. “*gongsi*”(company), “*daxue*”(university), ”*ju*”(bureau), “*yuan*” (institute), etc.
- Building name (BN) – prominent building name. Tags may include “*dasha*”, “*guangchang*”, “*dalou*”, etc.
- Building number (BNR) – building or housing number in work unit or residential area, including floor and room number. Tags include “*shi*”, “*lou*”, “*dong*”.
- Relative orientation (RO) – position relative to a known place or building, including distance. Tags include “*qian*”(front), “*youce*”(right) and “*zuoce*”(left).

Address structure

These address units are combined in different ways in address expressions. Various cases of combination are listed in Table 4.2. The plus signs in each row indicate a possible combination of address items as well as the sequence of these items. For example, the third row of the table declares an address type with city name, district name, street (road) name and street number. A parenthesised plus sign, i.e. (+), means a possible occurrence of that unit in an address combination. Since there is no rule or standard on whether a unit may appear, an address could be quite complicated in its components. Furthermore, there is no definite tag for each address unit, which implies difficulties in identifying units from an expression.

The expressions are grouped into two referencing schemes, i.e. the street-based and the name-based scheme. The street-based expression must contain a street name and preferably a street number. All other information is optional and can be ignored if the application is confined to a city, because generally a street address is enough to indicate a location and a city does not have duplicate road names. If this can be done correctly, then an address matching process may be applied later on in a GIS environment. The name-based group includes situations where a place name or a work unit exists while no street name can be found.

Table 4.2 Possible combinations of address units

	1 AC	2 AD	3 AS	4 PN	5 SN	6 SNR	7 WU	8 BN	9 BNR	10 RO
Street based	(+)	(+)	(+)		+	+				
	(+)	(+)	(+)	+	+	+				
	(+)	(+)	(+)		+	+	(+)	+	(+)	
	(+)	(+)	(+)		+					
					++					
Name based	(+)	(+)	(+)		(+)		+			
	(+)	(+)	(+)	(+)			+	(+)	(+)	
	(+)	(+)	(+)	+			(+)	(+)	(+)	
				(+)			+			+
							(+)	+		+

The sequence of units in addresses is normally from large (general) to small (detailed), without any space to separate them. The sequence can be seen in the table, i.e.

AC->AD->AS->PN->SN->SNR->WU->BN->BNR->RO

Understanding this sequence will help to identify different units in an address. There might be one type of exception in the above sequence, i.e. the PN and SN may exchange positions. In cases where a street number is available, a place name may come after a street name.

Decomposing address units

The decomposition of an address is the first thing to do in a geo-coding process. While manual decomposition is not a problem for an experienced local person, automatic decomposition is a big challenge to computer programmers. As there is no indication of what type of expression an address belongs to, a series of judgments have to be made. The judgments have to make use of the general tags for different address units as well as knowledge of the local city. Some strategies have to be applied, based on expression practices and possible technical solutions:

- If a street name and number can be extracted, other parts can be ignored. A street name with number is enough for an address matching process.
- If a street name does not exist, it means a name-based method will be used. In this case a sequential search is necessary to extract different units. To facilitate the search, an index file may be set up for administrative units, place names and work units respectively. It has to be realised that the place-name list could be very long and that it is nearly impossible to list all work units.
- Apparently in some cases a fully automatic decomposition is not possible, and manual interference is necessary.

- Specific to Wuhan, a street name will be no longer than five Chinese characters (10 single-byte characters). If a street name is longer, most probably it is prefixed by a place name. As a convention, three place names usually appear ahead of street names, i.e. *wuchang*, *hankou* and *hanyang*. These are the three parts of Wuhan that are separated by the two rivers.

Based on these suggestions, the decomposing process is divided into two steps (Figure 4.8). Firstly it is assumed that most addresses contain street name and street number, and the street-based process is carried out to extract them. For this purpose, following the procedures in the figure, a test program is written using Avenue in ArcView. The script gets addresses from the address table, extracts street names and street numbers, and updates the corresponding fields in the table. If a street name is not found in an address expression, then the name-based process is started, which extracts address units hierarchically. In this process naming tags have to be applied to give hints on possible address units. To improve the detection, several index files have to be constructed. These index files contain conventional names that are already known for a specific city, e.g. the city name, names of administrative districts, place names, and names of work units.

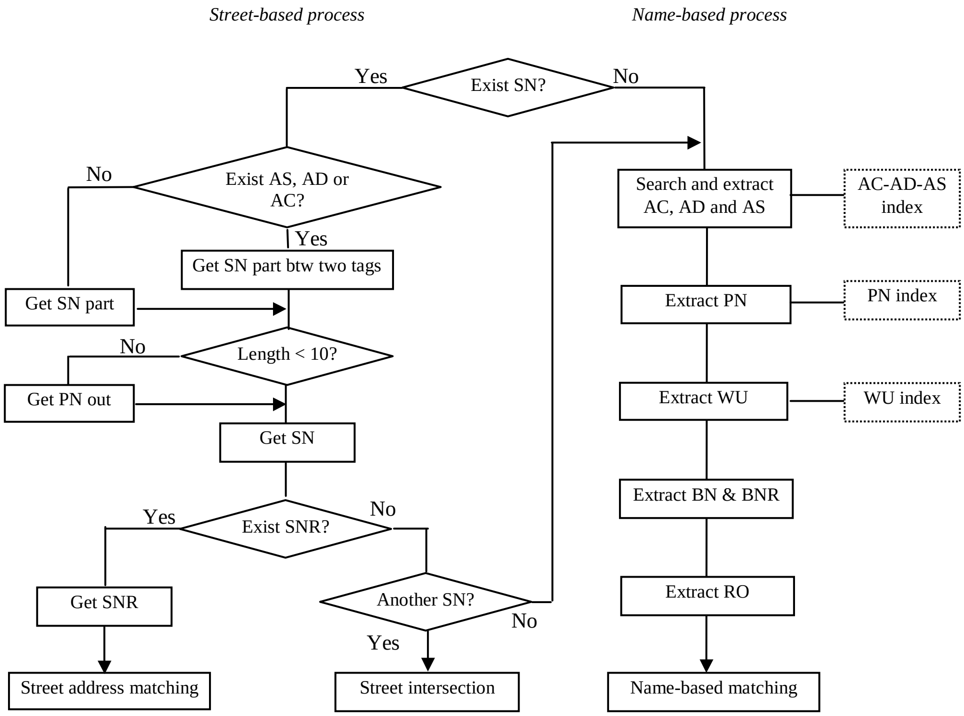

Figure 4.8 The process to decompose a Chinese address expression

Based on the decomposition process, the sample address set is split up into two groups (Table 4.3). This reveals that the majority of addresses (about 84 percent) contain street names, and that addresses with both street names and street numbers dominate the sample set. This statistic indicates that street names and street numbers are popular components of address expressions. However, this situation should not lead to the conclusion that name-based matching is not necessary, because name descriptions are still popular in address expressions.

Table 4.3 General components of the sample addresses

Address group	Nr. of cases	Percentage
Addresses with street names	1210	84.5%
Of which: with street names and street numbers	*1029*	*71.9%*
with only street names	*181*	*12.6%*
Addresses without street information	222	15.5%
Total	1432	100%

Analysis of street-based addresses

According to the automatic decomposition result, the majority of addresses make use of street names. A conditional search combined with a manual operation is carried out to probe problems resulting from the decomposition. The variations in the 1,029 addresses with both street name and street number are firstly evaluated, which reveals 87 incomplete or wrong addresses. These addresses fall into the following categories: there are still place names in front of the street names; some extracted names are actually not street names; a sub-address number exists.

For the 181 cases with street names and without street numbers, the reasons are one of the following: place names and / or building names attached (65 cases: 36 percent), spelling (58 cases: 32 percent), only street names (45 cases: 25 percent), street intersection (7 cases: 4 percent), not streets (6 cases: 3 percent).

The assumption that there are no duplicated street names is valid only in the built-up districts of Wuhan. The suburban districts usually have towns equivalent in size to a small or medium city. Streets in these towns are not necessarily unique if they are lumped together with those in the central city. That is to say, it is necessary to keep the suburban district names if all addresses in the administrative area of Wuhan are to be geo-coded. Apparently names of cities or postcodes are needed in regional address matching. In this study, these matters are ignored.

Analysis of name-based addresses

The decomposition of non-street cases is more difficult as no definite tags are used in place names or building names. For the purpose of exploring these address structures, a manual effort is applied to decompose the 222 cases of name-based addresses into address units. The occurrences of various units from these addresses are shown in Figure 4.9. The unit of place name (PN) is most frequently used in name-based address expressions, representing about 72 percent of the 222 cases. Building number (BNR: 61 percent) and administrative district (AD: 50 percent) are also frequently used. City name (AC: 29 percent), work unit (WU: 25 percent) and building name (BN: 18 percent) are not used very often. Others, including administrative streets (AS) and relative orientation (OR), are seldom employed.

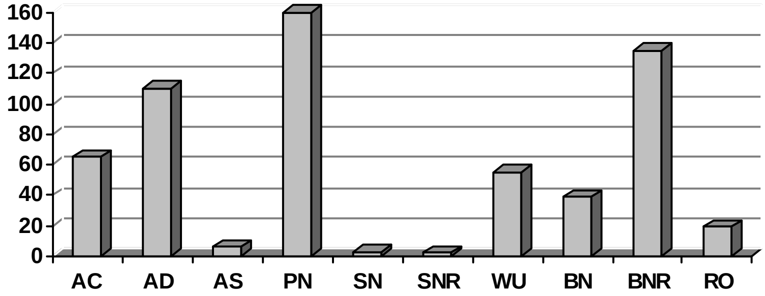

Figure 4.9 Occurrences of address units in the 222 name-based cases

Altogether 50 types of combinations have been found among the address units, only the most frequent combinations being shown in Table 4.4. The table reveals that the most popular compositions all contain place names (PN: type 1-4). Work unit (WU) is also important.

Table 4.4 Typical combinations of address units in name-based addresses

Type	AC	AD	AS	PN	WU	BN	BNR	RO	Cases	%
1		+		+			+		61	27
2				+			+		22	10
3	+			+			+		20	9
4	+			+					17	8
5~50	(cases less than 8)								102	46

The above statistical illustrations imply the data types necessary to build a name-based reference system. Apparently a name-based referencing base may be composed of such entities as administrative units, place names, building names and work units. The spatial extents of these units have to be clarified. This is not a problem with administrative units, i.e. the city, districts and streets, as they are in a hierarchy that is used for administrative purposes. For buildings and work units, points can be generated as their spatial locations. When a work unit is large, a boundary can be delineated. These units are all distinct in spatial locations or extents.

However, much effort is needed regarding the unit of place name. A place name usually represents a spatial area with only a fuzzy boundary, which sometimes may be encompassed by the boundary of another place. Many residential neighbourhoods exist in the address expression. These neighbourhoods are pieces of land with clear boundaries developed by real estate companies. They are identified as place names but are different from conventional place names. Although the conventional places do not have clearly defined extents, the neighbourhoods do. Of the 160 addresses that contain place names, 26 have residential neighbourhoods that are identified as place names.

Discussion

An analysis of the sample addresses helps to clarify the real situation in Wuhan and sheds light on more comprehensive processes to decompose address units. Although the sample addresses used for the analysis may not completely represent the way of address expression in Wuhan, it can be concluded qualitatively that most expressions are using street addresses to indicate spatial locations. In most cases street names and their numbers can be identified correctly if an appropriate algorithm is used in the process. Manual interactive correction is necessary when automatic extraction fails. Since addresses are sometimes outside the study region, e.g. the built-up area of Wuhan, special attention has to be paid to where an address belongs to. The quality of address matching depends heavily on how well addresses can be decomposed.

Study on the address units helps to establish local travellers' propensities in expressing locations, by means of which the important address units can be identified. These important units may facilitate more in-depth understanding of the key address structure. They also imply which referencing bases are important and which drop hints on how to improve survey forms at the local level. For example, this study reveals that street name, street number and place name are the most important address units to be considered in surveys.

4.5 Location referencing in Wuhan

4.5.1 Street-based referencing

For street address matching in Chinese cities, the referencing street segments should contain information on street name, left low address, left high address, right low address and right high address. This is the minimum information required for automated address matching. In ArcView, the address style "US Streets" has more optional fields: directional prefix, prefix type, street type and directional suffix. These items are not suitable for the Chinese situation and can be ignored. ArcView also provides several other address styles for geo-coding, e.g. US street with zone, single house, ZIP and so on.

When applying standard address matching routines to the situation of Wuhan, many adaptations have to be made. First of all, the techniques for Chinese word matching have to be developed. In a Chinese expression, a name is composed of several characters, each of which is represented by two bytes in the computer. There are also similar characters in the Chinese language, which also need to be considered in character matching. Since the sequence of expression is different from the Western style, there should also be an interface program to extract the various constituent parts from address expressions. Secondly, as data on street addresses are not complete or systematic, strategies have to be developed to handle situations where no information is available on base street maps. Thirdly, the general public is not practised in remembering street numbers, which may lead to incomplete information in a travel survey. In the absence of street numbers, it is assumed other information could be provided, such as company name and neighbourhood name.

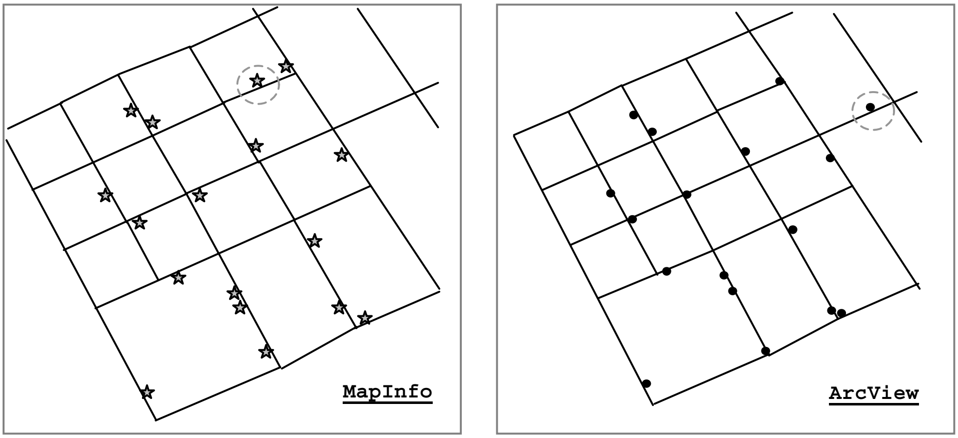

Figure 4.10 A sample address matching in two systems

Figure 4.10 shows address matching results in part of the study area, obtained using Mapinfo and ArcView. The two systems give the same results for addresses with correct information. For incomplete information the two systems apply different matching strategies. The two points circled on the two maps are good examples of how the matching is performed by the two systems. The two points represent the same street address: "*165 Min zhu jie*". Since in the street database the road "*Min zhu jie*" has an address range between 1 and 100, the address with number 165 is assumed to be wrong. However, there is another street called "*Min zhu yi jie*", with an address range between 1 and 250. It is apparent that neither of the systems can make an exact match, so less accurate matching methods are used. Figure 4.11 depicts how the two systems respond differently. In Mapinfo, it is assumed that the street name is correct and the address is located in the street segment with highest address range (see the left part of the figure). In ArcView, however, the street number is assumed correct, and a search is carried out for similar street names. In both systems preference is set to allow less accurate address matching, otherwise the address will not be matched.

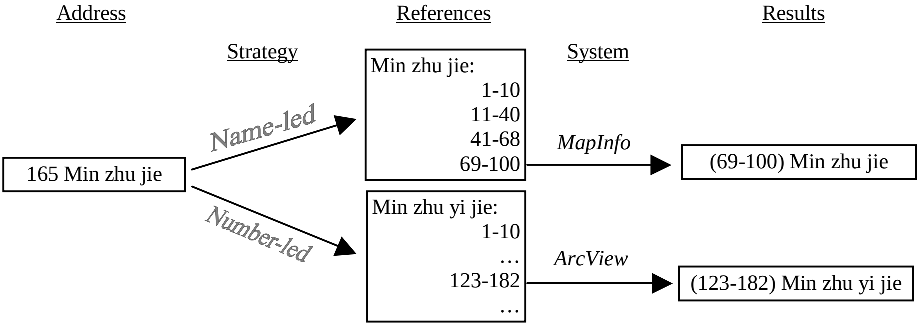

Figure 4.11 Two methods for locating an erroneous address

The correctness of address matching results can be checked either by a field visit or by comparing them with existing data. Figure 4.12 illustrates three examples of verifying matching results with a standard topographical map of the study area. The topographical map contains, among other things, building outlines and annotations of large agency names. These names are also collected and kept together with their street addresses (lists shown with grey background). The stars are the matched locations from the listed street addresses, and the annotations from the topographical source are shown around them. Comparing the annotations with agency names in the lists indicates these matches are correct.

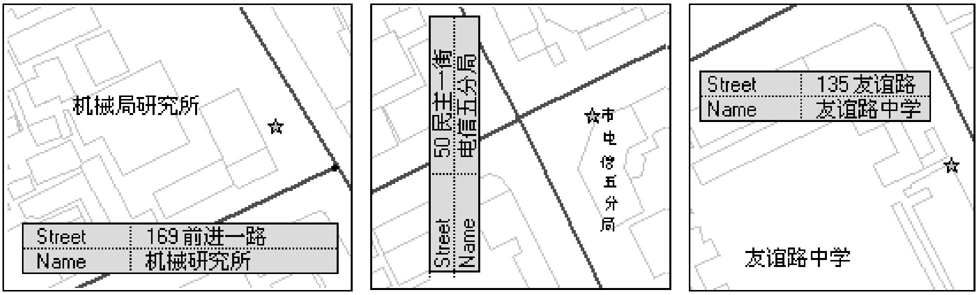

Figure 4.12 Address matching checked with topographical maps

From the above example it can be concluded that, given a reliable referencing street base and address expression, the general process of street address matching in GIS packages is applicable to the Wuhan situation. However, in real applications it is exactly the quality of the source information, i.e. either the street referencing base or the addresses themselves, that determines the final success of geo-coding. For streets, the numbering system is incomplete and error-prone. For address expressions, there is no standard and it is difficult to separate the various components. Address matching in a Chinese environment therefore requires more effort in character processing than in Western cities.

4.5.2 Name-based referencing

Hierarchy of name-based referencing entities

The name-based location reference requires that the spatial locations of entities with names and related attributes serve as referencing bases. The following spatial entities have been considered and discussed in former sections:

- Administrative city (AC)
- Administrative street (AS)
- Work unit (WU)
- Building name (BN)
- Administrative district (AD)
- Place name (PN)
- Street / road name (SN)
- Building number (BNR)

The administrative units (AC, AD and AS) have been used for administrative and statistical purposes. These units are in a hierarchical order in terms of spatial extent. A city has several districts, and a district contains several administrative streets. Work units and buildings are important references as their locations can be identified precisely – although often requiring some effort. Work units usually refer to large governmental agencies, institutions and enterprises. Therefore a work unit may have many buildings.

The case of places is more complicated. A place has no defined spatial boundary and may either be part of a larger place or contain other smaller places. The places are generally named after their geographically related narratives or events in history. For example, urban Wuhan is divided into three parts by two rivers, and the three parts are historically called “the three towns of Wuhan”. The names of the three “towns” frequently appear in address expressions. These three “towns” are the highest level in the place hierarchy. Smaller places are associated with individual locations and can be regarded as the second level.

The relationships among the name-based referencing types have to be clarified so that an appropriate referencing spatial database can be designed. Figure 4.13 illustrates the hierarchical structure and the relationships among the entities. According to the areas being covered, place names are specified at two levels: level 1 covers areas larger than districts, and level 2 falls between the work unit and the administrative street. The relationship between the entity types is one-to-one or one-to-many. Streets / roads are linear entities whose relationships with other types are not defined in the figure.

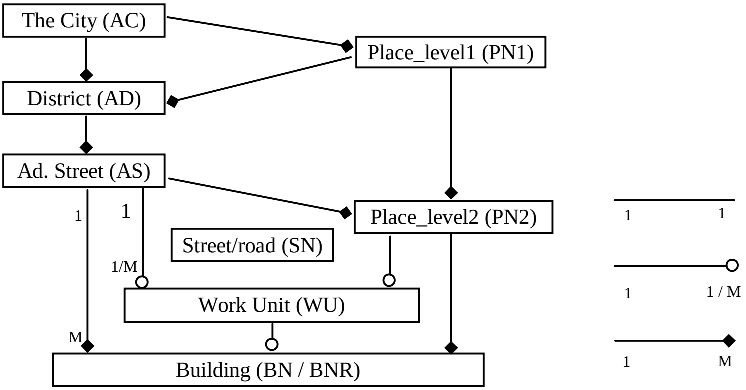

Figure 4.13 Hierarchy and relationships among name-based referencing entity types

Name-based matching

In principle, name-based matching is a one-to-one match between names in a referencing base and address names to be located, regardless of the types of spatial entities in the referencing base. Matching name characters is not a problem as long as the names are correctly spelled. A typical name matching can be carried out with a statement like the following:

> Select [*name*] from [*ref_layer*]
> Where [*name*] = [*address_name*] (or [*name*] like [*address_name*])

However, as has been shown, the real situation is much more complicated. On the one hand, it is difficult to extract names from address expressions as there are no standard rules to apply. Even if the names are correctly extracted, it is still hard to identify which referencing level a name corresponds to. On the other hand, names in a referencing base belong to different layers at different levels. For an efficient search, these layers have to be properly linked.

There are two approaches to organising the name-based entities. One is to put the entities of different referencing bases into different data files, and the other is to keep all entities in one data file. The former approach produces several geographical layers with predefined entity hierarchy, as shown in Figure 4.13. This makes it easier for data input and maintenance but requires programming to link the layers during the name matching process. The process starts from the lowest level and continues to the highest city level. If the level of an address name is already known, it is more convenient to get the corresponding layer and make the match. Figure 4.14 shows an example of this data organisation method.

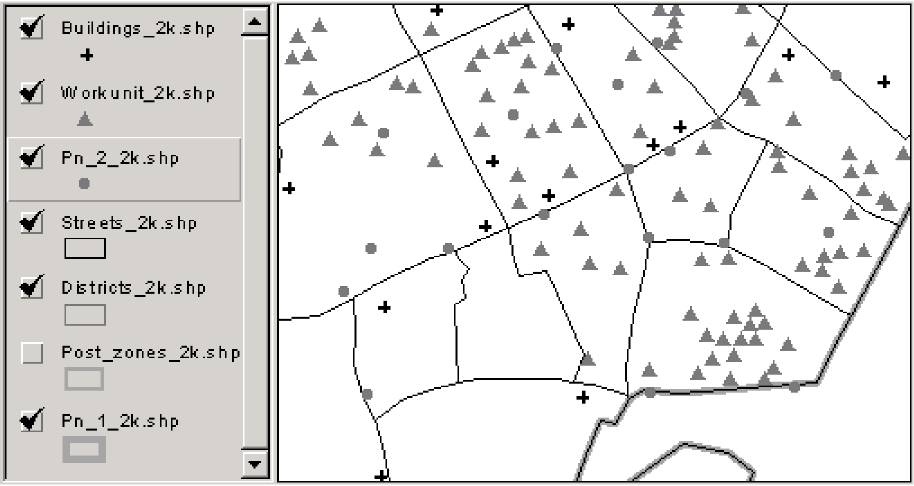

Figure 4.14 Name-based referencing with multiple layers

The other approach is based on the object-oriented or object-relational concept, in that each entity is a spatial object with type and name. Only one spatial data file is created. Entities in this data file are marked with identities of level types in the hierarchy. This method requires less programming effort on file operations and results in more efficient name matching. However, mixing different types of entities together presents a challenge to data management, especially when there is a large number of entities.

A note needs to be made for the representation of matched results. The identified location of an address from the name-based matching is the location of an entity in the referencing base. As referencing entities are represented with point, line or polygon features in a spatial database, the matched results have to be adapted to fit specific needs. Normally, the address to be matched is a point location, and a point representation is appropriate. For this purpose, linear and areal features have to be simplified to point features (centroid) after successful matching. This simplification apparently introduces uncertainty in the final results. For some applications, features may be acquired without simplification, e.g. a linear street or a zonal street. Statistics can be produced for these one- or two-dimensional features to show how many addresses fall inside. If possible, these data can be disaggregated within the features, which will generate scattered points other than the simplified centroids.

4.5.3 The problem related to location referencing in Wuhan

Although many possible references exist to locate an activity in a Chinese city, they vary in terms of precision, geo-reference and completeness. In practice no comprehensive location system has been developed in Wuhan (or any other city of China). This is due to the following facts:

- Inconsistency. The references themselves are not consistent.
- Incomplete data. Usually the update of the data cannot keep pace with the fast-changing urban environment.
- Awareness of usefulness. Departments have little idea of the implication of their data sets for uses beyond their own purposes. The cooperation between departments has been weak.
- Lack of standards. Even if the departments would like to cooperate, under current circumstances they would meet many technical problems. The lack of standards makes it difficult to link different data sets. The data frameworks may vary in terms of coordinate system, entity definition and representation, scale of data collection, and underlying spatial database system.
- Lack of appropriate technology. Although GIS technology has been quite popular in some departments, not all agencies are aware its advantages or have the necessary technical staff to do the job.

As a result of government efforts to promote modern information technology, the situation will gradually improve in Chinese cities. In the meantime, transport planners, business managers and even the general public will pay increasing attention to the locations of socio-economic activities. The two location referencing methods are necessary means for meeting these requirements.

4.6 Discussion

The public agencies in Chinese cities possess most of the referencing base data. If GIS technology is applied in these agencies, various referencing methods will benefit both the agencies and the general public in a variety of applications. Table 4.5 shows those agencies that hold information on the referencing bases. The availability of types of data will decide what kind of referencing bases may be built up, which again will decide which referencing methods have to be used.

Table 4.5 Referencing data and their holders in Wuhan

Referencing bases	*Available from*
Street name, Place name	Office of Place Names
Street address	Bureau of Public Security
Postcode	Postal Bureau
Work unit & building	Urban Construction Committee
Administrative unit	Municipality
Telecom zone	Bureau of Telecommunications

Generally speaking the agencies with referencing data do not realise the potential value of their data in applications based on information technologies. Data on street names, street addresses and place names are available from public agencies. These data may not be complete or up to date, but they provide a good starting point in constructing a referencing information system. Also, it has to be realised that one agency alone will not be able to construct and maintain such a system, because its data will cover only one aspect of the referencing system. To build such a system, data from all relevant agencies have to be incorporated, which will necessitate cooperation among the agencies. With these aspects in mind, it is necessary to include the reference system as an essential part of a spatial data infrastructure, as described by Masser (1998).

Understanding address structures may facilitate transport surveys in which descriptions of locations are required. For example, street name and street number may be preferred in many surveys, but other address units may also be used in case street information is unavailable or inaccessible. The analysis in this study indicates that in Chinese cities it is quite possible to use address units other than street names; for example, place names and building numbers are frequently used. Despite their relative vagueness in spatial location, these units are easy and flexible to capture and maintain. In situations where less precise locations are possible, these address units may play a useful role.

In transport activity surveys, travellers’ locations may be expressed using street addresses, street intersections, postcodes, and even GPS-derived coordinates. To handle different kinds of location descriptions, a fully developed location referencing system should incorporate various location referencing methods. The two schemes examined in this research are realised in different ways in the computer, with one using direct name matching and the other using linear interpolation on the basis of name matching. The name-based matching is fundamentally operated in relational database management systems (RDBMS), and the address matching is a standard function of a GIS. Therefore, incorporating these methods also implies integrating the systems as well as the data. This role could only be fulfilled in a multi-purpose GIS environment in which different modules are linked together. To achieve this end, some development efforts are necessary in existing GIS systems.

4.7 Conclusions

Location referencing is a twofold process. On one hand the addresses to be geo-coded have to be clearly expressed so that they can be decomposed into appropriate address units. On the other hand, the referencing bases have to be properly organised according to referencing methods. Both these issues have been discussed extensively in this chapter.

It is very difficult to extract address units from a Chinese address expression; well-defined searching algorithms and local knowledge are required. To avoid this dilemma, address components should already be separated during transport activity surveys. The street address matching in existing GIS systems is generally applicable to Chinese cities. However, as differences exist between the Western and Chinese address structure, further improvements in automatic address matching are necessary.

The key to name-based referencing is to maintain a hierarchical data set for the referencing bases so that the matching process can follow a proper sequence. Due to the variations in spatial accuracy among the base data, this method is supposed to be a supplement to street-based matching.

For better location referencing performance, a comprehensive location referencing system is needed in Wuhan and other Chinese cities. The system should incorporate both the street-based referencing method and the name-based referencing method, in which various referencing bases are systematically organised in spatial databases. As the referencing bases differ in spatial resolution, an evaluation and subsequent standardisation of precision for each candidate is also necessary.

Chapter 5 Adapting Bus Line Representation For Transport Data Integration [*]

5.1 Introduction

In heavily transit-oriented cities, public transport planning and operations management is a challenging task due to the complexity of the system. Wuhan, in China, for example, has about 7 million people, most of whom are living in the built-up area of less than 300 km^2. The density is extremely high in inner areas, and mobility relies heavily on buses. In 2000 there are more than 5,000 buses running on nearly 240 lines, with many overlapping routes. A comprehensive database system is important to face these challenges.

This chapter deals with integrated bus representation in GIS and applications in public transport analysis. Existing approaches to linear and public transport representation are reviewed. The need for detailed representation is put forward, and justified by illustrating the situation in heavily bus-oriented cities such as Wuhan. Based on dynamic segmentation, the existing transit data model is extended to allow directional representation of bus lines and the exact location of individual bus stops. Some examples are given to demonstrate the effectiveness of the model in public transport analysis. An application of the representation method to trip guidance is described in more detail.

In this chapter a distinction is made between “bus line” and “bus route”: a bus route is one directional run of a bus line, i.e. each bus line has two directional running routes. Also, an individual stop site means one stop location of the generally stated “stop” that is typically composed of at least two sites across a street. In correspondence to the “bus route”, such an individual stop is referred to as a “route stop”. Accordingly, the general stated stop is termed “line stop”.

5.2 Linear data representation and integration

Linear objects are abstracted and represented as one of three spatial data types in spatial science – the line. This type of object is particularly related to urban transport, as urban activities are realised with the movements of people and goods through urban road networks. In many cities, public transport is an important mode for facilitating such linear movements. This section reviews the representation and integration of three types of linear data – road networks, traversals and public transport lines.

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[*] Based on Huang & Masser (2002a; 2002b).

5.2.1 Road networks

Urban road networks are often referred to as base road networks, as they shape the spatial structures of cities. Streets are widely used to reference urban activities, using street names, intersections and street addresses. The road network is also the major concern in urban transport and traffic planning.

To serve as a referencing base, road networks have to be represented by their smallest elements – road segments and intersections. These two elements are termed as the Framework Transport Segment Reference Point (FTRP) and the Framework Transport Segment (FTSeg) in the NSDI Framework Transport Identification Standard (FTIS) developed by the US Federal Geographic Data Committee (FGDC, 2000).

The NSDI FTIS has been proposed specifically for a standard representation of transport networks. The FTRP and FTSeg are the two components of this standard. The FTRP represents the specified location of a required endpoint of the FTSeg, or an optional referencing point offset along the length of the FTSeg on a physical transport system. Depicted as point features, objects in an FTRP table are recorded with, among other attributes, the latitude and longitude coordinates. The FTSeg refers to a specified directed path between two FTRPs along a physical transport system that identifies a unique segment of that system. The FTSeg is a nominal representation of the real world in that it contains no explicit geometry besides its two FTRPs. This means the FTSeg does not record its midpoints in the database.

The FTIS allows the representation of some special phenomena in road networks, including the non-planar cross of two roads and two road segments that share the same endpoints. With these elements available at the fine physical level, data models for transport and other applications can be developed on top of the same basis. For example, the simplified link-node structure in a transport planning model system may be derived from this standard. The standard itself is not for immediate model applications; rather it provides a basis for model network construction and data exchange.

The Geographic Data File (GDF) is a European standard used to describe and transfer road networks and road-related data. The GDF is more than a generic GIS data standard; it provides rules on data capture and guidelines for specifying customised user maps (*http://www.ertico.com/links/gdf/gdf.htm*). The GDF has a three-level structure:

- Topology (level 0). A common GIS topology description that is widely accepted, i.e. by means of nodes, edges and faces.
- Features (level 1). The most used level of GDF, it contains simple features such as road elements and rivers, their attributes, and relations on connectivity.
- Complex features (level 2). Aggregated from the simple features in level 1, such as the aggregate of a roundabout to a point intersection.

Initially developed in the European Digital Road Map (EDRP) project, the GDF has been primarily designed for car navigation systems. It has also been found suitable for many other transport and traffic applications, such as fleet management, traffic analysis and automatic vehicle locations. Like the FTIS, the GDF itself is not an end product for immediate utilisation. It allows users to customise according to their specific needs regarding content and level of detail. Improvements have been made in an attempt to promote the GDF as an international standard (ISO/TC204, 2000).

The two standards have a different range of details in representation. Road networks in the GDF exist at all three levels of detail. The representation in the FTIS corresponds to a level somewhere between level 0 and level 1 of the GDF. Therefore, both standards manage to describe roads at the lowest level in terms of GIS applications. Both standards are capable of depicting non-planar roads and intersections. A model network in a conventional transport planning package makes use of a link-node structure that is a simplified representation of the real road networks. While non-planar transport features may not be described in transport modelling, they are important for operational applications in Intelligent Transport Systems (ITS). In fact, ITS applications require even more details of the roads such as the lanes (Goodchild, 2000).

An attempt on lane level representation has been made in the development of an Urban Transport Information System (UTIS) in Newcastle upon Tyne. The objective of UTIS has been to provide a system that will satisfy the demands of traffic and transport planners as well as other transport-related groups (Wright *et al*, 2000). The UTIS data model is characterised by its definition of lane sections and lane section nodes, which are termed as the “lowest common denominator”. The definition at the lane level facilitates modelling in traffic engineering such as micro-simulation. A common data transfer format based on the GDF standard will be developed at this level (Etches *et al*, 2000). The information at the lane level can also be aggregated to a higher level – the road sections and junctions, as well as the whole road network.

5.2.2 Traversal

A traversal is a path or route in a road network from an origin node to a destination node, and is represented by a directed sequence of links (Spear & Lakshmanan, 1998). Bus routes and passenger trip routes are typical examples of traversals. Traversals can be represented with either independent or dependent methods.

Independent representation

The independent method maintains a separate database containing all details of traversals, including geometries, topology and attributes. Independent traversals have no direct internal linkages with road networks. This independent representation is suitable for fixed-route features such as tramlines, subway lines and bus lanes. Such a method can be implemented in a stand-alone database, but the relationships with other transport features have to be set up with the aid of spatial tools (e.g. Choi & Jang, 2000).

The iconic model proposed by Sutton and Wyman (2000) belongs to the independent category. This model employs a dynamic location method that allows spatial intersect queries from geographical shapes without the use of topological relationships. Events are stored as coordinate pairs, and routes are represented with coordinates plus an attribute for measure. Relationships between different routes, or between routes and events, need to be built by combining spatial and temporal queries. Dynamic location is an object-oriented method that encapsulates transport geometry and attributes in a single database record. While the iconic model has the advantage of maintaining the integrity of individual events and routes, the relationships among the objects are not predefined and have to be identified through spatial intersect. Also, in cases of large-scale transport systems, this model may result in large database files because of the explicit storage of coordinates for all of the features.

Dependent representation

In GIS applications, traversals can also be represented with the dependent method that describes routes with reference to base road networks. This method can be implemented with the technique of dynamic segmentation, in which the traversal retains the spatial geometry and topology of underlying features (Dueker & Vrana, 1992; ESRI, 2001). Another closely related technique in this aspect is the linear referencing system (LRS), which identifies a location on a linear feature (Figure 5.1). Linear referencing methods consist of traversals and traversal reference points that together serve as a means to reference locations of unknown points along linear features. These relative referencing techniques facilitate the integrity of transport data, in the sense that a change in a traversal data set will not generate too much work in the underlying geographical network.

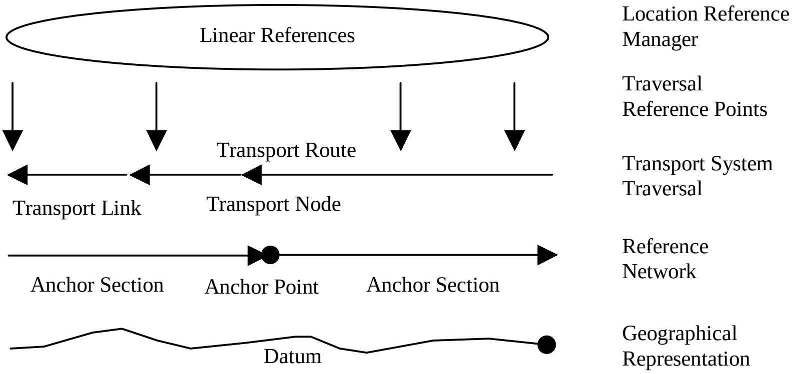


Figure 5.1 Linear reference with dependent representation
(based on Sutton, 1997)

A generic data model for linear referencing systems has been proposed by a US National Cooperative Highway Research Program project (NCHRP 20-27/2). The data model has a structure of three levels (Vonderohe *et al*, 1995). The lowest level is the linear datum, which is made up of anchor points and anchor sections and relates the database representation to the real world described by cartographical representation. The linear datum is similar to the FTRP and FTSeg in the NSDI FTIS. At the second level the logical network models provide the topological framework for transport applications such as routing. The third level contains various linear referencing methods that are associated with the network models. The traversal and traversal referencing points are the two components utilised by the linear referencing method. With these three levels of representation, the NCHRP model serves as an integrator for various linear referencing systems. This model has been further extended in the NCHRP 20-27/3 project to incorporate spatio-temporal objects and to form a Multi-Dimensional Location Referencing System (MDLRS) for transport applications (Koncz & Adams, 2002).

The GIS-T enterprise data model is another type of dependent representation model (Butler & Dueker, 2001). The model consists of four primary components: 1) a facility inventory of transport entities; 2) a network that includes nodes, links, traversals and traversal segments; 3) a measurement datum consisting of anchor points, anchor sections, reference objects and geographical points; and 4) cartography features. The basic GIS-T data model consists of seven inter-connected entities: jurisdiction, transport feature, event point, point event, linear event, area event and intersection (Dueker & Butler, 1998). Traversals and their elements (such as nodes and links) are defined as tables with reference to the point, linear and area events.

5.2.3 Public transport lines

Public transport management involves many tasks, ranging from policy, planning and operations to evaluation. Bus stops and bus routes are among those data needed by both transport planners and operations managers. Transit demand modelling makes use of transit stops, routes and street segments to integrate data from different sources so that transit analysis can be carried out at the route level (Peng & Dueker, 1995). Peng *et al* (1998) declared that an enterprise GIS database for transit applications should address relational linkages between the transit routes and stops in the transit network, between the transit network and the street network, between the spatial network and temporal service scheduling, and between transit network, street network and surrounding non-network information such as land uses and landmarks.

Public transport is one mode of transport activity that has basically fixed operating routes along the street network. Like ordinary traversals, the spatial representation of transit stops and routes in computer databases may follow either the independent or the dependent method. With the independent method, the linkage between routes and the street network has to be constructed with spatial search or spatial overlay. The dependent method is realised by referencing bus routes to the street network, but some manipulating efforts are needed to explain the linkage in a tabular format.

Choi and Jang (2000) have illustrated a scheme for generating an independent transit network from a street map database for transit demand modelling. It improved on the traditional method of transit model network construction by means of GIS spatial analysis and dynamic segmentation. With an independent representation, the research did not maintain an internal linkage between the transit network and the street network. Although this is appropriate for model network applications for transit planning, the linkage has to be built up again for a purpose such as multimodal route planning. Concerning the level of detail, while the application has improved the simplified stop representation by differentiating one-way and two-way stops, it does not take account of more complicated stop locations and directional bus routes.

Trip guidance for public transport users is necessary in large and transit-oriented cities. This involves a variety of strategies and methods, ranging from simple route maps to interactive trip planning. A passenger information system in an Advanced Public Transport System (APTS) incorporates data on routes, fares and schedules, as well as other dynamic data, into one cohesive database for such applications as pre-trip planning and in-vehicle information provision (Casey *et al*, 2000). The system may be constructed in a Web-based GIS framework so that transit passengers may plan their trips interactively (Peng & Huang, 2000). Among the data used in public transport systems, spatial data play important roles in various transport applications. There have been many types of such a system, yet in most systems the representation of bus lines and stops is simplified in the form of non-directional lines and single stops. These representations need to be expanded for better system performance.

Several efforts have been made to build a detailed spatial database for bus lines and stops. A pilot project was conducted in Fairfax County, Virginia, to demonstrate applications of GIS in transit planning, operations and marketing (Jia & Ford, 1999). It was realised from the project that the representation of directional bus routes is necessary and possible in GIS. The transit database from the study included GPS-collected stop locations but did not clearly indicate the linkages among stops, routes and street networks. In another case, the development of a much detailed bus stop inventory database – containing information on stops with references to streets, street intersections, landmarks and surrounding areas – for advanced public transport systems has been described by Sarasua *et al* (1997). Although these methods require more effort than the usual cases, it is worthwhile in view of subsequent applications in planning, marketing and operations management. Nevertheless, these attempts did not explore the integrated representation of multi-directional bus routes and multi-site route stops. A clear and consistent representation scheme is necessary in such complex circumstances.

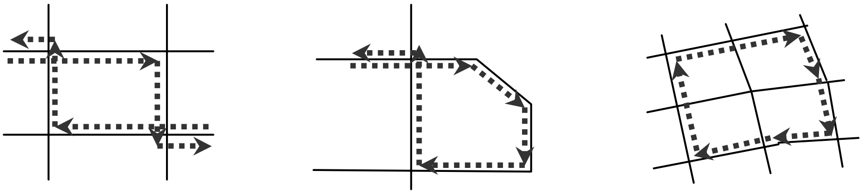
An object-oriented data model for integrating transit operational data with a road network at a disaggregated level has been presented by Trepanier and Chapleau (2001). To meet different needs in transit planning, the transit route may be defined with four levels of resolution, which range from the schematic time point description to the finest directional route itineraries along the street network. The transit network object model includes route, route directions, and stops. The transit network and the road network are linked at bus stops, and route itineraries can be constructed in GIS when necessary. It is not yet clear how the directional bus routes are constructed and maintained in the database, nor have the applications of the directional route representation been demonstrated.

It can be seen that many attempts have been made on bus line and stop modelling. These models vary in terms of level of detail, relation with the road network, and representation techniques. The challenge is that a clear understanding of detailed bus representation and a consistent model are still lacking. Nor has the full advantage of representation at such detail yet been demonstrated.

5.3 The need for more detailed representation

Most GIS and transport model applications have utilised a simplified method to represent bus lines and line stops, i.e. one line symbol represents two directions of a bus line, and one point represents a line stop that includes two or more stop sites. As buses have different timetables in their two directions, directional route representation is necessary to facilitate planning and operations management. In the meantime, trip descriptions can be made clearer if individual stop sites (route stops) are incorporated.

The need for more detailed bus representation can be further justified by special cases existing in heavily transit-oriented cities like Wuhan. Firstly, a bus line may have two different or partly different routes in its two directions (Figure 5.2). Reasons for these cases might be traffic controls (e.g. one-way streets and vehicle controls) or demand-driven (e.g. omitting certain stops during peak hours). Conventional single line representation is not appropriate for the different route situation.



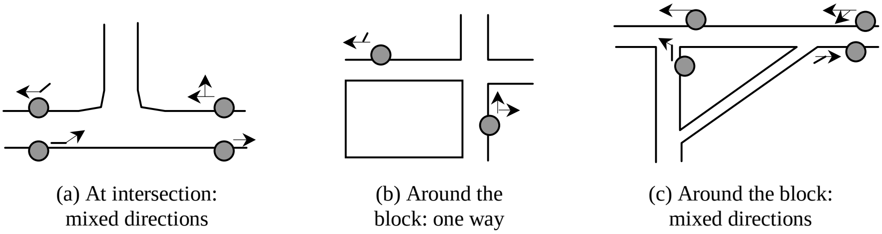
Different routes in two directions

Partly in one direction

In one direction

Figure 5.2 Cases of bus lines with different routes

Secondly, at a place where several bus lines meet, a stop of the same name may have several individual sites. Ordinarily a bus stop has two stop sites on opposite sides of a street and the two sites are not far away from each other along the street. However, in large cities there are many cases in which a stop takes more than two spatial locations owing to the coexistence of many bus lines. Some of these special designations are depicted in Figure 5.3. One stop name with several spatial locations may happen at a big intersection (a), around a block (b & c), or simply along a street. There are two major reasons for this phenomenon: 1) different bus lines have different routes so at an intersection the stops cannot be in one location (a & c), and, even if straight along a street, different routes may have different stop locations using the same stop name (c); 2) Some bus lines are running different routes in their two operating directions, for example just around the block (b).


(a) At intersection: mixed directions

(b) Around the block: one way

(c) Around the block: mixed directions

Figure 5.3 Cases of route stops of the same name with different spatial locations

The spatial layout of routes and stops is of great importance for pre-trip planning in which searching for transfers is necessary. The representation of transit lines in two directions will reflect the reality and give better guidance to transit passengers in their pre-trip route searching. From a broader perspective, this need for detailed bus representation is also in line with that of lane representation as a part of the ITS. For ITS applications, the lanes on a street have to be represented in the database so that vehicles can be tracked at the lane level of detail (Goodchild, 2000).

The optimised integration of street networks and transit routes will benefit both planners and transit operational managers. For planners, the referencing of routes to street networks implies also referencing to other spatial data such as socio-economic activities, land use and transport facilities (Figure 5.4). For operations managers, the optimised routes allow more efficient passenger information services such as pre-trip planning and real time information provision.

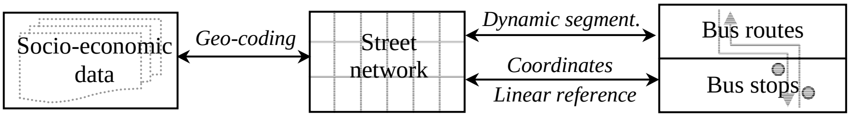


Figure 5.4 Connecting public transport and socio-economic activities

In a transit-oriented city, the following features need to be considered in representing bus stops and routes:

- Transit networks have to be defined with reference to base street networks
- Bus stops have to be represented on both sides of the street
- A bus stop serving many lines may have more than two spatial locations
- A bus line may take different routes in two directions
- A bus line may change its route by ignoring some stops at peak hours

5.4 A comprehensive bus representation model in GIS

In response to the need for detailed representation of bus routes and route stops, a comprehensive data model is proposed in GIS. This model identifies exact route stop locations, bi-directional bus routes, as well as relationships among stops, routes, lines and street networks.

5.4.1 Bus route stops

Bus route stops are individual stop sites that serve one or more bus routes. They are point features from the perspective of GIS. In a referencing system, there are three ways of representing a route stop: based on geometry, based on street network or based on route (Figure 5.5). The spatial locations of stops can be described with coordinates (independent). Stops may also be defined in pure table format, with relation to streets or bus routes, and without directly acquiring coordinates (dependent).

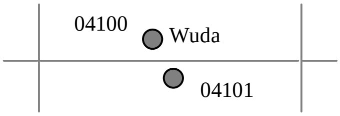
Individual stop locations can be identified by means of point coordinates of the same coordinate system used for the base street network (Figure 5.5a). The coordinates can be acquired through digitising existing stop maps, on-screen designing or an automatic data collection device such as GPS. The topological relationships between stops and streets can be generated through spatial operations in GIS.

By means of linear location referencing, the locations can be decided along street centrelines (Figure 5.5b). A linear location along a street segment is recorded as a percentage of the total distance from the starting point of the segment. Generally a linear measure along a street segment for location referencing purposes pays no attention to whether the measured site is located on the left or right of the segment. Address matching is an exception in that the database keeps the address range on both sides of the street. Similar topological relationships can be added to the attribute table of stops, i.e. to record information on the sides and linear positions of the stops along the street segment. For example, an offset can be added to the attribute table as:

{Stop_ID, Stop_Name, Offset, Position…}

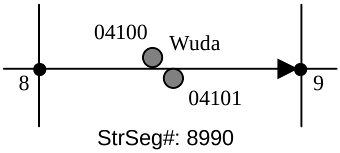
Where for example, a negative value in the offset means the left side and a positive value indicates the right side. The implication of this representation is that the street segments are directional, normally following the input sequence of their vertex coordinates.

A potential problem here is that the street representation may not be detailed enough to allow the precise location of stops. Street networks are conventionally represented by street centrelines instead of street boundary lines. This method has been implemented as a standard for many applications, such as the link-node structure for urban transport demand forecasting, and street address matching for socio-economic activities. The representation of spatial variations of bus stops with the same names requires a more detailed location referencing base than street centrelines. However, as no such referencing base is available, the popular street centreline file has to be utilised. In doing so, some adaptations have to be made.



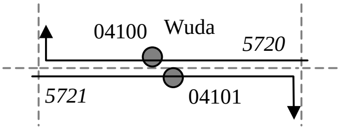
Stop_ID	*Stop_Name*	*X*	*Y*
04100	Wuda	2878	53473
04101	Wuda	2888	53465

(a) Geometry-based



Stop_ID	*Stop_Name*	*Offset*	*StrSeg#*	*Location*
04100	Wuda	-6	8990	45%
04101	Wuda	6	8990	50%

(b) Referenced by streets



Stop_ID	*Stop_Name*	*Route_ID*	*Seq_Nr*	*Location*
04100	Wuda	5720	8	1600
04101	Wuda	5721	6	1450

(c) Referenced by bus routes

Figure 5.5 Three schemes of route-stop representation

Bus stops may also be defined as point events along bus routes in a route system (Figure 5.5c). As it keeps the stops along a route in good sequential order, as well as generates the distances between the stops easily, the event definition is beneficial in certain transit applications. However, when searching for relationships among bus stops defined on different routes, more complex operations are needed. A route-stop table is necessary for many applications.

Each of the above three representations of stops has its advantages and disadvantages. The first method is more straightforward and can generate the other two. Actually, all three representations are convertible as long as they use the same coordinate system. For practical purposes, it is convenient to keep all the three definitions in the database.

The spatial location of each stop has to be identified and assigned a unique identifier. To ensure efficient application, the coding of a stop identifier (ID) requires some attention. A sequential numbering of IDs will undoubtedly work, but the number will not give any indication of the spatial characteristic of the stop. A properly coded stop ID needs to include information on the region in which the stop falls, so that spatial operations in subsequent applications can be minimised. The bus stop inventory database in Atlanta made use of a grid system to number the stops (Sarasua *et al*, 1997). In the case of Wuhan, an appropriate source of areal features is the statistical system, which has a good hierarchy of statistical units and has been used for socio-economic statistics. The medium unit level in the statistical hierarchy is appropriate for such a purpose. The stop ID may have five digits, i.e.

Stat_Unit_Nr (2) + Sequential_Nr (2) + The_Stop_Nr. (1)

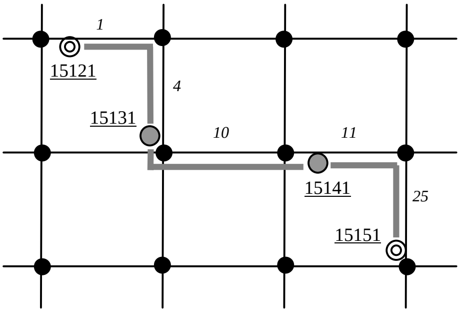
The first two digits are the conventional codes for the statistical unit, the second two digits are the sequential stop number within the corresponding unit, and the fifth digit shows the sequential number of route stops with the same stop name (i.e. line stop name). For example, an ID of “12190” represents a stop located in statistical unit “12”, with a sequential number “19” and the first among the same-named stops (“0”).

5.4.2 Directional bus routes

Similar to the case of positioning stops, bus routes can be represented as either independent or dependent. The independent scheme is to define routes as linear features with coordinates. This representation is widely applied in public transport model networks for transit demand forecasting. It is also possible to maintain bus routes as stand-alone route objects in a GIS database. This independent method has the advantage of simplicity in application and ease of maintenance, but the linkage to street network is not included.

The dependent scheme keeps no geometry of bus routes but defines routes with reference to street networks by making use of dynamic segmentation in GIS. A route is composed of inter-connected sections that are defined by relative positions along street segments. The positions are linear measures along the segments, which are stored in a designated attribute table or a section table. That is to say, a route is defined by measurements along street segments instead of by directly recording coordinates.

Figure 5.6 illustrates how a directional bus route is represented. The graph at the top left shows a schematic street network with segment number, a bus route and its stops with stop ID. The route-stop table at the top right, serving as a linkage between routes and their stops, contains data on route number (R#), line number (L#), direction, stop ID and stop sequential number (Figure 5.6a). The operational details of the route, such as schedule and distance, can be added to the table as required. In order to represent the counter-directional routes of a bus line, an additional code identifying the direction of the route is added to the bus line number. A combination of line number and directional code uniquely determines a route, e.g. “220” and “221” represent bus line 22 in direction “0” and “1” respectively.



(a) Route-stop table

R#	L#	Dir	Stop#	No#
220	22	0	15121	1
220	22	0	15131	2
220	22	0	15141	3
220	22	0	15151	4

(b) Sections by street segment

R#	Sec#	Str#	F_Pos	T_Pos
220	1	1	20	100
220	2	4	0	100
220	3	10	0	100
220	4	11	0	100
220	5	25	100	90

(c) Sections by stops & intersections

R#	Sec#	Str#	F_Pos	T_Pos
220	1	1	20	100
220	2	4	0	90
220	3	4	90	100
220	4	10	0	100
220	5	11	0	85
220	6	11	85	100
220	7	25	100	90

Figure 5.6 Defining bus routes based on dynamic segmentation

The dependent spatial representation of the route is based on tables. The spatial base underlying the definition is the street centreline segments. A route is composed of a sequential list of sections. Each section is described by a street segment and a range with a “from position” (F-Pos) and a “to position” (T-Pos) along the segment. The positions are measured as percentages from the starting point of the segment. Figure 5.6 (b and c) shows two different methods of defining route sections: by street segments without considering intermediate stops (b), and by considering both street segments and stops (c). The former is simpler and easy to manage. The latter has more records in the table, but it gives hints on whether a stop exists. For example, the second and third rows in table c imply a stop exists 90 percent of the way along street segment number 4. Although this latter method is conceptually sound, it is more complicated and requires more technical effort to handle. On the other hand, the definition in table b requires less effort in database construction and is sufficient for general applications.

For the return route of the bus line shown in the above figure, the “direction” (dir) is set to “1”, the sequence of sections in the route table is reversed, and the “from” and “to” positional measures in each section are transposed.

Although recording the return route of a bus line following the same physical route in its two directions causes redundancy in data storage, the scheme indicates good directional orientation of each individual route, which is beneficial for route guidance or trip planning. Since the information on schedules and passengers in two directions is different at a given time, this two-directional representation may provide a better linkage between bus routes and their performances. In fact, no extra effort is needed to adapt this definition into a conventional one, i.e. by simply ignoring one direction of the line.

5.4.3 Linking routes, stops and streets

Based on the previous definition, a data model can be set up integrating bus routes, route stops, bus lines, line stops, streets and schedules (Figure 5.7). The street, route stop and line stop features are geographical layers with attributes. The locations of route stops are also described in the stop table by their relative locations along streets. Bus routes are defined by dynamic linkage to streets via route sections in a GIS. A route-stop table is necessary to link bus routes and route stops. Routes and route stops can be aggregated as bus lines and line stops, where one bus line usually consists of two routes and one line stop is associated with several route stops. The operational details of bus routes, such as schedule and distance, can be attached to the route table as required.

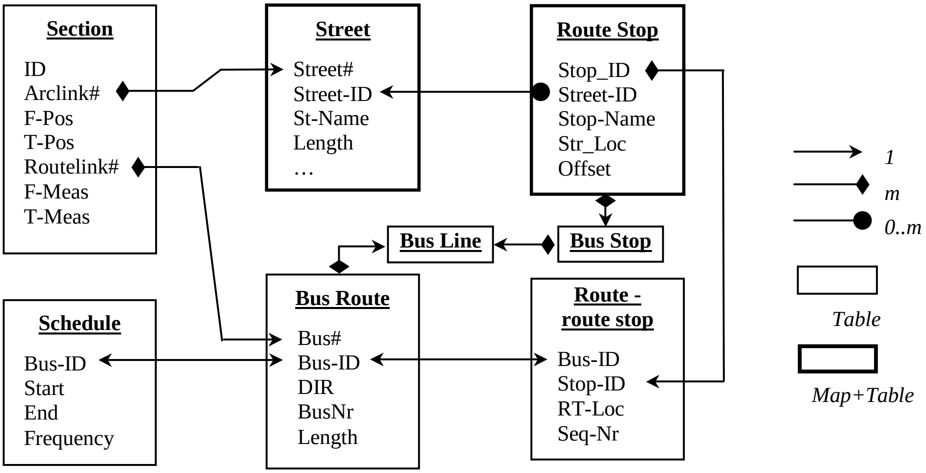


Figure 5.7 A model linking bus routes, lines, stops and street network

It is beneficial to maintain the route stops in a stand-alone spatial layer and link them to bus routes and street networks. With referencing to street networks, route stops can be constructed by screen digitising or coordinate transforming from another data set. The linkage of route stops to street segments can be built up by spatial search or interactive user input with the help of a designated program (e.g. Choi & Jang, 2000). The linkage of route stops to bus routes can be set up with event tables by using dynamic segmentation. Actually, this also means indirectly associating route stops with streets. But when considering that in large cities a route stop may serve many bus routes, it is more convenient to represent the stops in such a direct and independent way.

Making use of this representation model, bus stops and bus lines can be represented in great detail. However, in transport planning and service management, different applications require different levels of detail in data representation. Long-range transport planning works at a strategic level and needs only simplified network representation. On the other hand, trip planning and travel guidance need more detailed representation. The advantage of this model is that the transit network can be easily generated or extracted from the detailed definition to meet the needs of applications at different levels. The task of generation to a less detailed level from the preliminary scheme can be fulfilled by simplifying representations of routes and stops. For example, the bus lines can be represented by one of their directional routes. In the meantime, by ignoring the small variations in spatial locations, the bus stops can be uniquely identified with stop names.

5.5 Applications of the data model in public transport analysis

5.5.1 Acquiring bus volumes on street segments

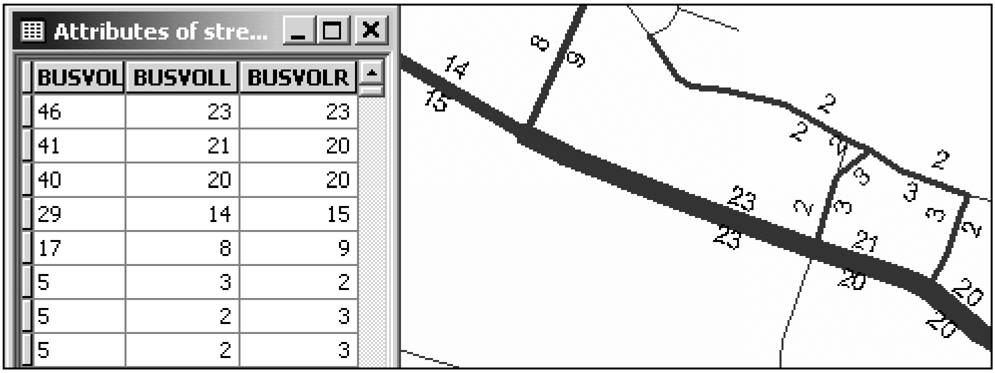
In urban travel demand forecasting, after O-D (origin-destination) flow has been generated and trip modes have been split, trip assignment follows. For bus passenger demand, the assignment procedure will result in demand for bus volume on streets. The forecasted bus volumes may be compared with existing volumes on streets. The detailed bus representation model may facilitate the counting of existing bus volumes on each street segment.

Defining bus routes with reference to street segments is convenient for identifying bus volumes for each street segment. As the linkage between a route and its underlying street segment is maintained in the route definition, when examining a route, all the street segments it passes through can be acquired. On the other hand, identifying a street segment also implies the availability of all routes going through that segment. The following statement gives a structured description of how to acquire bus volume based on table operations (refer to Figure 5.7 for the meanings of the variables):

```
FOR EACH street _segment
    GET street# FROM [street]
    COUNT No_of_routes IN [Section]
        WHERE arclink# = street#
        GROUP BY route_direction (F-Pos>T-Pos vs. F-Pos<T-Pos)
    RECORD No_of_routes for the segment FOR EACH direction
```

Implementing the above task takes several steps in the Arc/Info table environment. Using macro language (e.g. AML), the procedure can be automated. The other possibility is to export both the arc attribute table and the route-section table to a database management system where standard query language is applicable. Apart from a purely tabular operation, a spatial search may also give the same result. The typical sentence for this would be “select all routes that share the same arc with the selected street segment”, followed by some summarisations. Figure 5.8 displays the number of bus routes in two directions on each selected street segment.

If the bus schedules are available, bus volume within a given time span can be estimated for each street segment. The bus volume on each street indicates the existing situation and can be utilised to evaluate travel demand models. By comparing the model outcome with existing bus volume, suggestions can be made in the final planning scenario on how the existing situation can be improved. In addition, the generated bus volume may be utilised to evaluate bus service conditions in the urban area, especially the spatial distribution and intensity. For example, Figure 5.8 shows a heavy concentration of bus routes in a street corridor in Wuhan. This information is important for transport demand management and traffic control.



BUSVOL	BUSVOLL	BUSVOLR
46	23	23
41	21	20
40	20	20
29	14	15
17	8	9
5	3	2
5	2	3
5	2	3

Figure 5.8 Directional bus volume along street segments

5.5.2 Getting bus volume between TAZs

In aggregate transport modelling, the demand for bus travel between each pair of zones can be calculated. The existing operational bus lines can be used to evaluate this demand. For this evaluation, there should be an indication of how many bus lines exist between each pair of transport analysis zones (TAZs). In spatial databases, bus routes are linear features, and TAZs are polygons. A line-in-polygon operation will generate information on which routes pass through the polygons.

As TAZ boundaries are sometimes in close parallel with road segments, the line-in-polygon operation may produce incomplete results, e.g. a route close to a TAZ does serve the zone but may not be recognised as a connecting route. A proper solution to this problem is to create a service area for each route, and overlay the service area with TAZ polygons. In principle, this is a process of creating selection sets that satisfy given criteria. The process may be carried out for each bus line or each directional bus route. For detailed applications, if a bus line takes two different routes in its “outbound” and “inbound” directions, then the sequence and number of TAZs connected by the two routes may be different (Figure 5.9). Another possibility for creating the TAZ selection set is to make use of route stops directly, in which case the process will be a buffered point-in-polygon operation.

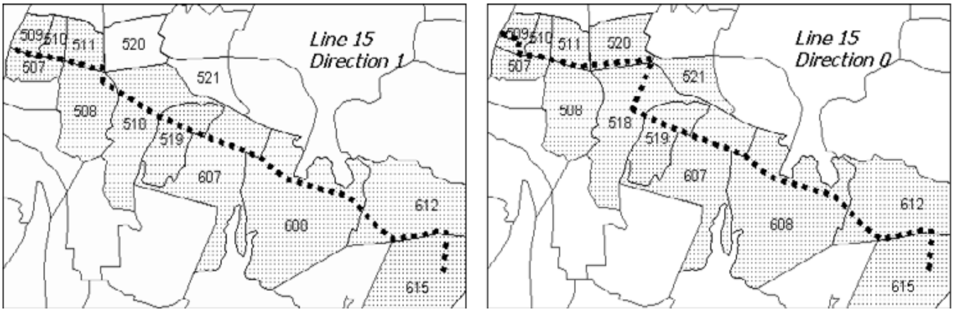


Figure 5.9 Two routes of one bus line serve different TAZs

An empty O-D matrix for this purpose can be created out of the standard transport O-D matrix. The matrix is updated after each search of a route that generates a selection set of zones. The connectivity between any two zones in the selection set can be detected using stops on the source route. This is a complex process because of the request for direction. The general rule is to start from the first stop in the route, and to identify connections of the first TAZ to other TAZs in which other stops fall. The value of each pair of zones in the matrix is incremented once if a connection is detected. Table 5.1 shows a part of the matrix after the search in Figure 5.9. In the situation where a bus line runs different directional routes, the TAZ connection table may not be symmetrical.

Table 5.1 TAZs connected by two routes of one bus line

To From	…	518	519	520	521	607	608	612	615
…									
518		2	1	0	0	1	1	1	1
519		1	2	0	0	1	1	1	1
520		1	1	1	1	1	1	1	1
521		1	1	0	1	1	1	1	1
607		1	1	0	0	2	1	1	1
608		1	1	0	0	1	2	1	1
612		1	1	0	0	1	1	2	1
615		1	1	0	0	1	1	1	2

5.5.3 Evaluating bus services

The evaluation of bus services requires information on bus operations and their servicing area as a whole in a city. The length of bus routes can be retrieved from the route definition. For example, a query on 25 routes that pass through one street segment in the Wuhan database reveals the following facts:

Maximum length: 32119 m
Minimum length: 5766 m
Average length: 17629 m

0 ~ 12 km: 5 routes
12 ~ 22 km: 14 routes
22 ~ 40 km: 6 routes

The Chinese national standard for length of bus route in a built-up area is up to 12 km (Ministry of Construction, 1995). The statistics show that most bus lines have been operating over a longer distance than that suggested by the standard. Local transport planners often complain that the distance of individual bus lines is too long, but find it difficult to produce detailed statistics without a spatially integrated bus database. The alignment of bus routes along street segments can effectively generate such information.

With information on route length and relevant data, some other variables can be estimated. One case is the vehicle miles travelled (VMT), which is generally used in transport evaluation. As most bus schedules are fixed during a given period of time, the VMT for each bus in a day can be obtained by multiplying its route length in two directions by its number of runs. By accumulating the value, the VMT for all buses in a city can be estimated. The number of bus hours in each run can also be estimated by dividing route length by the expected average speed. For example, in large Chinese cities the average speed in normal traffic conditions is between 16 and 25 km/h. If a route length is 20 km, then the expected single-trip run will take 48 to 75 minutes. To put it the other way round, if bus operating records show the time actually used between start and end stops, then the average running speed can be estimated. The benefit is that the route length can be precisely determined through the route data model.

The generation of bus service areas has been a typical showcase for GIS applications in urban transport. The process is characterised by creating buffer zones around bus routes or bus stops, and by overlaying the zones with streets or land uses (Nyerges, 1995; Thorsen & Rasmussen, 1999). Bus service levels can be evaluated by identifying those areas served and not served by bus lines. When detailed land use or census data are available, the serving areas can even be created for each bus line, and socio-economic data within each serving area can be summarised. A detailed bus route representation will also generate a larger service area than that of a conventional one. For example, when a radius of 300 meters is used for creating zones, if the distance between a stop pair is 10 meters, then the service area will be 2 percent more than that of a single stop in a representation based on a conventional bus line.

5.5.4 Integrating data from public transport surveys

Planning and evaluating public transport services requires detailed operational data that can be partly acquired from on-site surveys. Surveys of urban public transport involve a comprehensive effort that usually generates large amounts of data. Apart from socio-economic characteristics, the respondents have to answer questions concerning the bus lines and bus stops that they use during their transit trips, e.g. stops of boarding and alighting, trip origins and destinations, number of transfers and trip frequencies (Cambridge Systematics, 1996; GIS/Trans, 2001). Bus routes in the survey are used as key identifiers, usually marked by directions.

Data from public transport surveys are attached either to the bus stops, e.g. boarding and alighting, or to the whole or parts of bus routes, e.g. passenger characteristics and schedules. When the spatial itineraries of the directional routes are available, the survey results can be attached for spatial visualisation and analysis. This method may enhance traditional data processing of survey data, and gain new insights into the spatial characteristics of the public transport system. For example, along a directional route, passenger volumes can be mapped between stops as linear route events, indicating travel demand for any given period of time. If the same information is visualised for all the bus routes, the spatial distribution for transit trips will be disclosed. In this kind of processing, data in two directions makes a big difference, especially in peak hours. Therefore, the directional representation scheme is important to the integration of transit survey data.

5.6 Application in passenger trip guidance

5.6.1 A bus trip guidance framework

Trip guidance is a topic in ITS. For public transport, passenger trip guidance is to provide schedule and transfer information prior to travelling (pre-trip planning), or to provide real time messages showing arrival and departure of public vehicles. These are generally referred to as an Advanced Public Transport System (APTS), which helps to increase travel efficiency and service quality. This section focuses on the issue of trip guidance in the aspect of pre-trip planning, and demonstrates how the route data model can facilitate this purpose.

Fundamental to a bus trip guidance system are the base street network and the bus route system described earlier in this chapter. A complete trip guidance framework involves the following steps: 1) constructing an effective bus route network; 2) generating the user trip path; 3) searching for bus route trips and transfers; and 4) giving bus trip and transfer guidance. Firstly an effective bus route network is set up, which contains those routes in operation during the time period when a transit trip occurs. Based on shortest distance algorithms, this network is used to generate a physical user trip path. The user trip path serves as a clue for searching for bus routes and route connections. Plans for bus routes and transfers are generated from the search results and, when necessary, by considering the schedules of the routes involved. In cases of a transfer, further details are produced on how to move from an alighting stop to a boarding stop.

To fulfil these tasks, the bus route data model is expanded to include features needed in trip guidance. Figure 5.10 shows a class diagram for generating bus trip guidance. Based on the Unified Model Language (UML), the diagram contains object classes and their static relationships in a conceptual perspective (Fowler & Scott, 2000). Apart from the general object feature and line segment feature, three spatial features, i.e. the BusDirStop, BusDirRoute and Userpath, are important to the guidance application. The BusDirRoute means directional bus route, as discussed previously, and similarly the BusDirStop indicates directional individual stop sites. There is an association class reflecting multi-multi relationships between the stops and routes. The UserPath class contains a user path feature resulting from bus trip optimising. For convenience, a user path feature is usually defined as a route feature. The Transfer class contains detailed information on user bus trips, generated on the basis of user path and directional bus routes and stops.

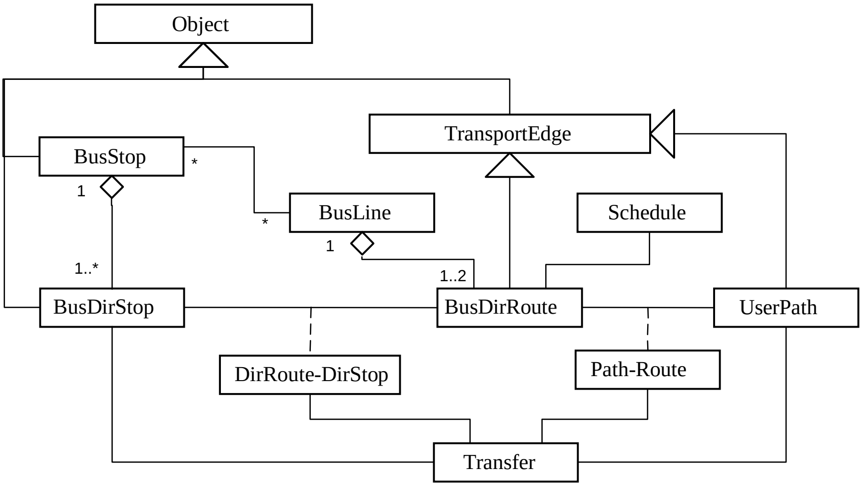


Figure 5.10 Conceptual object class diagram for bus trip guidance

5.6.2 Constructing effective bus network

In a heavily transit-oriented city, duplicate bus routes are common and their headways are different. This characteristic makes the scheduling problem quite complicated. The first important thing is to construct an effective bus network for optimal path searching. Defining bus routes with reference to the street network is convenient for constructing a bus network. An effective solution is to select all the street segments in a base street network that have associated bus routes (Figure 5.11a). General path searching algorithms will then be applied to this selected set.

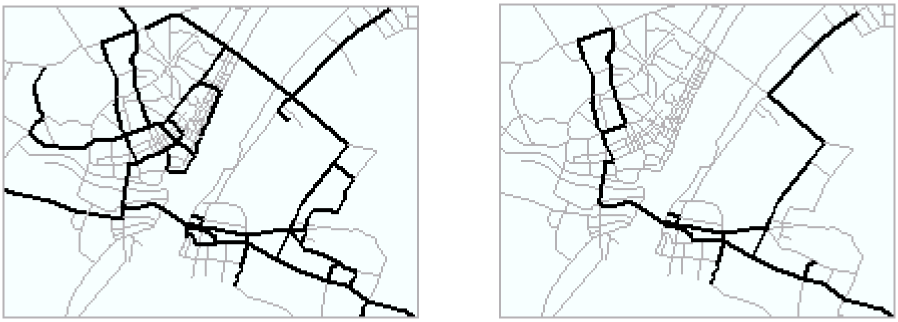

(a) 5:00 ~ 21:00
(b) 21:00 ~ 5:00

Figure 5.11 Bus route networks at different time periods

If a path at a specific period of time (such as between 21:00 and 05:00) has to be found, bus schedule data will be utilised (Figure 5.11b). In this case it is easier to construct a new set of street segments, which is supposed to be quite different from the former one. This network construction ensures each of the street segments has at least one bus route running through it, which can facilitate the subsequent processes of optimisation and route searching.

5.6.3 Generating user trip path

For optimal path finding in the whole street network, a variety of algorithms are available (Zhan & Noon, 1998). When applied to transit networks, the shortest path algorithms have to be adapted to reflect special characteristics such as time schedules (Koncz *et al*, 1996; Wong & Tong, 1998). Peng & Huang (2000) have categorised transit shortest path finding into two groups, i.e. headway-based and schedule-based, and combined the two approaches for system-wide path building. In an online interactive trip planning system, users are supposed to search for the optimal path based on their specific criteria, such as shortest time, least transfers or greatest comfort. A path with trip chaining may also be incorporated based on the combination of different optimising criteria.

For practical transit applications, it is also necessary to provide passengers with several path choices. In addition to generating user paths from specialised network routing programs, interactive trip planning systems may also allow users to designate their paths manually.

Within the framework of the route data model, a user trip path is generated using shortest distance algorithms on the bus route network available at a given time period, which is also a subset of the base street network. The user path is represented by a traversal referenced by a set of sequentially connected street segments. The user path in these circumstances is a physically optimised path that does not as yet give trip information on which route to take or how to make a bus transfer. A final optimal route can be acquired after searching the bus routes on the user path and comparing the schedules of these routes. As the purpose of this study is to explore the ways of providing best guidance to travellers, less emphasis is put on the schedule-based optimisation.

5.6.4 Searching bus routes

When a user path is generated, the street segments along the path are recorded sequentially in a table, or directly converted into a path route. A route is directional in that it records “from position” and “to position” along each street segment. This link direction can be used to find those bus routes that run through the segment in the same direction, which is the process of matching F-Pos and T-Pos on the same street in two tables. The general rule is that the same street segment is associated with one user path route and several directional bus routes. If the F-Pos is larger than the T-Pos in the user path table, then those bus routes whose F-Pos is larger than T-Pos are in the same direction as the user path (shadowed rows in Table 5.2). The matched results are kept in a path-route table for subsequent bus route searching. This matching method simplifies route searches by avoiding direct acquisition of street network table.

Table 5.2 Matching directions of bus routes and user paths

Directional bus route			
DirRoute	Street	F-Pos	T-Pos
660	375	0	100
661	375	95	0
150	375	0	100
151	375	100	0

User path			
Path_Sec	Street	F-Pos	T-Pos
1	373	0	100
2	376	0	100
3	375	100	0
4	370	100	0

The path-route table contains, among other things, all the user path sections and the directional bus routes that run through these segments (Table 5.3a). This table is utilised for identifying the types of bus access between origin and destination. The types of bus access may be classified by number of transfers, i.e. direct access (no transfer), one transfer, two transfers and so on. According to the definition of the route network, there must be at least one bus connection available along the user path, no matter how many transfers are made.

To identify possible types of access, the simple statistical frequency for each bus route in the path-route table is acquired (Table 5.3b). In the frequency table, if the frequency of a certain route equals the total number of sections of the user path, then this bus route is a direct connection between the origin and destination and no transfer is needed.

Table 5.3 Path-route table and frequency table

(a) Path-route table

Path section	DirRoute
1	8060,5520,5720
2	8060,5520,5720
3	151,661,8060
4	151,121,661,8060

(b) Frequency table

DirRoute	Frequency
8060	4
5720	2
5520	2
661	2
151	2
121	1

To search for connections with transfers, the situation is more complex. As two or more transfers can always be simplified to a one-transfer problem, only the one-transfer search process is illustrated here. Bus routes with direct access are firstly excluded from the route set. Then, all the bus routes running through the first and last section of the user path are enumerated respectively. Next, each route in the first section is matched with each in the last section to create a two-route pair. The frequencies of the two routes in each pair are summed. If the sum is equal to or higher than the total number of path sections, then the trip can be accomplished with these two routes in one transfer.

The process of transfer identification is summarised in Figure 5.12. It has to be noted that in a rare case a user path generated from a subset of the bus network may be associated with only one directional route in some of its sections. This will produce no solution if the route runs in an opposite direction to the user path. To avoid this situation, a check can be made early at this stage, or at the previous stage.

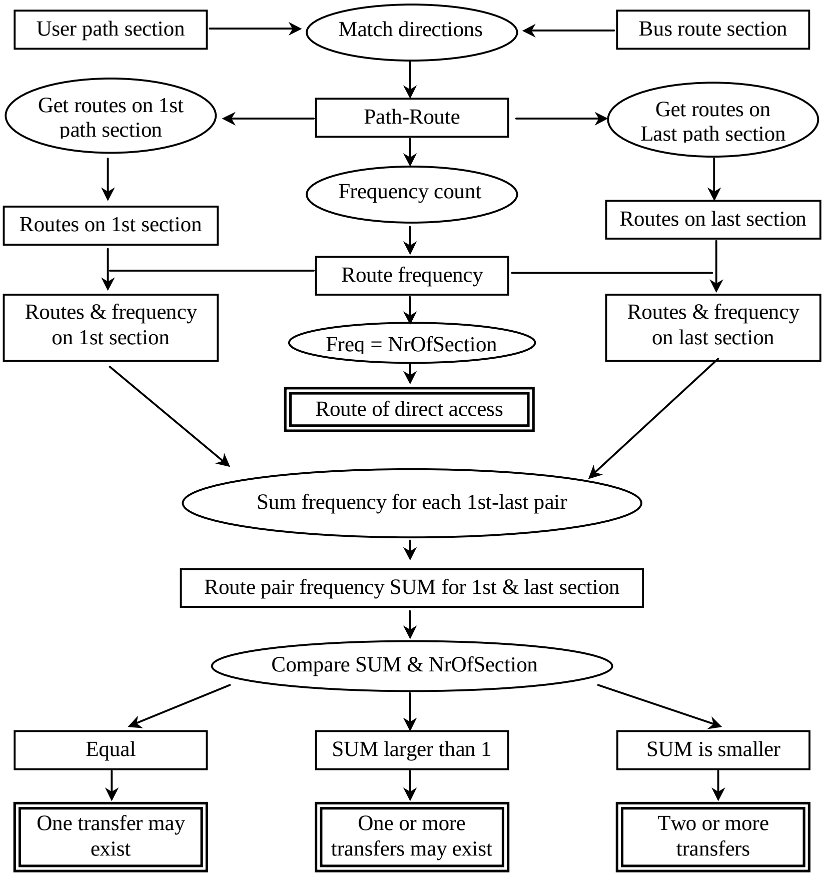
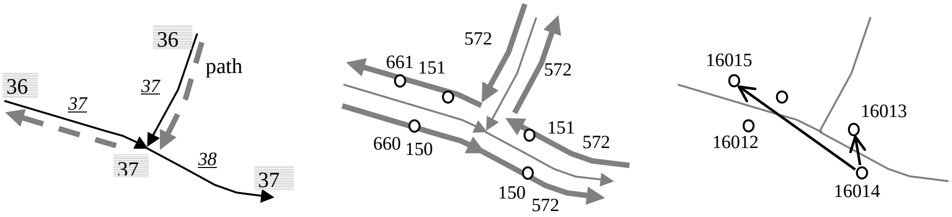


Figure 5.12 Identifying bus route access and transfer

The problem now becomes where the transfer will be made. If the two routes have overlapping segments, then a transfer can be made at any stop along these segments. A more difficult case is where the two bus routes do not overlap but intersect somewhere along the user path. The general procedure to solve this takes three steps. Firstly, find the intersection node. Secondly, search all the stops distributed within a certain distance around the intersection. This may be achieved by either a spatial search or a tabular search. Thirdly, from the route-stop table, find the two individual stops that serve the two directional routes. When the two stops are available, transfer guidance can be determined. In addition to the route number, the system may explain further which individual stop to take in a transfer. Figure 5.13 depicts the elements necessary to this transfer search. The advantage of defining directional bus routes is seen in this application.



(a) Links and user path (b) Routes with directions (c) Stop transfer

Figure 5.13 Elements needed in searching for bus transfer

It needs to be noted that basically the route search makes use of route and path sections that are referenced by street segments. This can be referred to as a section-based search, as against a stop-based search. The stop-based search follows a different method: firstly stops on streets underlying the user path are identified; then route connections are designated by matching routes at origin, intermediate and destination stops. One apparent disadvantage of a stop-based search is that it will omit the case described in Figure 5.13, as stop 16014 is not located on the streets underlying the user path.

5.6.5 Giving trip guidance

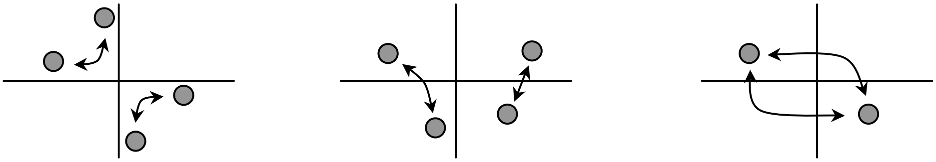
From the previous route search, each section of the user path may be associated with more than one bus route. When putting all the routes together in sequential order, optimal plans for bus taking can be made and transfer points decided. Usually the plan will also contain more than one scenario if several bus routes are available on the path. In the example of Table 5.4, there are three bus connections between origin and destination, one with direct access and two with one transfer. For each connection, a description of bus taking can be made.

Table 5.4 Passenger bus trip connections

Trans_ Type	Trans_ ID	SeqNr	Bus route	F_stop	F_name	T_stop	T_name
0	1	1	8060 (806)	16041	Wuda	16052	Fupo
1	2	1	5520 (552)	16041	Wuda	16014	Butun
1	2	2	151 (15)	16013	Butun	16052	Fupo
1	3	1	5720 (572)	16041	Wuda	16014	Butun
1	3	2	661 (66)	16015	Butun	16052	Fupo

These descriptions have to be accompanied by a map showing the locations of the stops and their names and codes. From the passenger's perspective this method is not straightforward because of the ambiguous depiction of the directional stops. Although with the help of a map their locations are clearly shown, the map and the stop codes are not always available to the public. This is more problematic during a transfer around an intersection. At an intersection there are three or four street segments and buses could go in various directions. In this case it is very important to guide the passenger to the correct stop. When a two-stop pair for transfer is identified, the spatial locations of the two stops relative to the streets can be retrieved, and a simple spatial operation will tell how to get from one stop to another.

Consider a four-street intersection, the relationships between stops can be categorised into three groups (Figure 5.14). The first group relates to stops in the same quadrant of an intersection, which means no street crossing is necessary to make a transfer. The second group relates to stops where the traveller has to cross a street once. The third group relates to stops on two opposite corners, indicating a longer walking distance and street crossing twice. These relationships can be detected simply by connecting the two stops to form a line segment, and using a spatial intersection to identify how many times this segment intersects with the street segments.



In the same quadrant

Cross one street

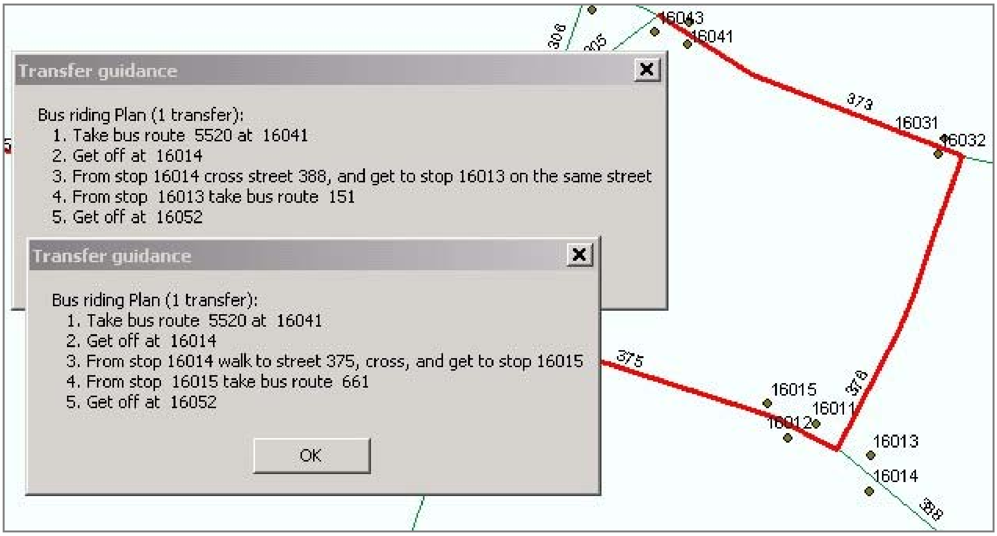
Cross two streets

Figure 5.14 Transfer at a four-street intersection

When the type of transfer has been identified, text descriptions can be generated to give more explicit directions. For example, the following sentences could be the descriptions for the three groups of situations.

- *The same quadrant*: go from stop 1 along street 1 towards the intersection, turn left / right at the intersection to street 2, walk about 50 m to get to stop 2.
- *One-street crossing*: cross the street where stop 1 is located to get to stop 2; or walk along street 1 from stop 1 towards the intersection, find street 2 and cross, turn left / right, walk for about 100 m to get to stop 2.
- *Two-street crossing*: cross street 1 where stop 1 is located, cross street 2, find street 3, walk about 20 m along street 3 to get to stop 2.

Figure 5.15 shows an interface in ArcMap with maps and examples of bus trip guidance. In the guidance descriptions, the street number can be easily replaced by street name, using a database search. A street name is often used for location referencing in cities.



Bus riding Plan (1 transfer):
1. Take bus route 5520 at 16041
2. Get off at 16014
3. From stop 16014 cross street 388, and get to stop 16013 on the same street
4. From stop 16013 take bus route 151
5. Get off at 16052

Bus riding Plan (1 transfer):
1. Take bus route 5520 at 16041
2. Get off at 16014
3. From stop 16014 walk to street 375, cross, and get to stop 16015
4. From stop 16015 take bus route 661
5. Get off at 16052

Figure 5.15 An example of bus trip guidance

For giving clear guidance on transfers, other information on transport facilities and land use is helpful. This includes pedestrian paths, zebra lines, traffic lights, pedestrian overpasses and underpasses. If properly integrated, these pedestrian facilities may help to provide consistent instructions on how to walk from one bus stop to another. Land use information such as landmarks and special buildings may also serve as good indications of direction. Including all this information in transfer guidance falls under the broader topic of transport data integration.

5.7 Conclusions and discussions

The current practice of bus representation has been extended to meet the requirements of public transport applications. The new scheme is based on phenomena that exist in large transit-oriented cities, where depictions of individual route stops and directional bus routes are necessary. No comprehensive effort to provide such details has been made in previous studies. It is also appropriate to implement the representation in a GIS environment, where the techniques of dynamic segmentation and data integration are available. The linkage between routes, stops and urban streets is maintained in the data model, which facilitates the integration of such transport data as socio-economic activities, bus schedules, transit surveys and trip guidance. In addition, some application examples have specifically demonstrated the effectiveness of this data representation model.

While the extended scheme facilitates detailed analysis on public transport and passenger trip planning, the construction of the whole database necessitates intensive effort. When a base street segment changes, some of the bus contents have also to be updated. Furthermore, the application of dynamic segmentation implies that the base street network and related database should always be loaded into the system during operation, which may require more system resources than a stand-alone but less integrated bus system.

This chapter has demonstrated techniques of linear data integration and their applications in transport analysis. It can be concluded that dynamic segmentation is the fundamental technique for dependently referencing such linear features as bus routes. For the general task of transport data integration, several challenges have still to be met. This research does not show exactly how to integrate and apply schedule data in the bus representation model. In addition to the bus mode, public transport is also concerned with other modes, e.g. subway, light rail and tram. These other modes have their own characteristics in spatial distribution, and representation of these lines may entail scenarios different from those of bus line representation. Therefore, more effort is needed on how to represent the other modes effectively and, most importantly, on how to integrate the different representations in a multimodal public transit system.

Chapter 6 Disaggregating Zonal Data For Transport Applications [*]

6.1 Introduction

A zone is a spatial area that has some common characteristics. In geographical information science, zones are represented as polygons, either in vector format or in raster format. Land uses, statistical units, postcode zones and administrative jurisdictions are zones that might be needed in urban transport planning. For example, the relationship between land use and transport is always a topic for transport planners. While the transport facilities are basically linear in nature, land uses tend to be grouped parcels or zones that are usually associated with classified categories of uses. The transport analysis zone (TAZ) is a spatial zone that forms the foundation of conventional transport model systems. In such aggregate modelling systems, each TAZ is attributed a number of trip origins and destinations. These trips are then assigned to the road network, based on the interaction between TAZs.

The TAZ needs to be associated with information on numbers of residents and employment, which are derived from statistical units or land use categories. An important aspect of transferring data from statistical units or land use parcels to TAZs is the compatibility of their zonal boundaries. If the TAZs spatially contain the source zones, then data transfer is a matter of aggregation. However, in most cases this straightforward spatial relationship does not exist. This incompatibility problem falls under the general topic of areal data integration, usually solved by techniques of areal data interpolation. Areal interpolation methods are applied in cases where the target zones and sources zones are spatially incompatible.

The advocates of disaggregate analysis in transport planning have reduced the spatial analysis unit to the finest level. Such small units may take the form of individual point sites, or small areal units such as raster cells. While the developments in positioning technologies and socio-economic databases have provided promising instruments for data collection at this detailed level, there is still a lack of sufficient means to effectively collect such detailed data for large regions. This implies that most data have to be generated from larger spatial zones such as statistical units. From the spatial perspective, this calls for the task of disaggregating data from larger zones to smaller zones.

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[*] Based on Huang, Ottens & Masser (2003).

Looking back to the TAZ issue, the process of deriving TAZ data from statistical units can be accomplished in two steps, i.e. a disaggregation step and an aggregation step. Therefore, a disaggregated data set may serve both aggregate and disaggregate modelling. This disaggregation issue is the focus of this chapter. Firstly the general issue and approaches to zonal data interpolation are introduced. Then the characteristics of zonal transport data in Chinese cities are discussed, which sets the local context for data disaggregation. A weighted method for disaggregation is proposed, and is incorporated into two disaggregation methods. Experiments are carried out with these two methods within GIS, and a comparison is made between the results of the two methods. Finally, based on the analysis and discussion, some conclusions are drawn.

6.2 Approaches to zonal data integration

6.2.1 Zonal data transition

Spatial planning for social applications involves various types of zones. The size and shape of these zones may have significant influences on the outcome of statistical analysis. The modelling of different geographical processes makes use of different spatial unit systems, which generates the modifiable areal unit problem (Openshaw, 1983). Socio-economic phenomena have to be associated with spatial zones. However, the use of socio-economic data for planning has to be cautious in terms of zones that the data represent, because quite often zones designed for one purpose may not be suitable for another (Alvanides & Openshaw, 1999). As data have been collected with different scales and spatial units, it is necessary to transfer data from one zone system to another. Depending on the types of data available, the manipulation of areal data may follow one of three processes, i.e. aggregation, interpolation or disaggregation (Figure 6.1). Such data transition tasks include a set of source zones and a set of target zones, in which data units in source zones are transferred into target zones.

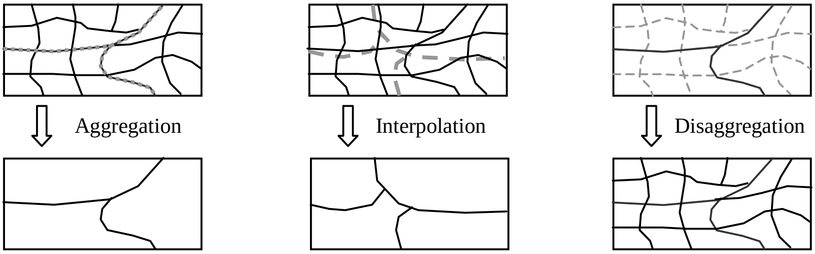


Figure 6.1 Three types of data transition from source to target zones

6.2.2 Aggregation

Aggregation requires generating larger zones from some basic spatial units. For example, enumeration districts for census planning in the UK are delineated from the basic unit of the postal address, and the districts have to be adjusted for each census effort (Martin, 1999a). The census tract forms a geographical base that can be aggregated for many socio-economic applications (Huxhold, 1991; Salvemini, 2001). Another example of aggregating statistical units is the generation of TAZs for transport demand modelling. When smaller statistical and land use units are available, the formulation of TAZs is a process of spatial aggregation. The design of the TAZ should consider several criteria, such as homogeneity of land use, zone size, compactness, completeness, uniqueness, compatibility with other zones, and so on (Masser *et al*, 1978; Garber & Hoel, 1988; O'Neill, 1991). Automatic or interactive TAZ generation may be carried out with the aid of GIS technology and statistical methods such as spatial autocorrelation (You *et al*, 1997; Ding, 1998). Alvanides and Openshaw (1999) have developed a specialised package for designing zonal systems.

6.2.3 Areal interpolation

Areal interpolation refers to the transition of data from source to target zones, where the two sets of zones are of similar size and intersect with each other (Goodchild & Lam, 1980). Two basic types of areal interpolation have been available: the non-volume-preserving methods that are actually point-based areal interpolation, and the volume-preserving methods that are based directly on zone operations (Lam, 1983).

A point-based areal interpolation is suitable for generating surface distributions in raster data structures, which are independent of any zonal considerations. A typical application is to produce a surface model for population-related data from centroids of census enumeration districts (ED) (Martin, 1989; Martin & Bracken, 1991). The method is especially applicable to regional geographical phenomena where socio-economic activities are evenly distributed.

The area-based volume-preserving methods refer to either the polygon smoothing, such as the pycnophylactic approach that is based on raster cells, or the area-weighting approach that is based on polygon overlays. The pycnophylactic approach creates a smooth surface with raster cells from a choropleth map (Tobler, 1979). The data values in the raster cells are then aggregated into the target zones. The approach performs less satisfactorily where abrupt variations in value occur.

The area-weighting method assumes a homogeneous distribution of values within source zones and may yield good results on population estimates at the census tract level (Goodchild & Lam, 1980). The concept of overlay has become an important function in GIS. The following equations are the basic principle for the estimation. Each target zone t has several partitions ts delineated by source zones, and the population of this zone P_t is the sum of the population of all the partitions P_{ts}. The population in each partition *ts* is estimated as a proportion of the population of the corresponding source zone *s*. The proportion or weight is based on the area of the partition in relation to the total area of the source zone.

$$P_t = \sum_s P_{ts} \quad \text{and} \quad P_{ts} = \frac{A_{ts}}{A_s} P_s$$

With statistical techniques, the areal weighting estimation can be further improved by using ancillary data from the target zones (Flowerdew & Green, 1994) or from a separate set of "control zones" (Goodchild *et al*, 1993). More satisfactory results may be achieved by the raster-based dasymetric mapping approach that also utilises ancillary data from the local environment (Fisher & Langford, 1995). Depending on the types of data available, Mrozinski and Cromley (1999) have identified four categories of areal interpolation and demonstrated how the interpolation can be improved by using spatial interaction models in vector-based GIS.

Source and target areal data may be represented by both raster and vector structures. The benefit of cell-based interpolation is that the source zones are disaggregated into small units that can be aggregated to any kind of target zones when necessary – which is regarded as an appropriate solution to the modifiable areal unit problem. Vector-based interpolation may achieve the same result only if a set of base spatial units (such as detailed land use parcels) exists. As the techniques are sensitive to specific situations, the contexts of the applications have to be understood correctly to ensure utilisation of appropriate interpolation methods.

6.2.4 Disaggregation

Disaggregation is a special case of areal interpolation, in which the target zones are smaller than the source zones and there is no boundary intersection between them. Due to this spatial relationship, the spatial computation required in the vector data model is greatly reduced, and the use of the area-weighting method is more straightforward. Disaggregate data are important to various kinds of disaggregate models, such as the micro-simulation models, which are extensively based on small spatial units.

Actually, the first step in the traditional areal interpolation processes is already a disaggregating process. Cell-based interpolation approaches, such as the surface modelling and pycnophylactic methods, generate data for each cell. It is true that the area-weighting method also has intermediate results on overlaid partitions, but only in that they are not as regular as the cells.

For socio-economic phenomena, source data are usually related to statistics or registrations that have clear and discrete spatial boundaries. That is to say, volume-preserving methods are appropriate to the disaggregation of the data. Depending on the types of data available, statistical methods such as regression and expectation-maximum likelihood (EM) may produce good results (Flowerdew & Green, 1994). Regression methods require a minimum amount of zone data and many interactions to test the statistical significance. Sometimes they cannot reflect the real world situation, in that certain regression coefficients may not be positive and alternative methods have to be applied (Goodchild *et al*, 1993).

Monte Carlo simulation is another raster-based technique for socio-economic data disaggregation. The method requires a separate data source showing the “weight” of possible distribution, such as the land use types. Take land use for a population disaggregation as an example; in this process, each raster cell is assigned a weight according to its land use type. The weight is expressed as an integer number, which is larger for residential cells and smaller for other cells. Accumulating the numbers for all the cells of the statistical zone and for each cell will get a number range. The possibility of data falling inside a cell is expressed by the ratio of its weight number to the total accumulated number (total weight). A number generator creates a random number between 1 and the total weight, and the value of a cell is incremented by 1 if the random number falls inside the number range of the cell. Repeat the random number generating process for the number of times that is equal to the number of residents in the statistical unit. The final result is a map showing the population in each raster cell. The procedures and applications of this method are thoroughly illustrated by Spiekermann and Wegener (2000) and Wegener (2001).

One of the major applications of disaggregating zonal data is to satisfy the data needs of modelling at the micro level. Wegener (2001) presented an integrated micro-simulation framework for evaluating urban development policies. The model tools module in the framework simulates land use and transport activities, which takes synthetic micro data such as household and employment as its input. In the PROPOLIS study, by adding the environmental factor to the land use–transport model, a raster-based micro data model has been developed to simulate the local environmental and social impact of urban policies (Lautso *et al*, 2002). Disaggregated data are also an important input into the origin-destination model in traffic activity simulation or dynamic traffic assignment.

6.3 Zonal transport data in Chinese cities

6.3.1 Three types of zonal transport data

Land use, statistical units and transport analysis zones are the spatial areal units that are relevant for transport planning in Chinese cities.

Land use change in most Chinese cities has been very fast during the last two decades, and is manifested in both the rural-urban transition in fringe areas and the restructuring of inner areas. Due to these changes, land use boundaries shift frequently. Since these changes cannot be captured with such high frequency, land use data used for transport modelling purposes may not reflect the most recent situation. According to the Chinese standard urban land use classification, 10 major classes can be identified, i.e. residential, public facility, industrial, green, road or square, outward transport facilities, warehouse, special, utilities and non-built-up areas. However, in inner cities land uses are often mixed, especially residential and commercial uses. Two distinguishing phenomena exist: one is that in a building block the buildings immediately next to roads are commercial, while the inner or central areas are residential; the other case is that mixed uses occur within one building, with lower floors for commercial and upper floors for residential uses. Another common phenomenon is that a large institutional land tract is usually a mixture of office and residential uses; this is a typical practice in contemporary Chinese urban planning. While this situation has significantly minimised motorised travel demand in a given period, the highly mixed land use structure creates traffic problems in the long run.

The statistical unit system is closely linked to the administrative unit system in Chinese cities. The administrative hierarchy for cities is as follows: the municipality – district / county – street / town – residents/village committee. In the statistics for the year 2000, Wuhan municipality has 13 districts, 185 streets or towns, and 4,012 village or residents committees (Wuhan Statistical Bureau, 2000). Socio-economic data for the lowest unit is available from the census database, but the spatial delineations of their boundaries have never been completed. Also, for administrative reasons, these data are normally inaccessible to the general public. Therefore, the street level has become the smallest available statistical unit. Even at this level, the population structure and many other socio-economic indicators are not available, and, most importantly, the spatial boundaries of administrative streets may still be unclear. Due to historical reasons, sometimes streets have irregular shapes, making them difficult to integrate with other zones. For example, the TAZ delineation requires compact shapes, which will not be attained if street boundaries are strictly followed.

Three rules have been used to guide TAZ delineation: firstly, each TAZ should contain about 10,000 residents; secondly, TAZs should follow existing administrative boundaries as far as possible; and thirdly, a TAZ should have a compact shape. The first rule is to restrain TAZs within a scale appropriate to the dimensions of Wuhan city. The second rule ensures the utilisation of statistical information at the street level. In inner areas a TAZ is composed of one or more administrative streets. The third rule follows the general requirement of theoretical TAZ boundary delineation. However, this may contradict the second rule, as a street or street group may take on quite an irregular shape.

6.3.2 Spatial relationships among the zones

Spatial compatibility among these zones influences the integration of zonal data. Land use parcels are generally formed on the basis of building blocks in urban areas, and therefore are compatible with statistical units and TAZs. The relationship between statistical units (streets) and TAZs is complex, but the delineation of TAZs requires this problem to be solved. Most problems of incompatibility arise at the fringe of the built-up area, where street boundaries are not clear, or in irregular shapes, or too big.

There is another fundamental aspect influencing the compatibility among the zones, i.e. the base referencing system. Topographical maps usually serve as such bases. The coordinate system is slightly different between large-scale and small-scale topographical maps. When these two kinds of maps are utilised, coordinates should be transformed. However, institutional coordination is usually weak, each organisation having its own set of systems. Even when using the same base referencing system, it is still difficult to exactly match data from different agencies. Zones such as land use, administrative boundaries and TAZs are designed independently by different agencies for their own usage, without considering compatibility with other zone systems.

The spatial relationships among TAZ, land use and street (statistical unit) in Wuhan are summarised in Table 6.1. The TAZ and street as statistical unit may intersect with each other in the fringe urban area. For aggregate transport modelling, socio-economic information such as population and employment has to be transferred from statistical units to TAZs.

Table 6.1 Spatial compatibility among transport zones in Wuhan

	Street (SU)	TAZ	Land use
Street (SU)	-	Contained/Intersect	Contain
TAZ	Contain/Intersect	-	Contain

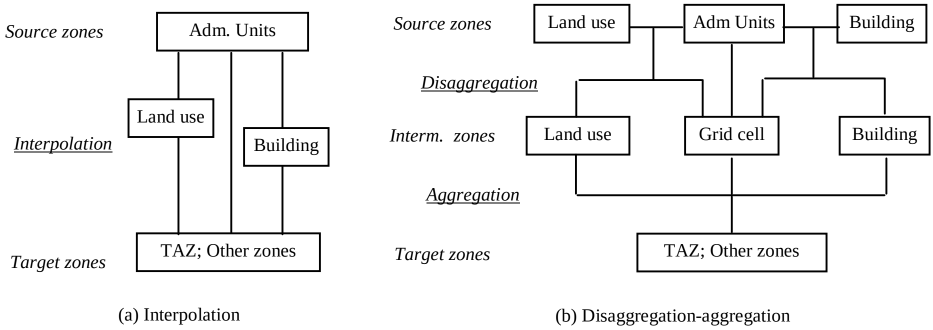
More complicated disaggregate transport models simulate activities on a regular base unit, usually the raster cell of appropriate size. The raster cells may be regarded as special zones for disaggregate applications. Socio-economic information in each cell may be acquired from the statistical unit and land use zones.

6.3.3 Towards an adaptable TAZ system

Based on their spatial topological relationships in urban Wuhan, the estimation of socio-economic data in transport modelling zones from statistical and land use zones may take two approaches, i.e. interpolation and disaggregation-aggregation (Figure 6.2).

The areal interpolation process is used in cases where administrative units (streets) are not compatible with transport zones. Interpolation algorithms operate on the two spatial units under the assumption of even distribution or maximum smoothing, with or without ancillary information on land uses and buildings (Figure 6.2a). As stated earlier in this chapter, a number of techniques are available for the interpolation. This interpolation method is suitable in the case where TAZ boundaries are fixed and will not change. In other words, one session of interpolation is implemented only on one set of TAZ delineation and statistical zones. If a new set of TAZ delineation is necessary, the process has to start again.

The disaggregation-aggregation process is applicable in situations where certain intermediate units are available. The intermediate units are smaller than both the source and target zones, and are compatible with these zones. Examples of intermediate zones include land use, buildings and grid cells. The process consists of two stages, i.e. disaggregation and re-aggregation (Figure 6.2b). The first stage makes use of disaggregate algorithms to allocate socio-economic attributes to individual intermediate zones. It is clear that the intermediate disaggregated zones are suitable for many different kinds of purposes, such as micro-simulation of urban activities and land use–transport interactions. From this perspective, the disaggregated zones are also regarded as target zones. When necessary, these intermediate zones may also be re-aggregated in the second stage to larger target zones such as TAZs for transport planning. If a subjective target zone had been defined, the re-aggregation from these smaller zones is straightforward.



(a) Interpolation (b) Disaggregation-aggregation

Figure 6.2 Two approaches to zonal data transition and their spatial units

As no small unit exists for socio-economic data, the disaggregation stage is the major issue that has to be tackled in urban Wuhan. Socio-economic data for statistical units at the street level have to be disaggregated into either land use parcels, or grid cells, or buildings. Land uses and buildings themselves serve as ancillary information in the process.

6.4 A weighted approach to zonal data disaggregation

6.4.1 The context for weighted disaggregation

The study concentrates on urban areas where statistical data and land use data are accessible. The major issue in this context is the disaggregation of socio-economic data from statistical zones to smaller parcels or regular cells. Socio-economic data may refer to population, employment or a kind of service. In this study, population is the variable to be disaggregated. Land use type is available for small parcels, and is used as an indicator or weight in this context. The land use parcels are spatially and semantically comply with the statistical zones – in other words, their boundaries do not intersect.

In principle, different land use types imply different densities of data elements. For example, roads, squares and water areas are obviously not places for living, and should contain no population. The population density in a high-quality residential area is different from that in a low-quality area. The population density of a pure residential area is also different from that of an area with mixed land uses. Commercial and industrial parcels are usually mixed with some apartments. Therefore, in the presence of land use information, the assumption of even density distribution – as in conventional areal interpolation – is no longer necessary and the estimation can be improved. From a statistical point of view, a density is an interval / ratio type of data, to which a weight value can be added.

The idea of weighting is by no means new, as a lot of research on areal interpolation has made use of additional information to improve the estimates. The use of control zones is one such attempt that assumes an even distribution of density in these zones and makes use of a disaggregation-aggregation process (Goodchild *et al,* 1993). Flowerdew and Green (1994) also concluded that the use of ancillary information could usually improve the estimates, provided the ancillary variable was not strongly related to the variable of interest. One possible source of land use data is the remote sensing image. An attempt has been made to incorporate pixel counts for each land use type into regression and statistical models (Langford *et al,* 1991).

6.4.2 A weighted disaggregation method

The classic areal weighting method may be used to distribute the data from statistical zones to land use parcels, without considering land use type. For each statistical zone, data for each land use parcel is estimated by

$$P_i = \frac{A_{is}}{A_s} P_s = A_{is} * D_s$$

Where

P_i is the estimated population (or other data) for land use parcel i
P_s is the population (or other data) for statistical zone s
A_{is} is the area of land use parcel i in zone s

A_s is the area of statistical zone s
D_s is the population density of statistical zone s

The result is that the larger land use parcel gets more population, but the density for all parcels in the statistical zone remains the same. As the land use map provides more information than pure area, this areal weighting method can be improved by considering land use type. Assume a base density (D_0) exists for a statistical zone and within the zone several land use types exist. The density for each land use parcel i (D_i) can be figured out with a weight (W_i) over the base density, i.e.

$$D_i = W_i * D_0$$

and the disaggregated population (P_i) in land use parcel i is

$$P_i = A_i * D_i = A_i * W_i * D_0$$

Summing all P_i will get the total population P_s of the statistical zone, through which D_0 can be calculated.

$$D_0 = \frac{P_s}{\sum_{i=1}^{m} A_i * W_i}$$

Therefore,

$$P_i = \frac{A_i * W_i}{\sum_{i=1}^{m} A_i * W_i} P_s \tag{1}$$

If W is decided for each type of land use, then the population for each land use parcel can be estimated. W is an indicator of relative importance, which can be derived from regression analysis on existing data, or from field investigation or some other empirical sources. To allow scenario generation, W should be adjustable in disaggregating processes. As the land use situation differs from city to city, it is necessary to acquire these weights from empirical studies at the local level. The population density for each land use class is an appropriate indication of weight. The density may also be derived from other data sources such as floor space or residential building intensity. In general, the more detailed the land use classification, the more accurate the weight estimate. In Chinese cities, for example, residential areas are classified into four categories according to their quality. However, these classifications are usually difficult to achieve because such detailed land use data are not available.

6.4.3 Homogeneous weighted zones

The weighted disaggregating approach assumes each land use type has the same density, which is true if land use classification is detailed enough for a study area. In the absence of detailed land use data, a more general land use classification is usually applied, which masks the density differences within a class. For example, residential areas usually have different qualities and therefore different population densities. Even if the detailed land use classification is available, it may still fail to reflect the complex real situation. For example, in Chinese cities, the inner areas usually have more mixed land uses than the fringe areas. In inner areas the population is distributed across mixed land uses that cannot be further differentiated in existing land use classifications.

Therefore, sometimes land use classification cannot ensure each land use type maintains the same density across the study area. To improve the estimates, different regions in a study area may be assigned different sets of density. These different density areas are referred to as homogeneous density / weighted zones in this context. The formula for population disaggregation becomes

$$P_i = \frac{A_i * W_i^h}{\sum_{i=1}^{m} A_i * W_i^h} P_s \qquad (2)$$

Where W_i^h denotes the density / weight in homogeneous zone *h*. Other symbols remain the same with those previously define.

Spatially, homogeneous weighted zones are large areas covering different regions of a city. The number of such zones is dependent on the types of land use data available and the area of study. Generally, a simple delineation can be the inner city, areas around the inner city, and fringe areas. In the inner city, pure residential areas get less population density weight because some other land uses also bear large proportions of population, whereas in the fringe areas people mostly reside in residential areas. In the cases where land uses are classified as urban and other non-urban uses, and land uses are detailed enough to differentiate differences in density in the area of study, only one homogeneous zone is necessary.

6.4.4 Weighted area weighting (WAW) and Monte Carlo simulation (MC)

The previous descriptions in this section are based on land use parcels and the principles of area weighting. Due to the incorporation of the land use weight, this improved method can be referred to as weighted area weighting (WAW).

As has been described in the second section of this chapter, the Monte Carlo (MC) simulation also makes use of the weight concept. The difference is that the MC simulation is a data-constrained process and is based on a regular raster representation. The raster base indicates an equal area for the disaggregated unit. Without land use weights, the MC simulation is equivalent to the classic areal interpolation, i.e. even distribution or equal opportunity for the raster cells. Therefore, associating land use weights with the cells will make these cells different in terms of possibilities of data distribution. With reference to equation (2), due to the equal area of raster cells, the probability of one data unit being assigned to a cell (*prob*$_i$) is

$$prob_i = \frac{W_i^h}{\sum_{i=1}^{m} W_i^h}$$

and the final expected number of data units assigned to cell *i* is,

$$E(P_i) = prob_i P_s = \frac{W_i^h}{\sum_{i=1}^{m} W_i^h} P_s \qquad (3)$$

From a computational point of view, the MC simulation generates different results for each individual run. This is caused by the random number generation in the process. It is clear from equation (3) that statistically there is no significant difference between different runs based on the same set of weight structures.

These two methods can be implemented as standard tools in a GIS environment. As they share the same principle of disaggregation, it is expected they will generate similar disaggregated results.

6.5 A GIS framework for data disaggregation

6.5.1 Data models

Data disaggregation is a process of transferring data from statistical units to smaller land use parcels or land use–related raster cells. The spatial relationship is a simple “contain”, without boundary intersection. There is not much restriction on the delineation of homogeneous land use density zones, only that a homogeneous zone should “contain” land use parcels. The source zones and homogeneous zones are represented with polygons, and the target zones are represented with polygons in the case of WAW or raster cells in the case of MC.

Figure 6.3 shows the entities and their relationships in weighted area disaggregation. Statistical unit, homogeneous zone and land use parcels are spatial polygons with attributes attached. Spatially, land use parcels are “contained” in statistical units and homogeneous zones. A spatial join operation may create these links and assign zonal IDs to land use parcels. The attribute table of statistical units stores unit ID and statistical data such as population and employment. The attribute table of land use keeps parcel ID, land use code, ID of the statistical unit that the parcel falls in, and ID of the homogeneous zone that the parcel falls in. A stand-alone density weight table is created and related to the homogeneous zones because each zone corresponds to a set of density for all land use types. The LU-data and SU-data tables are temporary tables for computing and keeping intermediate results. The disaggregated results are kept in the DataLU item in table LU-data.

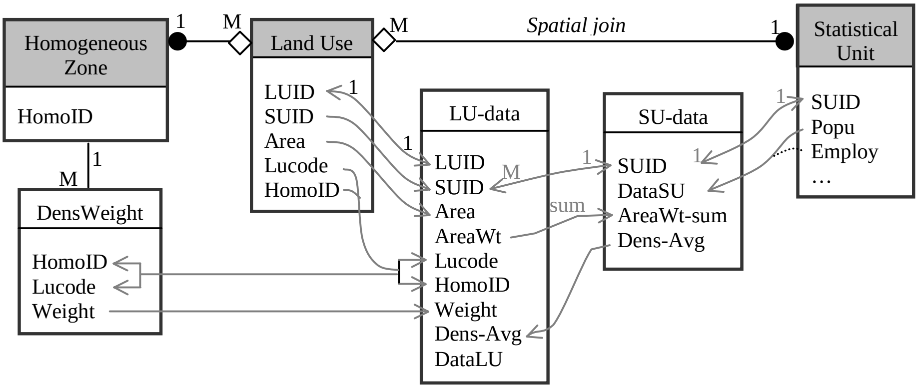


Figure 6.3 Entities and data flow in areal data disaggregation

Data disaggregation based on MC simulation requires the target zone to be represented by raster cells. Other zones may be represented either by the vector or the raster model. If these zones are represented by the vector model, each cell in the target raster map has to be associated with a coordinate pair in its attribute table so that a point-in-polygon search can be made. To simplify the spatial search, however, it is convenient to represent all the zones in raster format (Figure 6.4). The raster versions of these maps are based on the same polygon-to-raster scheme so that their cells are referenced by the same set of row and column addresses. Statistical data and other data needed in the disaggregation are respectively kept in three tables.

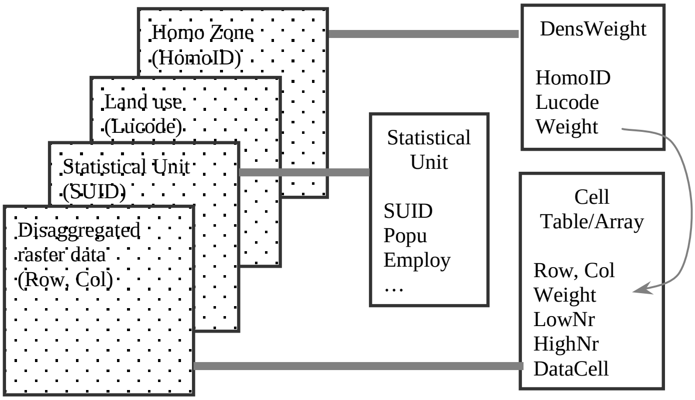


Figure 6.4 Entities and tables in raster-based data disaggregation

6.5.2 Algorithms for disaggregation

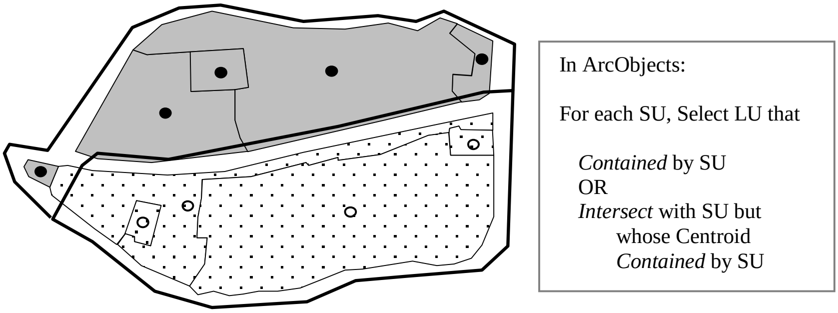
The weighted area disaggregation may follow two similar computational processes, i.e. the table-based operation and feature-based operation. The table-based operation is carried out at one time for the whole parcel table, with less programming work but more manual manipulation of intermediate data. The efficiency of table-based computation will be higher only when the user has enough knowledge in table manipulation.

The feature-based method concentrates on one statistical unit at each run, which is suitable for programming control and which can be automated as a standard tool in ArcGIS. Figure 6.5 illustrates the steps in the feature-based computational process.

```
Carry out spatial join
        Assigning HomoID from homogeneous zone to land use parcels
        Assigning SUID from statistical unit to land use parcels

FOR EACH land use parcel
        GET density weight FROM DensWeight table INDEXED BY HomoID + Lucode
        CALCULATE AreaWT = area * weight

FOR EACH zone in Statistical Unit
        SELECT ALL land use parcels THAT ARE COMPLETELY WITHIN the zone
             SUM UP AreaWT FOR ALL SELECTED land use parcels
             CALCULATE average density: Dens-Avg = DataSU / AreaWT-Sum

             FOR EACH SELECTED land use parcel
                     CALCULATE DataLU = AreaWT * Dens-Avg
```

Figure 6.5 Steps in feature-based data disaggregation with WAW method

The spatial relationships between land use parcel and homogeneous zone, and between land use parcel and statistical unit, are semantically identified as “contain”. The task of spatial join is theoretically a simple polygon-in-polygon operation in GIS. In reality, since the areal data are usually acquired from different sources, the boundaries of these zones may not fit well. This situation makes the pure polygon-in-polygon operation produce an incomplete selection set. There are two solutions to this boundary-overlapping issue. One is to modify the boundaries of zones in the layers to make them compatible, which will consume much time and effort. Another solution is to construct the linkage through other spatial relationships, which may avoid dealing with trivial boundary intersections (Figure 6.6). Since the nature of the overlapping between two boundaries is slight, this difference may be neglected. A parcel is considered to fall inside another if its centroid falls inside another polygon. In this way, the polygon-in-polygon operation is replaced by the point-in-polygon operation. As few GIS systems provide direct support of this kind of polygon relationship, some alternative approaches may be used in the developer language of the system.



In ArcObjects:

For each SU, Select LU that

    Contained by SU
    OR
    Intersect with SU but
        whose Centroid
        Contained by SU

Figure 6.6 Spatial joining by avoiding reshaping or overlaying

The MC simulation is based on raster layers. As has been pointed out, it is convenient to convert all three types of areal zones into raster layers, with zone identities or codes as the values of the layers (Figure 6.7). The simple spatial relationship among raster layers is an advantage for this process. Since the simulation cannot be realised only by raster operations, a stand-alone attribute table (or in-memory array) is created to associate with the raster layers. As can be seen from the figure, the raster representation provides an easier way for spatial join among the three layers, and the major simulation process is carried out based on the table.

The obstacle to the implementation of MC simulation in GIS is that cells in raster layers are not individually managed. A cell can be referenced by its row and column in a raster layer, but each cell stores only one value. Therefore, specific database design is needed in order to fulfil the simulation task. By programming, each raster layer can be attached to an attribute table (as shown in Figure 6.4). Another issue that needs some effort is the selection of cells contained by a statistical zone. Raster cells are not manipulated in the same way as the features in vector-based representations, and GIS packages usually do not provide the functionality of generating a selection set of raster cells. The solution is to select these cells and put them into a table or in-memory array, in which the simulation process is carried out.

```
Based on one standard raster scheme, make raster layers from statistical unit, land use parcel, and homogeneous zone. The values for three layers are:
        SU-raster: value SUID
        LU-raster: value Lucode
        Homo-raster: value HomoID

Create a Cell-table / In-memory Array: Row, Col, SUID, lucode, HomoID, Weight, LowNr, HighNr, DataCell

FOR EACH CELL in Cell-table/Array
        GET Weight FROM DensWeight TABLE INDEXED BY lucode and HomoID

FOR EACH SUID IN statistical unit's ATTRIBUTE TABLE
      GET SUID and DataSU from statistical unit table

      In the Cell-table/Array:
        FIND ALL CELLS with value SUID
        SORTING SELECTED CELLS IN row+col ORDER
        ASSIGNING LowNr and HighNr for EACH SELECTED CELL
              ACCORDING TO the WEIGHT
        GET the Total weight (the biggest HighNr)
        REPEAT number generator FOR DataSU number of times:
              GENERATE a random number between 1 and total-weight number
              INCREASE DataCell of CORRESPONDING CELL WITH 1

USING (Row, Col, DataCell) to CREATE THE DISAGGREGATED raster
```

Figure 6.7 Steps in raster-based disaggregation with MC simulation

6.5.3 A computational framework in ArcGIS

ArcGIS provides an integrated set of tools for handling GIS data from various ESRI products, such as coverage, shape file, grid and geodatabase. Moreover, ArcGIS provides a development platform: ArcObjects. As the platform is based on the Component Object Model (COM) technology, it is convenient for implementing in standard programming languages such as Visual Basic and Visual C++.

The programming environment for data disaggregation makes use of Visual Basic Applications (VBA) within the framework of ArcMap, an application of ArcGIS for desktop GIS functionalities. VBA-based development may reduce programming requirements for interfaces, and provide tightly coupled tools within ArcGIS. When the VBA codes are ready, it is possible to transfer the codes into VB or C++ to make a customised COM object for data disaggregation.

Figure 6.8 shows the main application environment for data disaggregation. WAW and MC applications are represented in a designated toolbar that can be removed or added by the users. Users have the freedom to add, remove or change the views of data layers in the framework.

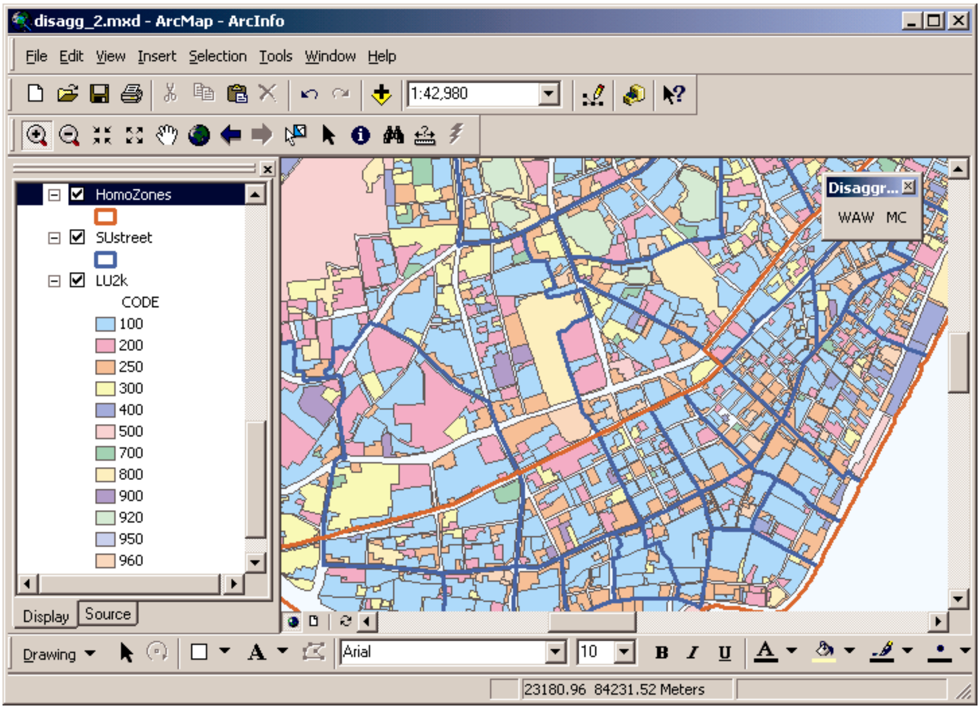
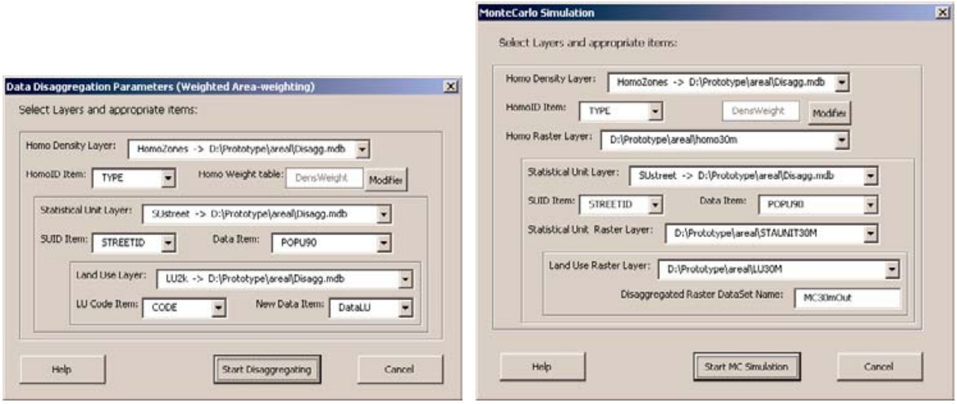


Figure 6.8 The GIS context for data disaggregation

The WAW and MC methods have similar data sources, and therefore two similar interfaces are developed to set parameters for the disaggregation processes (Figure 6.9). Data items in the drop-down combo boxes are automatically generated, provided that these data are included in ArcMap's Table of Contents (TOC). It is also possible to get the data sources directly by acquiring file names on the disk. Making use of ArcMap's TOC helps users in getting the correct data for disaggregation. For keeping output data, the WAW process requires that users create a new item in the land use table in advance. The MC process creates a new raster file whose name has to be provided by the user. If users provide a file name that already exists, they will be asked to give another name.



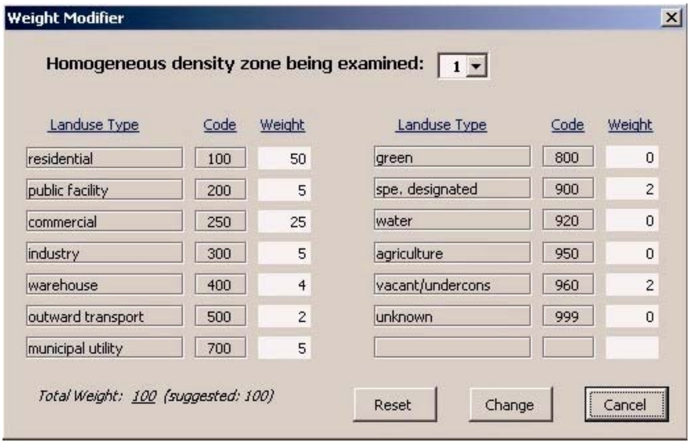
Select Layers and appropriate items:
Homo Density Layer: HomoZones -> D:\Prototype\areal\Disagg.mdb
HomoID Item: TYPE
Homo Weight table: DensWeight
Statistical Unit Layer: SUstreet -> D:\Prototype\areal\Disagg.mdb
SUID Item: STREETID
Data Item: POPU90
Land Use Layer: LU2k -> D:\Prototype\areal\Disagg.mdb
LU Code Item: CODE
New Data Item: DataLU

Select Layers and appropriate items:
Homo Density Layer: HomoZones -> D:\Prototype\areal\Disagg.mdb
HomoID Item: TYPE
DensWeight
Homo Raster Layer: D:\Prototype\areal\homo30m
Statistical Unit Layer: SUstreet -> D:\Prototype\areal\Disagg.mdb
SUID Item: STREETID
Data Item: POPU90
Statistical Unit Raster Layer: D:\Prototype\areal\STAUNIT30M
Land Use Raster Layer: D:\Prototype\areal\LU30M
Disaggregated Raster DataSet Name: MC30mOut

(a) WAW (b) MC

Figure 6.9 Interfaces for WAW and MC in ArcMap

The common issue for both disaggregation methods is the allocation of weights for each type of land use. The homogeneous zone discussed in the previous section indicates the geographical variations in density structure, which are kept in a separate attribute table. Although the density weights have to be decided by the users in advance, the system has to provide an interface allowing users to change the weights when appropriate. A weight modifier is developed to fulfil this task (Figure 6.10). The modifier reads land use type, land use code, and weight for each HomoID from the DensWeight table. Users cannot change land use type or code, but may change the weights. A recommended total weight is also suggested. Adding a new homogeneous zone ID is not possible in this form, which must be made in creating the homogeneous zones.



Homogeneous density zone being examined: 1

Landuse Type	Code	Weight	Landuse Type	Code	Weight
residential	100	50	green	800	0
public facility	200	5	spe. designated	900	2
commercial	250	25	water	920	0
industry	300	5	agriculture	950	0
warehouse	400	4	vacant/undercons	960	2
outward transport	500	2	unknown	999	0
municipal utility	700	5			

Total Weight: 100 (suggested: 100)

Figure 6.10 The weight modifier

6.6 The application of the disaggregation framework

6.6.1 Data for disaggregation

The data to be disaggregated are the population from the 1990 national statistics, available at the administrative street level. Spatial distribution of these streets is acquired and adapted from the local administrative map, which contains minor errors. The boundaries of these streets have been adjusted to fit the land use parcels at several apparently incorrect intersections. Thirty-five streets are used in the data set, ranging from smaller ones in the inner area to big ones in the fringe area (Figure 6.11). The population density is very high in the inner area (lower part of the map). It can also be noticed that several of the streets take quite irregular shapes. In the following analysis the streets are referred to as statistical units (SU).

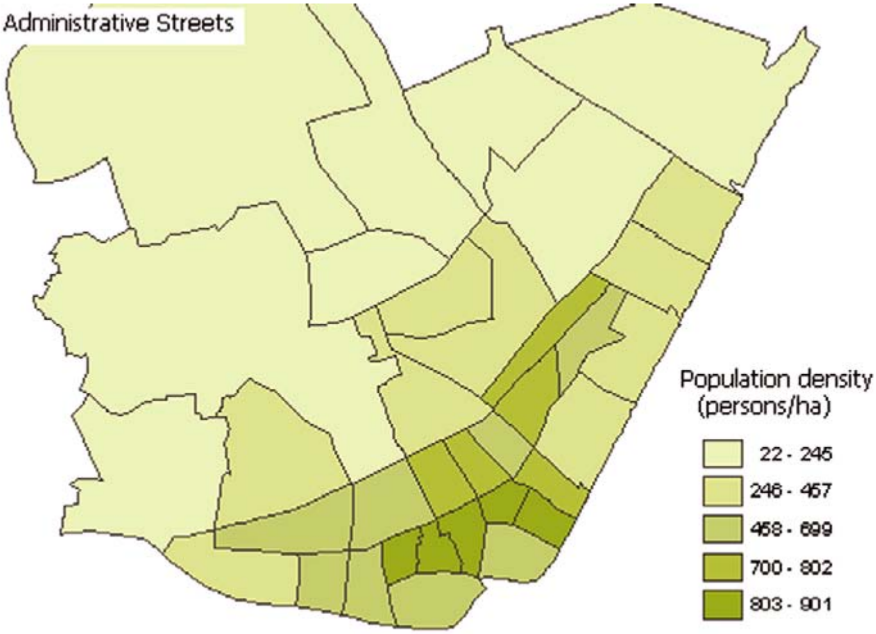


Figure 6.11 Statistical units and their population densities

Land use parcels in the data set are acquired by combining small-scale topographical maps with remote sensing data. Land uses are classified in accordance with the national standard for urban land classification. The important types for population distribution are residential, commercial, industry and public facility. Other uses such as municipal utility and warehouse will have very small numbers of residents. These qualitative analyses lead to the final designation of weights to different land use types.

Two homogeneous weight zones are identified based on local experience. Figure 6.12 shows the hypothetical examples of density structure for the two zones. The zone in the inner urban area (type 1) has more mixed land uses that cannot be clarified in the classification. The degree of mixed uses in the outer urban area (type 2) is less intense. The figure shows an example of land use weight structure for the two homogeneous zones. The land use map is shown as a background.

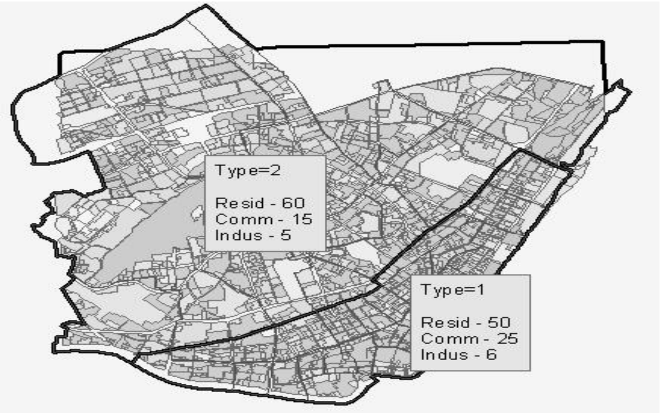


Figure 6.12 Homogeneous weight zones

6.6.2 The disaggregation results

The WAW results are kept in an item in the attribute table of land use polygons, and the results of one MC run are written in a new raster file during the process. As the WAW and MC results are based on different base spatial units, the disaggregated population is not visually comparable from the cartographical point of view. To make a comparable visualisation, population densities are calculated and classified on the same levels (Figure 6.13). Parcels and pixels with zero value are excluded from the maps and subsequent statistics.

It is clear that the two maps give very similar outcomes, and that population densities are higher in the inner city for both of the results. These are expected because of the same principle for disaggregation. However, the MC density map has one more class than the WAW map, showing a higher density that is not available in the WAW result. It can be seen that these higher densities happen in the inner city area. Further details of differences between the two results are shown in Table 6.2.

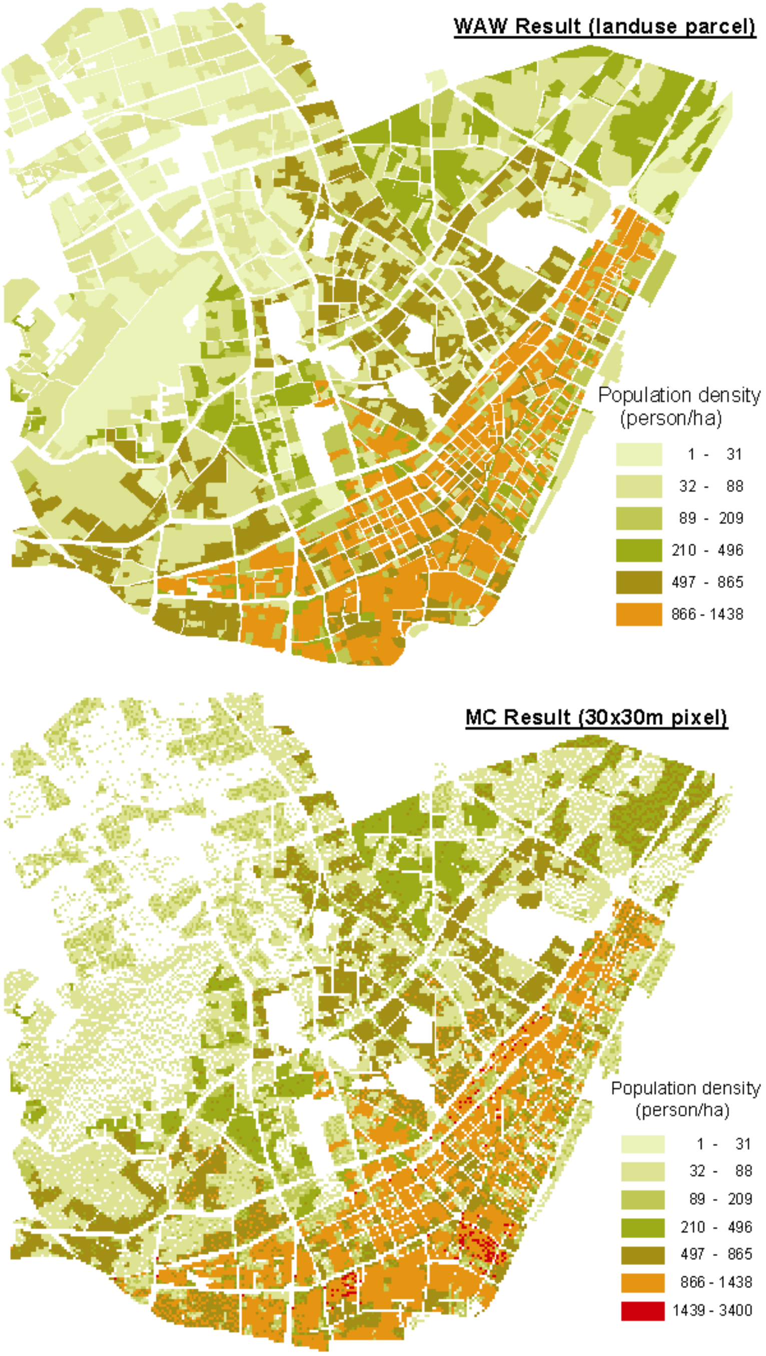


Figure 6.13 Results of disaggregation from WAW and MC in ArcGIS

Table 6.2 Statistics on the two sets of disaggregated data

Method	Base units	Count	Area (ha)			Population density (/ha)			
			Min	Max	Mean	Min	Max	Mean	s.dev
WAW	LU parcels	2035	0.015	169.1	1.93	2	1438	366.5	385.3
MC	MC cells (one run)	35221	0.09	0.09	0.09	11	3400	402.8	402.7

A further test may show how different the two results are. Using the LU parcels as zones to summarise data in the MC raster cells (called zonal statistics in the Spatial Analyst of ArcGIS), the total MC-based population for all LU parcels can be calculated. As each LU parcel has a population count from the WAW, it is possible to compare the two counts. There is no doubt that the two groups of values are directly correlated. Figure 6.14 shows the histogram of the absolute differences between the two results for all LU parcels. The absolute differences have values between 0 and 737, a mean of 35.3 and a median of 13. A detailed scanning of the two groups of values reveals that the number of WAW results that are larger than the MC results is as many as the number the other way round. Other statistics also show that there is a weak correlation between the WAW-MC difference and the size of the land use parcels. The map also indicates that most of the parcels with large differences are located in the inner high-density area.

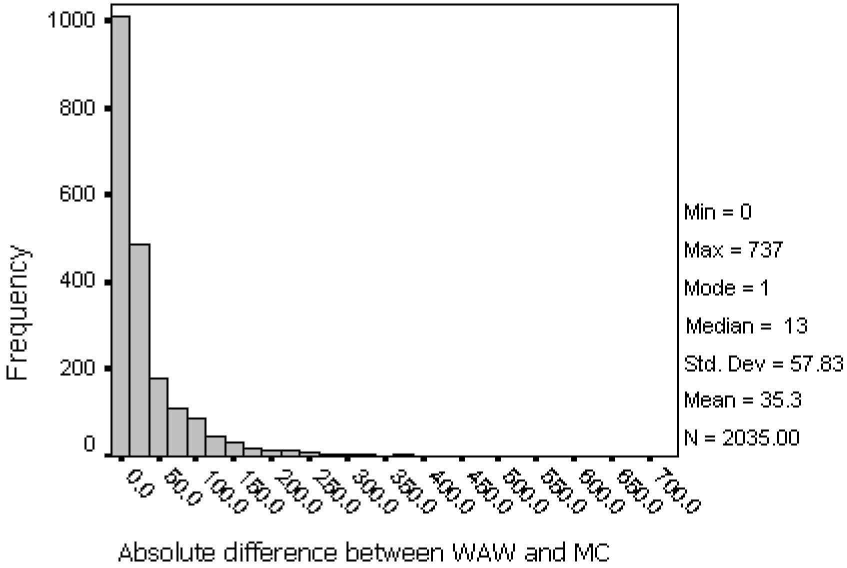


Figure 6.14 Histogram of LU parcel-based population differences between WAW and MC

What do make a considerable difference to both methods are the identification of land use types and the assignment of weights to these types. The land use map plays an important role in data disaggregation in urban built-up areas, and the classification should be as detailed as possible. While it is possible to use statistical methods to estimate the weights, they are not discussed here as they fall outside the focus of this study. As the processes have been developed as standard tools in the ArcGIS environment, it is convenient to carry out experiments with different sets of weights. The shape and number of homogeneous zones can be adjusted when more information on density is available.

6.6.3 Re-aggregation: comparing the two methods

As has been stated, re-aggregation may be regarded as the second part of a zonal interpolation process. If the population data are available for the target zones, the re-aggregation may be used to check the reliability of the disaggregation methods. Since the methods or their variations have been tested in the published literature, it is not the major issue here to evaluate the individual disaggregation method. Rather, it is interesting to investigate how different the two methods are in a re-aggregation process.

For this purpose, two sets of zones have been defined (Figure 6.15). The irregular-shaped zones are delineated in compatible with the land use parcels, and the regular-shaped zones are smaller polygons incompatible with the land use parcels. Table 6.3 shows a statistical description of the two zones. As a TAZ can be either compatible or incompatible with land use parcels, these two types of zones represent two extremes in TAZ formulation.

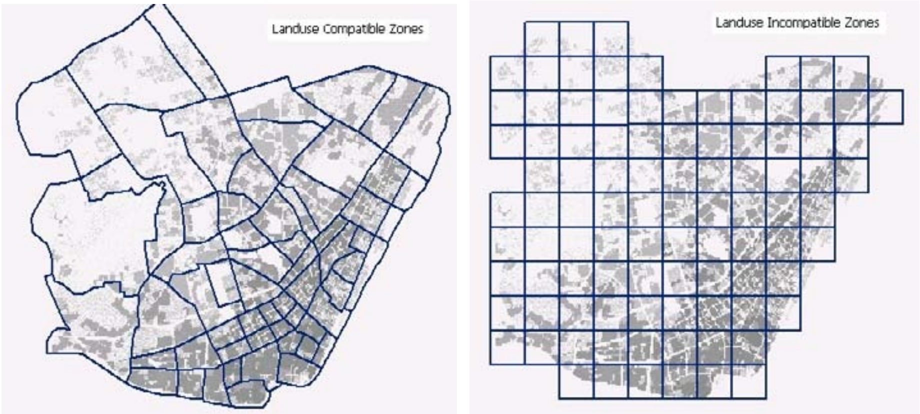


Figure 6.15 Two sets of zones for comparing WAW and MC data

Table 6.3 Statistical description of the two sets of zones

Zones	Count	Area (ha)			
		Min.	Max.	Mean	Std. Dev.
Landuse Compatible	62	14.18	884.45	525.33	97.16
Landuse Incompatible	96	56.25	56.25	56.25	0

As MC output is a raster data set, MC data are always compatible with any kind of zone. The aggregation of MC data to zones is a zonal statistical calculation that is available in GIS packages. On the other hand, the aggregation of WAW output (land use parcels) is not so straightforward. For compatible irregularly shaped zones, the operation is a centroid-in-polygon summarisation, which means a reverse process to the WAW computation. For incompatible zones, three methods are possible, i.e. the centroid-in-polygon selection (C-in-P), the polygon-on-polygon selection (P-on-P), and overlay. The first two are simple selection processes. The C-in-P process selects those WAW parcels whose centroids fall inside an aggregate target zone, and the P-on-P process selects those parcels that are inside or crossing the target zones. The overlay method is the conventional areal weighting interpolation and requires a spatial overlay operation in GIS. Intuitively the overlay method will produce the best result.

Some statistical results for the aggregation in the two types of target zones are shown in Table 6.4. According to the above discussion, there are two types of target zones (i.e. compatible and incompatible), and the incompatible zones have three types of methods for aggregating the WAW parcels. The table shows the smallest and largest aggregated values of the WAW and MC outputs for each type of aggregation. The more interesting information is the population difference between the two methods for each zone in the target zones. Theoretically the difference between the two methods is zero, regardless of the type of target zone. The significance value in the table is the result of a paired-sample T-test between WAW and MC populations.

Table 6.4 Re-aggregation results for the two sets of zones

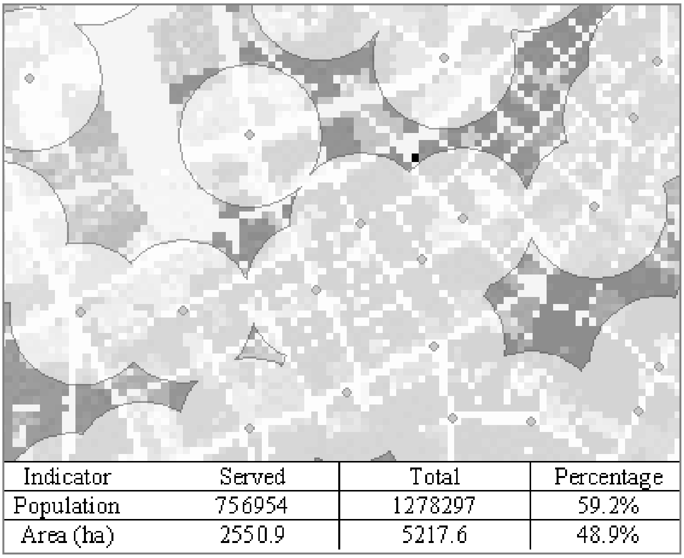
Target zones (aggregation method)	Cnt	Population			Population difference (MC-WAW)				
		Source	Min	Max	Min	Max	Mean	StDev	Sig.
Compatible	62	WAW MC	294 312	58183 58284	-1048	1252	-0.44	293	0.991
Incompatible (P-on-P)	96	WAW MC	1061 536	86016 53413	-46904	-107	-10717	8800	0.000
Incompatible (C-in-P)	96	WAW MC	0 536	64075 53413	-10662	16945	61	3374	0.860
Incompatible (Overlay)	96	WAW MC	542 536	53640 53413	-914	1016	-0.86	235	0.971

Some conclusions can be drawn from the table. Firstly, for the compatible zones, the WAW and MC outputs produce similar population totals and ranges (from about 300 to about 58,200); the aggregation shows statistically a small difference. This conforms to theoretical expectation. Secondly, the aggregation of MC results requires less operations as zonal statistics is one standard function in ArcGIS. Thirdly, in the case of aggregating WAW data to incompatible target zones, the three spatial aggregation methods generate quite different results. This is shown in the total population range as well as by the differences with the aggregated MC results. The P-on-P selection method produces the most unreliable outcome, and the C-in-P and the spatial overlay methods show smaller differences between the WAW and the MC.

Alternatively, given the number of target zones, there are many ways of spatially aggregating from source zones. This aggregation process may be repeated many times, which is another application of MC simulation in geographical statistical analysis (e.g. Besag & Diggle, 1977; Openshaw *et al*, 1987; Fisher, 1991). The concept of simulation has been utilised by Fisher and Langford (1995) for modelling the errors of different areal interpolation methods. Apparently, these simulations are different from the one described in this study.

6.6.4 Evaluating level of service of public transport

Buffer zoning or network-based location-allocation models have been applied in GIS to estimate and evaluate the level of service of public facilities such as schools, hospitals and fire brigades. The models usually calculate the area that a service covers. With detailed population data in small raster units, it is now possible to evaluate the level of service based directly on a population count. Figure 6.16 presents an example of public transport service in one part of the study area. Buffer zones of 300 meters are created for bus stops. The levels of service are reckoned by comparing data units covered by the buffer zones and data units for the whole area. Population and area are used as such data units. In this particular study area, it can be seen that the use of population count results in a higher percentage of service coverage. Given the fact the bus stops are more densely located in the inner area, where population density is higher, the evaluation based on population count fits better with the reality.



Indicator	Served	Total	Percentage
Population	756954	1278297	59.2%
Area (ha)	2550.9	5217.6	48.9%

Figure 6.16 Two methods of evaluating the level of service for public transport

6.7 Disaggregating population for the whole city

The disaggregation framework described so far has made use of street-enclosed parcels as land use input and urban land use classification as the indicator for weighting. In principle, as long as the disaggregation criteria are satisfied, different scales of land uses may be used as input. Figure 6.17 shows an MC disaggregation of the population for the urban and fringe areas of Wuhan. In this case, population data are available for statistical units at the street level. The land use map for this larger area is based on the national land use classification that identifies land uses of urban, village, town, industry, transport, water, forest, agriculture and so on. Therefore, the large built-up area of the city has only one land use type, i.e. urban. The land uses of urban, village or town are the major places for living and are given large weights. Very small weights are also assigned to other land uses such as transport, development area, agriculture and so on. The implementation also makes use of population data at the Street (statistical unit) level, which explains the clear boundaries in the built-up area. Only one homogeneous density zone in this case is used. A 50-meter cell size is applied.

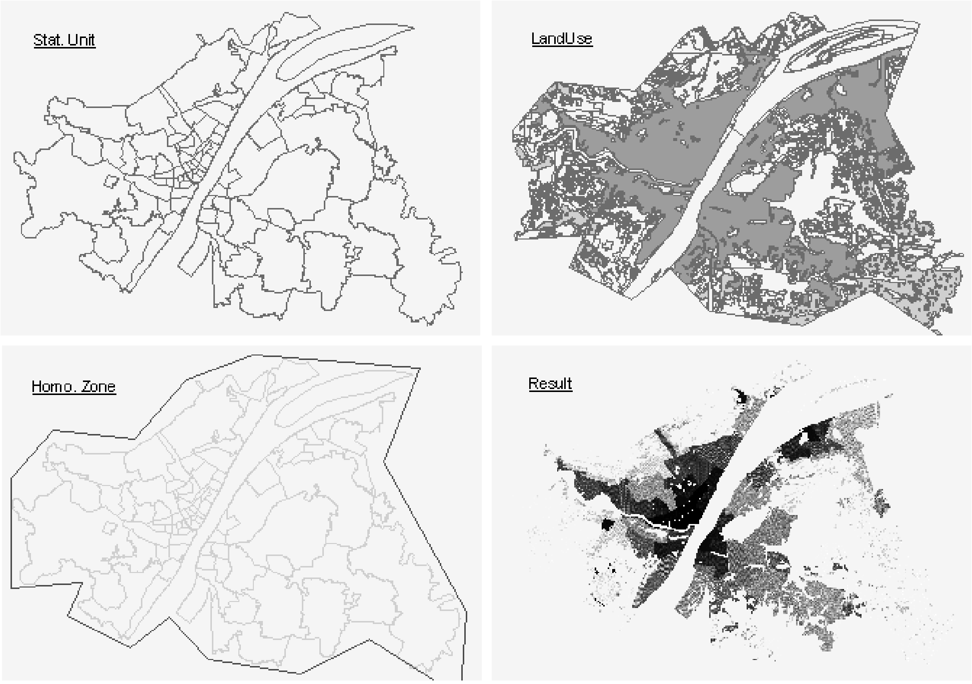


Figure 6.17 MC disaggregation for urban and fringe Wuhan

Since the land use parcels in this case do not satisfy the requirement of “contained by statistical unit”, the WAW within this framework is not applicable. But it is possible to use other areal interpolation methods as reviewed earlier in this chapter.

6.8 Conclusions

A general framework for disaggregating data in urban areas has been proposed and tested. Three spatial units, i.e. land use, statistical unit and homogeneous zone, are necessary elements in the framework. For WAW, the land use parcels should be semantically “contained” by the other two units. Weights are assigned to the parcels based on the land use types, and are modifiable in each run. In cases where the land use classification is not detailed enough to differentiate locational variations in density, the concept of the homogeneous density zone is introduced to improve disaggregation quality. This scheme is also applicable to the MC simulation, with the exception that no spatial compatibility is required among the three elements. Application tests have shown that the MC result is more convenient for further analysis.

With the WAW and MC tools readily available in GIS, data can be disaggregated directly within a GIS environment. This provides a more realistic method for integrating disaggregated data into an existing database framework that is usually maintained in GIS. Disaggregation produces detailed data that are needed in some applications such as micro-simulation. These data can also be easily re-aggregated into larger zones for aggregate applications such as transport demand modelling. When data criteria are satisfied, data disaggregation is considered as the first step in data aggregation and areal interpolation.

Geographers and planners have put much effort into the methodologies of data interpolation and disaggregation. These applications and evaluations have been carried out on a project basis that utilises ad hoc data structure in specific computational environments – which indicates a lack of common framework. On the other side, the GIS industry has been providing data management and analysis functions that may be utilised for purposes of data disaggregation. Disaggregation requires support for the multiple data representations that are mostly available in GIS. With some effort on integrating these representations, this chapter has demonstrated a methodology for making the disaggregation process a standard function in GIS. The standardisation may take the form of a specialised tool for data disaggregation within GIS or a system component (such as COM) that can be used in other development environments.

Chapter 7 Conclusions

7.1 Introduction

The constant growth of transport during the last half century has had two contrary impacts. While transport development facilitates economic growth, increases the mobility of residents, and improves the quality of life, it also leads to air pollution, noise, congestion, and encroachment on the natural environment. The key issue of transport planning is to balance these conflicting challenges by promoting more efficient transport systems while reducing negative impacts. Transport planners have to provide relevant information for such kinds of decision making. As the situation changes, transport policies are given different priorities, whose implications have to be evaluated using appropriate methodologies. The availability of better and more reliable information has stimulated new planning methodologies and forecasting tools.

Transport data have become increasingly available from many sources. There have been improved sampling methods for specific travel behaviour surveys, new surveying methods, as well as more detailed surveys of activities. New technologies have provided accurate and automatic means of data collection, such as the computer, GPS, Internet, vehicle recognition, traffic surveillance and remote sensing. Meanwhile, more and more data are being distributed by professional data collection agencies, and, most importantly, there is a growing trend towards data sharing among governmental organisations.

Accompanying the availability of data are the challenges of data management and data integration. A proper classification of these data is important for building a transport data framework. The classification may be made according to the functional use of the data. The level of detail is a necessary consideration in the representation of these data, as different planning missions require data at different scales. It is also a complex issue to integrate or reference data of various types, at different scales, or from diverse sources. This task cannot be effectively accomplished without the application of information technologies.

Computer technology has provided a new and challenging medium for information processing. Integration of transport data in information systems starts with the proper representation of these data. Relational data models, feature-based models, object-oriented models and temporal data models are among the tools for data representation. The integration of heterogeneous data or variously scaled data requires a computational process that utilises either standardised functions in information systems or tailor-made functions for specific purposes. Although much has been achieved with respect to the representation and integration of transport data by using database management systems and GIS, there are still new challenges in terms of more detailed transport data, local data requirements, and the structure of an integrated data framework.

It was under these circumstances that the general objective of this research was conceived. The major focus has been the exploitation of information technology for integrating multi-source and multi-format transport data. The vision of this research topic is to build a comprehensive data framework for transport applications and a transport decision support system.

However, it has been realised that there are big differences with respect to the state of data provision among the regions of the world. Therefore, it would be inappropriate to examine the issue without referring to a specific environment. The geographical context in which this research has been implemented is the city of Wuhan in China. As a typical mega-city in China, Wuhan has a very different data environment from that of the large Western cities. A brief glance at this local context gives the impression that a complete institutional structure exists. But a more detailed analysis shows that the data needed for transport planning are variously incomplete, inaccurate, inconsistent and lacking cross-referencing. This situation provoked the research aims of integrating point, linear and zonal types of data that, apart from contributing to scientific development in general, have direct relevance to the local context.

While many analyses have been made of the local situation, it must be emphasised that this research is methodological in character. A general framework of data integration has been put forward after a comprehensive theoretical investigation of urban transport planning, data needs and information science. This methodological framework provides a starting point for examining the issue of transport data integration under local conditions. From this starting point, studies of different types of data integration have probed into the real problems to be solved. Yet the suggested solutions to these problems have not sought to offer complete implementation procedures, rather they have focused on the appropriateness of techniques in the local context and the implications in a broader sense.

This chapter summarises the findings and discusses the implications relating to the issues and methodologies of data integration dealt with in this research. Future research challenges are presented in the final section.

7.2 Summary of findings and conclusions

7.2.1 Findings in general

Improvements on data classification

To set the methodological framework for this research, a comprehensive review was carried out in terms of transport planning and modelling, transport data needs assessment, as well as the representation and integration of data in spatial information science. According to their source and usage, transport data have been examined and assessed under the general categories of demand, supply, performance and impact. The general principles of transport data representation and integration have been introduced from the perspective of geo-information science. Based on the reviews and evaluations, a framework for transport data integration has been put forward.

Understanding the categories of data is the first task of data integration. This research approaches the issue of data integration based on the classification of urban transport data. The classification is made from two different perspectives, i.e. the functional perspective and the representational perspective. These two perspectives correspond to institutional and methodological data integration respectively, and are the foundation for transport data integration in this research.

- The functional perspective categorises data according to the functional characteristics of the urban transport system and to planning requirements. The grouping of transport data into supply, demand, performance and impact actually follows the main aspects of transport systems analysis, and therefore is directly relevant to planning applications. This perspective is closely related to the functional data analysis of transport agencies and therefore to the institutional aspect of data integration.

- The representational perspective considers transport data in terms of their spatial and non-spatial characteristics that are important for representation in computer databases. From this perspective, transport data can be grouped into spatial and non-spatial categories, in which the spatial data are further differentiated as point, linear and areal types, and the non-spatial data are sorted out as values and temporal attributes. This representational perspective contributes to the design of database structures and, in this research, to the integration of transport data. The constructed methodological framework for transport data integration results from developing this perspective.

GIS for urban transport data representation and integration

While professional transport planning packages provide tools for data management to support transport modelling and analysis, most of them make use of proprietary database systems. These systems are developed to efficiently serve the modelling and analysis within the packages, rather than to provide general tools for data integration. For multi-source and multimodal data integration, GIS is a more appropriate technology. GIS technology deals with spatially referenced data and, most importantly, provides a series of tools for manipulating and geo-coding these data.

For this reason, the study of transport data integration has been based on GIS. Although geo-information science has provided general tools for spatial data representation and modelling, the representation issue continues to be a challenge due to the gap between complex reality and the growing demand of planning applications. The nature of the urban transport system makes planners recognise that the majority of transport data are spatial or spatially related. Many data models for transport have been developed and implemented in various systems, yet the planning field calls for more complex models.

This research has improved transport data representation by looking at the transport system in more detail. A prominent case is the spatial depiction of individual bus stops under the same name that are usually generalised as one point in conventional spatial databases. Furthermore the directions of bus routes are modelled to reflect some special situations that are important for network calculations. These detailed representations are essential for dynamic passenger route guidance and other planning and operations applications. The subjects of point and areal data integration in this research also highlight the acquisition of more detailed data.

Transport data integration makes use of a series of available GIS techniques. The use of these techniques depends on the specific needs and types of data under consideration. This research has examined the issue of data integration by focusing on point, linear and areal types of transport data respectively. Several GIS functions have been used to tackle these issues.

- In dealing with point-type data, location referencing schemes based on semantic and address matching are indispensable. The issue of referencing point locations in this context refers to the identification of spatial locations with semantically expressed addresses. The referencing bases for such purposes may involve all three types of spatial data, among which address matching or linear location referencing is specifically related to linear data.

- The integration of two groups of linear data such as bus routes and street networks requires dynamic segmentation and appropriate data modelling. Dynamic segmentation logically anchors routes to streets with geometries, which allows routes to be defined based on simple attribute assignment. However, the route definition may become very complex if a data model generates too many segments. That is to say, data models have great influence on linear data integration.

- In urban areas, transferring data from one set of zones to another can be achieved with a disaggregation-aggregation process. Existing GIS packages do not have the function for data disaggregation, and disaggregation has to be achieved through using the programming language embedded in GIS. The disaggregation process involves a series of computational steps in a GIS development environment. Disaggregated data can be flexibly incorporated into different sets of target zones. This zonal data transition can be best attained in an integrated environment where data manipulation and visualisation are available.

All these types of data integration have been carried out in a GIS context, in which source data are pre-processed and output data are incorporated. In other words, the GIS technology has contributed to transport data integration in terms of data representation, database management, data manipulation and data visualisation. This corresponds to the general objective of this research.

In addition to the above issues, this study has provided some examples of GIS-based data analyses that are beneficial to urban transport planning. One of these is the Transport Analysis Zone (TAZ) connectivity by bus routes, which is a buffered line-in-polygon operation. The other case is the evaluation of bus service areas, which includes a buffer operation plus polygon overlay in the case of vector data or zonal statistics in the case of raster data. These examples indicate that existing GIS functions can play a role in transport planning tasks involving spatial operations.

7.2.2 Data integration from the representational perspective

The methodological issues of transport data integration are based on the representational perspective. Research has been carried out respectively for point, linear and areal data types. The processes and results are reported in Chapters 4, 5 and 6. The summary here follows this sequence and links back to the original objectives.

Point-type data integration

In trip surveys or activity surveys, respondents are required to report the addresses or names of locations. The spatial locations and types of socio-economic activities are of great importance to travel demand forecasting and transport management. A location referencing system helps to identify the locations of activities and is also useful for travel guidance such as pre-trip planning and trip navigation. A major concern in this research is to identify locations in a base referencing system through semantic matching or address matching, rather than coordinate acquisition.

The location referencing process requires a referencing base, source address units and referencing methods. Any ambiguity in these three aspects will result in unreliable outcomes. This research has explored these three aspects in the context of Wuhan, China.

- The referencing base consists of such spatial features as streets, street addresses, points of interest, and publicly known zones. This study shows that there are no complete referencing bases readily available in Wuhan, China. The street address system in China is similar to the Western style, which implies the applicability of standard address matching in GIS. For name-based references, this study has examined all the possibilities, and proposed a hierarchical matching framework. In such a hierarchy each level represents a different degree of preciseness in space. Such hierarchies exist in every city of the world, which implies a potential solution for cities with a similar dilemma in transport data collection.

- For the source addresses to be geo-coded, it is necessary to divide them into address units. Experiments in this study show that nearly 85 percent of address expressions contain street names and street numbers. The other 15 percent of the expressions are mixed combinations of administrative units, place names, building names and so on. It has been concluded that the extraction of address units from Chinese address expressions is a complicated process and that, due to the special character of Chinese address sentences, the process cannot be completely automated. Because of the complexity, it is very important to clearly identify the address units in the survey forms. The results of the analysis of address components can help in designing survey forms that include frequently used address units. In cases where the extraction of address units has to be carried out, it is important to build a local knowledge base containing address unit tags and conventional place names.

- Depending on the types of address units, the referencing process makes use of either semantic name matching or address matching to link source addresses to features in referencing bases. The name-based referencing semantically matches source names to the names in a referencing database, while the road-based referencing makes use of address matching or linear location referencing schemes. If there is no exact matching, the result will be unpredictable. The research has shown that the address matching function in existing GIS packages is applicable to the Chinese situation, provided that the addresses are adapted to suit the standard format. The road-based and name-based referencing schemes may constitute an effective location referencing framework that is applicable to Chinese cities.

In addition to the above achievements, it is worthwhile to point out that this research is the first methodological attempt in China to locate socio-economic activities in cities. Due to the slow diffusion of GIS technology in Chinese municipalities, there has been limited awareness of the importance of automatic location referencing. This research has demonstrated the possibility of making use of road-based location referencing and has developed a hierarchical structure for name-based referencing. The findings indicate that the original objective of location referencing set for this research has been primarily achieved. However, it is felt that a comprehensive location referencing framework, incorporating the name-based, road-based, and coordinate-based schemes, is necessary in the Chinese urban context — but this could not be addressed in this research.

Comparing the Chinese case and the Western world, the following final remarks in regard to the technology and data for location referencing can be made:

- Location referencing of socio-economic activities in Western cities is mainly based on address matching. There is no technical problem in this aspect. Such techniques are standardised in GIS packages, and the Chinese situation has to be adapted to fit them. This research has accomplished such an adaptation.

- Data quality is a real challenge in location referencing, a challenge present in any context. In China, governmental agencies such as the sectors of public security and planning management are an important source of referencing data. Due to the lack of institutional cooperation and interest, the street address database has not been linked to the geographical street network in Wuhan. Also, during the last decades, the updating of street addresses has not been able to keep pace with the rapid inner-city development. In the UK, a streets campaign has been launched to achieve a more reliable national register of named streets (Barr, 2001). In the United States, the annual Street Smart and Address Savvy Conference of the Urban and Regional Information Systems Association (URISA) reflects a need for reliable data (*http://www.urisa.org*). It has also been observed that some business mapping or navigation applications have begun to construct location databases. While the objectives are different, these business databases may contribute to travel surveys to some extent.

Linear data integration

The relationship between two sets of linear features, or between one set of linear features and one set of areal features, can be identified by spatial overlay in the case of independent data representation. If one linear feature shares the same geometry with another feature, the linkage between them can be set up through the technique of dynamic segmentation. The bus line is such a feature that runs on the street network and can be referenced by streets.

This research has extended conventional bus line representation to a more detailed level. In the heavily bus-oriented city of Wuhan, bus lines constitute a huge public transit network that is important to transport system analysis and transport planning. Two phenomena justify the need for detailed bus line representation. One is that the two directions of a bus line may take different routes on the street network. The other case is that many bus lines may run on one street segment and the same stop has to be dispersed to effectively serve these lines. These dispersed sites still belong to one stop and have the same stop name, but spatially they are complicated enough to confuse passengers (especially when they are located around an intersection). To improve the bus data representation for transport applications, representation methods for bus routes and route stops have been developed, and a comprehensive data model has been put forward.

- Each bus line has been differentiated as two directional routes that are defined separately with reference to the street network. Based on dynamic segmentation, a route is composed of a set of consecutive sections. A section can be defined as a part or the whole of a street segment. Two schemes are available for the definition: one is to take intermediate bus stops into account and define each individual part between stops and street intersections; the other is to ignore these stops (except the terminals) and take each intermediate street segment as one section. Although the former method gives the most complete information, from a practical point of view the latter definition requires less effort on database construction and is sufficient for most public transport applications.

- Accordingly, individual route stops are also represented in the database. These stop sites are spatial features with geometries that are linked to street segments and bus routes by linear location referencing methods.

- A data model linking the base street network, bus lines, line stops, bus routes, route stops and other bus operations data has been constructed. The data model can be implemented based on either relational or object-oriented approaches.

The benefits of the detailed bus representation model in transport analysis have been demonstrated from several perspectives in this research. The bus volume on each street segment can now be summed for two directions separately. Further, a TAZ matrix showing bus route connections can be composed. The level of bus service can also be evaluated in more detail in terms of route length and service area. Given the detailed spatial representation, the results from public transport surveys can be linked more easily to spatial stops and routes for visualisation and statistical analysis. A more in-depth application of such a representation, however, is in the matter of passenger trip guidance. The directional routes can facilitate more efficient transfer searching, and the route stop locations enable the generation of dedicated transfer guidance. If other spatial features around the stops are integrated, more efficient guidance may be provided. To summarise, all the above applications can be automated and linked to other transport information in a GIS database.

The need for representing directional bus routes and route stops has been partially expressed in several earlier studies (e.g. Sarasua *et al*, 1997; Jia & Ford, 1999; Choi & Jang, 2000; Trepanier & Chapleau, 2001). These studies have been based on specific local situations in which the challenges regarding levels of detail are different. In contrast to these studies, this research has proposed a complete data model of bus representation that is applicable in different circumstances. In addition, the applications of the model in transport planning and passenger trip planning have been demonstrated, which has not been found elsewhere in such detail.

Two practical implications of the representation model have to be mentioned:

- Not all transport applications require bus information at the level described in this research. In certain cases, the detailed representation has to be generalised to a higher level, e.g. from directional routes to lines, or from route stop sites to line stops. The key issue is to maintain a flexible representation model so as to provide data at a level compatible with the needs, and the possibility to integrate data from other sources.

- The detailed data model for bus lines and stops is effective for complex bus networks. A bus information system incorporating lines, stops, streets and other operations data is beneficial for analysing transport system and service provision. The representation scheme promoted in this study has established an efficient framework for such an information system.

This part of the research has accomplished the original objective of linear data integration in terms of general integration techniques and bus line–street integration. What is lacking here is the integration of other modes of public transport, such as tramline, light rail and subway. Obviously, the picture of linear data integration will not be complete until a multimodal public transport integration model has been achieved.

Zonal data integration

The integration of zonal data in this study refers to the estimation of data values in one set of zones from data values in another set of zones. Depending on the types of data under consideration, zonal data transitions include three types of operations, i.e. aggregation, areal interpolation and disaggregation. The areal interpolation operation can be regarded as a disaggregation-aggregation process. Transport planning involves many kinds of zonal data, among which the TAZ, land use and the statistical unit are most frequently mentioned. On the other hand, the micro-simulation of transport activities requires a finer representation of urban space – smaller zones than those conventionally used. Consequently, a need for disaggregating data from larger zones to smaller zones arose.

In the context of Wuhan, zonal data disaggregation involves the allocation of statistical data such as population and employment from statistical units to smaller parcels. The statistical data available to the public is the administrative Street, which is the second level of units in the Chinese urban hierarchical administrative system. In urban areas, land use data is ancillary information for the disaggregation process. In the area-weighting method, land use parcels are also the spatial units for keeping disaggregated data. Based on density variations, the general principle of disaggregation is derived using these two types of zones. Before the disaggregation process, the spatial relationship between the statistical unit and the land use parcels has to be evaluated. They should be spatially compatible.

Given the availability of land use data, a weighted approach has been applied in the disaggregation process in this study. Different land use types have different densities of socio-economic activities, e.g. residential parcels have higher densities of population (and bigger weights for population disaggregation) than other types of parcels. This study has further explored the case in which the land use classes are not detailed enough to reflect the density difference of the same type of class at different locations. To respect the variations, a homogeneous density zone has been proposed. Each homogeneous zone has its own set of land use weight, which is derived from empirical studies and should spatially contain land use parcels. That is to say, this new zone is only used for improving land use weighting. The homogeneous zone and land use parcel are equivalent to the "control zone" or "ancillary data" in previous studies of areal interpolation (such as Goodchild *et al*, 1993; Fisher & Langford, 1995) but are applied in a rather different context.

Based on these principles, this research has examined two technical approaches to implement the disaggregation process. Weighted area-weighting (WAW) is an adaptation of the classic area-weighting method, and Monte Carlo simulation (MC) is a stochastic probabilistic process. Although these two methods follow the same principles and make use of the same data sources, they are different in several ways. The major difference is that the outcome from WAW is kept in land use parcels, while the result from MC is based on raster cells. Experiments have been carried out to evaluate the differences between the two outcomes by re-aggregating to some larger zones. It has been shown that, using the zonal statistics function in GIS, the MC results can be directly summed for any kind of new zone. For WAW data, however, if the new zones are not compatible with the land use parcels, an overlay operation has to be implemented to avoid unreliable aggregation. This implies that the MC raster data are more convenient for subsequent re-aggregation. In addition the MC output is also directly available for applications of micro-simulation.

An important contribution from this zonal integration study is that two standardised disaggregation tools have been developed in a GIS environment. The computational process for WAW allows for some minor spatial incompatibility between the zones, provided they are semantically compatible. In this way some small errors in zonal boundaries are tolerable. Actually, owing to the raster-based operations, the requirement of spatial compatibility can even be ignored in the MC process. As statistical and land use data for transport planning often come from GIS databases, these tools indicate a tightly coupled solution to areal data disaggregation, as the processes are carried out within GIS and the results are kept together with the source database.

While the uses of homogeneous zones and land use densities have improved the disaggregation methodology, instructions are still lacking on the delineation of the homogeneous zones and the identification of density structures. Although these issues have much to do with specific local situations, general rules should be developed for the two variables. These are issues not foreseen in the original research objective.

7.2.3 The functional perspective

About two decades ago the urban transport challenge in China was recognised by urban and transport planners. While the major concentration has been on the efficient provision of infrastructure, recently there has also been more emphasis on demand management, evaluation and environmental impact analysis. It has to be noted that the urban transport system in China is very different from the Western ones. For example, public transport, bicycle and walking have been the major means of passenger transport. There is also a tremendous shortage of rapid public mass transport systems in Chinese cities. However, with the increase in income, the number of private cars is expected to grow rapidly in the near future. All these imply that the transport infrastructure will continue to expand and that attention will also be paid to the adaptation and evaluation of transport policies. In addition to the development of appropriate evaluation methods, data collection and database construction are the challenges that transport planners have to face.

To investigate the data environment as well as to provide a context for the technical data integration analysis, an institutional study was carried out in Wuhan. The findings of this study show that there is generally a good institutional transport structure in the city and that there is also a growing awareness of using information technology to support transport planning and management. Professional cooperation exists among transport organisations, but not yet at the level of data sharing. For future data sharing and the building of an integrated data support framework, data from these organisations have to be rendered consistent and cross-referenced. It is exactly in this context that the general techniques and specific local needs meet.

The institutional data study benefited from the functional classification of transport data. The classification provides a framework in which the functional data sets fit. This implies that, when a data sharing policy is available, it will be feasible to know where to get data for specific transport studies or what data contributions an institution can make.

The implementation of the current and envisaged future methodologies of transport data integration ultimately hinges on the institutional interactions among transport agencies. The need for data integration requires data sharing among institutions. Data sharing enables more efficient utilisation of data resources and is largely an institutional decision. This study has touched the preliminary aspects of the institutional issue by analysing the functions of transport agencies in Wuhan, as well as some possibilities and obstacles in promoting data sharing. For facilitating institutional data sharing, more in-depth studies are encouraged in terms of institutional culture, structure, interactions, benefits, constraints and data policies.

7.3 Future research

The ultimate objective in transport data research is to set up a comprehensive data framework to support transport planning. This research has examined the data requirements for urban transport planning and explored the methodologies for linking and integrating these data. These are the fundamental technical issues that must be addressed in building a transport data support framework. At the same time there are a number of issues that will need further attention in future research in this field. Of particular importance in this respect are the integration of temporal, multimodal and multi-source transport data, and matters related to the development of data warehousing, decision support systems and data infrastructures.

7.3.1 Temporal, multimode and multi-source

The transport system is a dynamic system that experiences changes over time. Time is an important aspect in data processing. Traffic volumes on streets will only make sense after they have been broken down by time period, such as the peak hour volumes, or the daily averages, or even seasonal values. Data used for estimating these volumes have accordingly to be marked with a time stamp. In travel demand research, it has been realised that time-use data form the foundation of the new activities-based demand models (e.g. Kitamura *et al*, 1997; Bhat & Koppelman, 1999). On the technology side, there have been many discussions on temporal data modelling and temporal data processing (e.g. Peuquet, 1999, 2001; Wilcox *et al*, 2000). In the meantime, there have been attempts to apply these models in transport applications (e.g. Etches *et al*, 1999; Frihida *et al*, 2002).

This research has identified the temporal aspect as a key component in the framework of transport data integration. Although the research on bus data integration in Chapter 5 has touched on the temporal issue, a more in-depth investigation into all kinds of temporal transport data is necessary. This should seek to make sure that all transport data are temporally stamped in transport databases, develop specialised tools for acquiring correct data from any given period of time, and forecast the trend of spatial and non-spatial evolution based on time series analysis.

To improve transport services, transport planners have been concerned with the integration of various transport modes, such as rail, subway and bus. The fundamental issue within this topic is the construction of a multimodal transport information system, in which data of different modes can be linked and referenced with one another in terms of spatial locations as well as operations. As different transport modes usually run on different routes and in separate spaces, the task of modal data integration also includes the spatial challenge of multi-dimensional data representation (Koncz & Adams 2002).

While this research has concentrated on spatial representation and data models of existing transport phenomena, attention should also be paid to other sources of data. One such data source is the output from transport planning models. Some of the outputs are linked directly to spatial features, such as the link volumes and the TAZ matrix; some are related to the total amount for the whole urban area, such as vehicle ownership and total capacity of facilities. Another possible data source is intermediate data produced by data inference or data summarising, such as the probabilities of travel choice from statistical choice models. Opportunities also exist with respect to data collected using new technologies, including high-resolution image data, GPS data and Internet-based survey data. The integration of these data requires innovative techniques.

7.3.2 Towards a comprehensive transport data support framework

A data warehouse consists of legacy data within an organisation and provides structured access for data query and analysis (Kimball, 1996). Transport organisations maintain large amounts of spatial or spatially oriented data. To set up a transport data warehouse, full investigations have to be made of the institutional structures and cultures, the data environment and data integration technologies. The data integration approaches described in this study will contribute to the data integration process leading to such a data warehouse, yet many other issues need to be settled. Some envisaged challenges include the selection of appropriate tools for query and analysis, the analysis of existing database structures, and detailed analysis of business processes.

Data warehouses provide the necessary information for decision making within organisations. For decision support of strategic urban transport planning, however, a more comprehensive system linking data from different transport organisations is needed. Such a system should make use of existing databases or data warehouse systems in those transport agencies, and set up technical as well as institutional linkages among these enterprise systems. The technical linkages facilitate data transfer based on data standards and data integration methods, and the institutional linkages ensure data sharing based on institutional business analysis. This means that such evaluations have to be carried out between each pair of transport agencies.

A comprehensive institutional evaluation might be carried out under the general framework of institutional assessment. The purpose of institutional assessment is to enhance institutional performance and capacity, which is achieved through investigations and evaluations of the external environment, institutional motivation, resources and performance (Lusthaus *et al*, 1995). An equally important issue is understanding the mechanisms and behavioural factors that are relevant for data sharing among transport organisations. The exploration of data sharing possibilities requires detailed analysis on the incentives and disincentives for decision makers within organisations (Nedovic-Budic & Pinto, 2000; Wehn de Montalvo, 2003). For this purpose, site-specific case studies are necessary to enrich the knowledge on local context for data sharing activities.

An effective method of data exchange in the future may be the use of data clearinghouses. A data clearinghouse provides searchable access to information, using hardware, software and telecommunication networks. In the geo-information field, the purpose of a data clearinghouse is to facilitate data sharing under the general rubric of spatial data infrastructure (SDI) (Masser, 1998) or geo-spatial data infrastructure (GDI) (Groot & McLaughlin, 2000). A clearinghouse requires the descriptions of all agency data, i.e. meta-data. The concept and structure of the data clearinghouse might be borrowed for building a data support framework for urban transport planning at the local or national level. Building a transport data clearinghouse requires a coordinating agency to classify data from transport agencies and to develop an Internet-based structure to make these data sources accessible. The technologies for data clearinghouses are available; what is needed are the contents and structure from the perspective of transport applications.

In summary, it is felt that this study has contributed to the development of appropriate methodologies for urban transport data integration. In the process it has also identified a number of emerging issues for further research. These include temporal data fusion, multimodal data modelling and integration, multi-source data incorporation, the structure of a data support framework, as well as the institutional challenges for data sharing.

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Acronyms

AC	Administrative City
AD	Administrative District
AML	Arc Macro Language
APTS	Advanced Public Transport System
AS	Administrative Street
AVL	Automatic Vehicle Location
BME	Bureau of Municipal Engineering
BN	Building Name
BNR	Building number
BPS	Bureau of Public Security
BPU	Bureau of Public Utilities
BTM	Bureau of Traffic Management
BUPLA	Bureau of Urban Planning and Land Administration
C-in-P	Centroid-in-polygon
CC	Construction Committee
COM	Component Object Model
DBMS	Database Management Systems
DIME	Dual Independent Map Encoding
DOT	Department Of Transportation
DRAM	Disaggregate Residential Allocation Model
E-R	Entity-Relationship
ED	Enumeration Districts
EMPAL	EMPloyment Allocation Model
EPA	Environmental Protection Agency
FGDC	Federal Geographic Data Committee
FTIS	Framework Transport Identification Standard
FTRP	Framework Transport Segment Reference Point
FTSeg	Framework Transport Segment
GDF	Geographic Data File
GDI	Geo-spatial Data Infrastructure
GIS	Geographical Information System/Science
GIS-T	GIS for Transport
GPS	Global Positioning System
IC	Information Centre
ID	Identifier
ISD	Institute of Survey and Design
ITS	Intelligent Transport System
IUPD	Institute of Urban Planning and Design
IUTP	Institute of Urban Transport Planning
LBS	Location-Based Services
LRS	Linear Referencing System

LU	Land Use
MC	Monte Carlo simulation
MDLRS	Multi-Dimensional Location Referencing System
MOE	Measures Of Effectiveness
NCHRP	National Cooperative Highway Research Program
NSDI	National Spatial Data Infrastructure
O-D	Origin-Destination
OGC	Open GIS Consortium
OLAP	On-Line Analytical Processing
OLR	Office of Light Rail
P-on-P	Polygon-on-polygon
PAF	Postal Address File
PC	Planning Committee
PN	Place Name
RDBMS	Relational DataBase Management System
SB	Statistical Bureau
SDA	Section of Domicile Administration
SDI	Spatial Data Infrastructure
SMART	Simulation Model for Activities, Resources and Travel
SN	Street Name
SNR	Street number
SU	Statistical Unit
TAZ	Transport Analysis Zone
TC	Transport Committee
TEA	Transport Equity Act
TIGER	Topologically Integrated Geographic Encoding and Referencing
TMIP	Travel Model Improvement Program
TSM	Transport System Management
UNETRANS	Unified NEtwork-TRANSportation data model
UML	Unified Model Language
URISA	Urban and Regional Information Systems Association
UTIS	Urban Transport Information System
UTMS	Urban Transport Model System
VBA	Visual Basic Applications
VMT	Vehicle Miles Travelled
WAW	Weighted Area Weighting
WU	Work Unit

Summary

Urban transport planning aims at balancing conflicting challenges by promoting more efficient transport systems while reducing negative impacts. The availability of better and more reliable data has not only stimulated new planning methodologies, but also created challenges for efficient data management and data integration. These tasks cannot be effectively fulfilled without the application of advanced information technologies.

The major focus of this study is to improve methodologies for representing and integrating multi-source and multi-format urban transport data. This research approaches the issue of data integration based on the classification of urban transport data both from a functional and a representational perspective. The functional perspective considers characteristics of the urban transport system and planning requirements, and categorises data into supply, demand, performance and impact. The representational perspective considers transport data in terms of their spatial and non-spatial characteristics that are important for data representation. These two perspectives correspond to institutional and methodological data integration respectively, and are the foundation of transport data integration. This research is based on the city of Wuhan in China.

The methodological issues of transport data integration are based on the representational perspective. A framework for data integration has been put forward, in which spatial data are classified as point, linear and areal types, and the non-spatial data are sorted out as values and temporal attributes. This research has respectively probed the integration of point, linear and areal transport data within a GIS environment.

The locations of socio-economic activities are point-type data that need to be spatially referenced. A location referencing process requires a referencing base, source address units and referencing methods. The referencing base consists of such spatial features as streets, street addresses, points of interest and publicly known zones. These referencing bases have different levels of spatial preciseness and have to be kept in a hierarchy. Source addresses in Chinese cities are usually written as one sentence, which has to be divided into address units for automatic geo-coding. As it is difficult to separate from the sentences, the address units have to be clearly identified in survey forms. Depending on the types of address units, the referencing process makes use of either semantic name matching or address matching to link source addresses to features in the referencing base. The name-based and road-based referencing schemes constitute a comprehensive location referencing framework that is applicable to Chinese cities.

The relationship between two sets of linear features can be identified with spatial overlay in the case of independent representation, or with internal linkage in a dependent representation. The bus line is such a feature that runs on the street network and can be dependently referenced by streets. In the heavily bus-oriented city of Wuhan, bus lines constitute a large public transit network that is important to transport planning and management. This research has extended conventional bus line representation to a more detailed level. Each bus line has been differentiated as two directional routes that are defined separately with reference to the street network. Accordingly, individual route stops are also represented in the database. These stop sites are spatial features with geometry that are linked to street segments and bus routes by linear location referencing methods. A data model linking base street network, bus lines and routes, line and route stops, and other bus operations data has been constructed. The benefits of the detailed model have been demonstrated in several transport applications.

Zonal data transitions include three types of operations, i.e. aggregation, areal interpolation and disaggregation. This study focuses on disaggregating data from larger zones to smaller zones. In the context of Wuhan, zonal data disaggregation involves the allocation of statistical data from statistical units to smaller parcels. Given the availability of land use data, a weighted approach reflecting spatial variations has been applied in the disaggregation process. Two technical processes for disaggregation have been examined. Weighted area-weighting (WAW) is an adaptation of the classic area-weighting method, and Monte Carlo simulation (MC) is a stochastic process based on a raster data model. The MC outcome is more convenient for subsequent re-aggregation, and is also directly available for micro-simulation. An important contribution arising from this zonal integration study is that two standardised disaggregation tools have been developed within a GIS environment.

The research has also explored the institutional aspect of data integration. The findings of this study show that there is generally a good institutional transport structure in the city of Wuhan and that there is also a growing awareness of using information technology. Professional cooperation exists among transport organisations, but not yet at a level for data sharing. An integrated data support framework requires data sharing. In such a framework, it should be possible to know where to get data for specific transport studies, or which kind of research an institution supports.

Samenvatting

Stedelijke vervoersplanning is gericht op het vinden van een balans tussen enerzijds het bevorderen van doelmatige vervoerssystemen en anderzijds het beperken van de negatieve gevolgen van vervoer. De beschikbaarheid van betere en betrouwbaarder gegevens heeft niet alleen tot nieuwe planningsmethodologieën geleid, maar ook uitdagingen gecreëerd voor doelmatig gegevensbeheer en gegevensintegratie. Deze opgaven kunnen niet effectief uitgevoerd worden zonder gebruik te maken van moderne informatietechnologie.

Het hoofdonderwerp van deze studie is het verbeteren van methodologieën voor het representeren en integreren van stedelijke vervoersgegevens met verschillende formaten. Het vraagstuk van gegevensintegratie wordt benaderd op basis van een classificatie van stedelijke vervoersgegevens, gemaakt vanuit een perspectief van functionaliteit en representatie. De functionele invalshoek gaat uit van de karakteristieken van het stedelijke vervoerssysteem en de planningsbehoeften en onderscheidt vraag-, aanbod, prestatie- en effect-gegevens. Op basis van representatie worden gegevens ingedeeld in ruimtelijke en niet-ruimtelijke groepen. Deze twee perspectieven komen overeen met respectievelijk de institutionele en de methodologische invalshoeken van gegevensintegratie en vormen de basis voor het integreren van vervoersgegevens. Het onderzoek is gelokaliseerd in de stad Wuhan in China.

De methodologische vragen rond de integratie van vervoersgegevens hangen samen met het representatie-perspectief. Er wordt een kader voor gegevensintegratie voorgesteld, waarin ruimtelijke gegevens worden geclassificeerd als punt-, lijn- en gebiedsgegevens en de niet-ruimtelijke gegevens onderverdeeld zijn in thematische en temporele kenmerken. In dit onderzoek wordt de integratie van punt-, lijn- en gebiedsgegevens in een GIS-omgeving uitgevoerd.

De locaties van sociaal-economische activiteiten zijn puntgegevens die gegeocodeerd moeten worden. Geocodering vereist een geografische referentiebasis, een bestand met adreseenheden en een coderingsmethode. De referentie bestaat uit ruimtelijke objecten zoals straten, straatadressen, en algemeen bekende punten en gebieden. Deze referenties hebben verschillende niveaus van ruimtelijke nauwkeurigheid en dienen hiërarchisch geordend te worden. Adressen worden in Chinese steden meestal aaneengesloten geschreven, waardoor opsplitsing in adreselementen noodzakelijk is voor geocodering. Omdat het lastig is om die eenheden te onderscheiden dienen adreselementen duidelijk aangegeven te worden in opnameformulieren. Afhankelijk van het type adreselement wordt in het coderingproces gebruik gemaakt van naam- of adrespassing om brongegevens aan de referentiebasis te koppelen. De ontwikkelde straat- en naamgebaseerde coderingsschema’s vormen een omvattend raamwerk voor locatieverwijzing dat toepasbaar is voor Chinese steden.

De ruimtelijke relatie tussen twee groepen lineaire objecten kan bepaald worden met een overlay als sprake is van onafhankelijke representatie of door interne koppeling bij een afhankelijk representatie. Zo kan een buslijn gegeocodeerd worden door middel van een stratennetwerk. In een sterk op busvervoer georiënteerde stad als Wuhan, vormen buslijnen een omvangrijk openbaar vervoersnetwerk dat van veel belang is voor de vervoersplanning. In deze studie wordt de conventionele wijze van representatie van buslijnen verder gedetailleerd. Elke buslijn wordt opgevat als twee directionele busroutes die apart aan het stratennetwerk gekoppeld worden. Vervolgens worden ook de haltes per route gerepresenteerd in de gegevensbank. Deze routehaltes zijn ruimtelijke objecten waarvan de geometrie wordt verbonden met de straatsegmenten en busroutes door middel van methoden voor lineaire locatieverwijzing. Er is een gegevensmodel gebouwd dat het statennetwerk, de buslijnen, de busroutes, de lijnhaltes, de routehaltes en operationele kenmerken van het busvervoer omvat. De voordelen hiervan worden in een aantal toepassingen aangetoond.

Bewerking van gebiedsgegevens omvat drie typen operaties, namelijk aggregatie, gebiedsinterpolatie en disaggregatie. Het onderzoek richt zich op gegevensdisaggregatie van grote naar kleine gebieden. In Wuhan gaat het daarbij om de toewijzing van statistische gegevens van statistische gebieden aan kleinere zones. Door de beschikbaarheid van grondgebruiksgegevens, kan een gewogen benadering, die rekening houdt met ruimtelijke verschillen, worden toegepast. Twee disaggregatiemethoden zijn onderzocht. ‘Gewogen gebiedsweging’ (WAW) is een aanpassing van de klassieke methode voor gebiedsweging en Monte Carlo simulatie (MC) is een stochastische methode gebaseerd op rastergegevens. De uitkomst van de MC-methode is het best geschikt voor re-aggregatie en is ook direct bruikbaar voor micro-simulatie. Een belangrijke bijdrage van de gebiedsintegratie-analyses is dat twee gestandaardiseerde disaggregatie-gereedschappen zijn ontwikkeld in een GIS-omgeving.

Het onderzoek strekte zich ook uit tot een verkenning van de institutionele aspecten van gegevensintegratie. De uitkomsten daarvan tonen aan dat er in algemene zin sprake is van een goede institutionele infrastructuur voor het vervoer in Wuhan en dat er ook een groeiend bewustzijn is om informatietechnologie te gebruiken. Er wordt op professioneel vlak samengewerkt tussen de vervoersorganisaties, maar nog niet wat betreft het gemeenschappelijk gebruik van gegevens. Het delen van gegevens is noodzakelijk voor een geïntegreerde gegevensondersteuning. In zo’n opzet wordt het mogelijk te weten waar de gegevens voor specifieke vervoersstudies beschikbaar zijn of welk soort onderzoek een organisatie kan ondersteunen.

摘　要

城市交通规划旨在提高交通系统的效率并尽可能降低其负面影响。近几十年来，更新更可靠的数据源不仅刺激了规划方法的改进与创新，而且对数据管理与融合提出了挑战。信息技术是迎接这些挑战的重要工具。

此研究的主要目的是增强城市交通数据的表达及融合方法。研究的基础是从两个方面对城市交通数据进行分类，即数据的功能方面和数据的计算机表达方面。根据城市交通系统的特点及交通规划的需求，交通数据按功能可分为供给数据、需求数据、运行数据和影响数据。交通数据的表达分类则是以数据主体的空间与非空间特征为依据。这两个角度的数据分类分别对应着交通数据融合的两个方向，即组织机构问题和技术方法问题。因此，交通数据的分类是数据融合的重要基础。该研究以武汉市为背景。

数据融合的方法研究以数据的计算机表达分类为基础。空间数据可分为点状、线状和面状的数据类型，而非空间数据则可归纳为数值和时态两类属性。据此，该研究提出了一个完整的交通数据融合框架，并在 GIS 环境下分别进行了点状、线状和面状交通数据融合方法的研究。

社会经济活动的场所是一类点状数据。为进行交通需求预测，需要获得这些场所的空间位置。满足这一目的的体系称为位置参照系统，该体系包括基准参照物、活动的地址、以及参照方法。城市中的基本空间要素，如街道、门牌号、特征点和公共区域，都可作为基准参照物。这些参照物所代表的空间精度是不一样的，需构成一个层次。中国城市中的活动地址常常被记录为一个完整的句子，为满足自动化地址匹配的要求，需将这些地址分解为标准的地址单元。该研究认为，中文地址的自动化分解是可能的，但需要有一个完整的地名库。参照方法是指不直接获取坐标而确定空间位置的方法，分为名称匹配和地址匹配两类。这两类方法以基准参照物和地址单元为基础来确定社会经济活动的空间位置，以此形成适合于中国城市的位置参照体系。

交通线路在计算机表达中属于线状数据。两类线状实体的关系可以通过空间叠加或内部连接来实现。公共汽车线路与街道网是两类线状实体，前者

可以依赖于后者用内部连接来表达。在象武汉这样的以公汽为主体公交的城市中，公汽线路构成了一个复杂的网络，是交通规划的重要任务。该研究将传统公汽线路的表达提高到一个更详细的层次。每条公汽线按运行方向分解为两条带方向的线路，同时每个公汽站点对应的多个详细位置也记录于数据库中。站点采用带坐标的独立表达方式，其与街道和路线的关系采用线性定位方法来确定。以这些关系为基础构成了一个完整的公汽数据模型。该模型在交通研究中有比较广泛的应用，本研究中用一系列例子作了证明。

交通小区和土地利用是交通研究中的面状数据。面状数据的融合主要是面状实体之间的数据转换，这样的转换包括三个基本的运算类型，即聚合、面内插和分解。该研究集中探讨了数据分解技术，即从大的面状实体向较小的面状实体的数据分解。在武汉市的例子中，面状数据分解的过程主要是指将统计数据从标准的统计单元分解到细小的地块中。该研究提出了以地块的土地利用和空间位置为权重的两个分解方法，即加权面积权重法(WAW)和蒙特卡洛模拟法(MC)。WAW 是对传统面积权重内插法的改进，而 MC 则是基于栅格数据模型的随机方法。试验表明，MC 的结果更适合于数据向交通小区的再聚合，并可直接应用于微观交通模拟中。该研究的另一个重要贡献是在 GIS 环境中开发了两个通用的面状数据分解工具。

该研究同时也探讨了数据融合中的机构问题。武汉市有一个比较完整的交通机构体系，并且信息技术正逐步得到应用。交通机构之间的业务合作比较频繁，但尚未达到数据共享的层次。数据共享需要一个综合的数据支持体系，在此体系中各机构的数据应有适当的连接。数据融合研究的目的就在于实现这样的连接。

--- 黄正东
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Curriculum Vitae

Zhengdong Huang was born on 14 October 1968 in Hubei, China. In 1986 he went to the Wuhan Technical University of Surveying and Mapping (WTUSM). After two years of study in the Department of Geodesy, he transferred to the newly established Education Centre for Urban and Rural Surveys, Planning and Management (ECURSPAM) at the same university. ECURSPAM was a joint programme between the university and ITC. In 1990, Zhengdong Huang got a Bachelor's degree in urban planning, and received the Graduate of the Year Award from the university. In the same year, he became a staff member of ECURSPAM. He got an MSc degree at ITC in 1993. Since then he has worked at the School of Urban Studies (SUS) at WTUSM, now the new Wuhan University. In 1999 he started his PhD study at ITC and Utrecht University, the Netherlands.

Zhengdong Huang has been working on database management systems (DBMS), Geographical Information Systems (GIS), and the application of these technologies in urban planning and management. His research interests include urban information systems, urban transport data integration, transport planning and transport simulation.