Analysis of an Integrated Transportation GIS for the City of Guangzhou, China

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ABSTRACT. This paper presents current conditions, needs and problems that face the citizens and transportation agencies of Guangzhou. Nowadays, the state of traffic/transportation infrastructures of Guangzhou requires new approaches for the management and planning of urban traffic flows. This paper reviews existing transportation GIS applications and research perspectives and proposes a preliminary framework for an integrated GIS for the city of Guangzhou. Taking into account existing applications, demands and problems, the purpose of our research is to provide an integrated multimodal GIS for Intelligent Transportation System.

KEYWORDS: urban traffic / transportation system, transportation data model, GIS
1. Introduction

Guangzhou is a metropolitan city in China whose economy keeps growing rapidly since the late seventies. Annual growth in Guangzhou, one of the most advanced eastern cities in China, has reached a double-digit rate. The Municipality of Guangzhou comprises 10 urban districts and 2 suburban counties, with a total urban area of 7434 square kilometres and a population of 10.15 million including a large number of floating populations [12]. Gross population density in the built-up area now exceeds 20000 inhabitants per square kilometre. As a result, population and car numbers are still growing rapidly. Nowadays, the city suffers from severe traffic congestions. Besides traffic congestions, the transport network of Guangzhou is also being under other severe pressures, e.g. management and maintenance of transportation infrastructure, traffic safety and environment quality.

As a rocketing growing commercial city, it is important for Guangzhou to employ powerful and advanced technologies for replacing the inferior methods, integrate sophisticated mathematic models, and make a better use of the available limited funds. The purpose is to construct an integrated, efficient, effective and comprehensive Urban Transportation Information System (UTIS) for managing, monitoring and planning purposes so that its development can coincide with city’s developmental pace. Practices and experiments of developed countries have proved that constructing an effective urban transport network can’t just depend on building new roads, because it is related with many factors including society, economy, environment, and scientific technologies [1]. Indeed, such a complex system relies on many social features, dynamic behaviours and complex interactions that influence transportation system. Taking into account the whole aspects of modern cities and related components at the right granularity level is required to understand and harmonize transport network, especially in Guangzhou [1].

One of the main demands in different aspects of transportation can be attributed to the capability to cope with the large volume of data with geographic spatial characteristics. Therefore, the adoption of newly emerging technology, such as Geographic Information System (GIS) can help to improve UTIS and related decision making process. GIS are becoming widely used in transportation planning agencies, especially among metropolitan transportation organizations [2], where the transportation professionals and researchers wish to combine GIS with other powerful technologies (i.e. the contact-less smart card technology, Geolocalisation systems such as GPS, GPRS, UMTS or WiFi). These advanced technologies are integrated to extend the transportation prototype to build a Nerve Network (NN) for decision-making support on transportation planning [16].

This paper reviews existing transportation/traffic systems and the suitability of GIS as support for transportation and traffic infrastructures in the city of Guangzhou, China. The remainder of the paper is organized as follows. Section 2 briefly
presents GIS and transportation system. Section 3 describes the existing transportation infrastructure and the transportation system already in place in Guangzhou. Section 4 presents the new applications and services of GIS for transportation, and briefly introduces a data model that we will work during further research. Section 5 draws the conclusions.

2. GIS and transportation system

Over the past years, integration of transportation and Geographical Information Systems (GIS) appeared to be a promising research area that should contribute to the development of sustainable cities, which is a broad expression that encompassed all of the activities that involved the use of GIS for some aspect of transportation planning, management, or science [3]. Government agencies, research institutions, and private sectors are among the actors that look forward data, either static or dynamic. The data contains difference transportation modes (bus, tram, metro, car, boat) and traffic related objects (pavement, stop signs, traffic lights, or construction equipment). For instance, integrating GIS and traffic information can be used to monitor traffic accidents, flows or congestions that have occurred in the past, this providing useful insight for transportation planning studies. Increasingly, urban and transportation planners and professionals are finding that the integration of traditional transportation research methods with the added value of GIS capabilities including integration of geographical spatial-analysis and cartography, provides a robust platform for both traditional and innovative transportation and traffic activities.

2.1 Principles

In many parts of the world traffic is generally organized, flowing in lanes of travel for a particular direction, with interchanges, traffic signals, or signage at intersections to facilitate the orderly and timely flow of traffic. Traffic can be separated into vehicular, non-vehicular (bicycling) and pedestrian traffic. Traffic management aims at improving traffic services by the microscopic or macroscopic and dynamic processes on analysis, abstraction and surveillance of congestion and safety.

Transportation is a facility consisting of the means and equipments necessary for the movement of passengers or goods, and is the means of conveyance to move forces, equipments, personnel and stocks and includes the requisite materials handling equipments [21]. Transportation management focuses on the macroscopic processes on transportation infrastructure and network strategic design and planning. A worthwhile transportation management system enables transportation planners to make decisions effectively while automating carrier bid, tendering, settlement, and the freight auditing processes [22]. This may not only improve cost, but also may help to improve customer service.
A Geographic Information System (GIS) can be defined as an information system specializing in the input, storage, manipulation, analysis and reporting of geographical (spatially related) information [23]. Betsy Woodhouse [27] presented GIS as a system of computer software, hardware, and data used to manipulate, analyze, and present information tied to a spatial location. Among the wide range of potential applications [30], integration of GIS, traffic and transportation systems have received a lot of attention in recent years [23]. A specific branch of GIS applied to transportation issues, commonly labeled as Geographic Information Systems for Transportation (GIS-T) [3], has emerged. Miller and Shaw [26] describes that GIS-T refers to the principles and applications of applying geographic information technologies to transportation problems.

Transportation is one of the fastest growing of many fields in which GIS is used [23]. Diverse areas of transportation, including high way and rail way infrastructure management, international shipping, airport management, fleet logistics, traffic management and intelligent transportation systems (ITS), transit bus and rail service planning, transportation modeling, supply chain modeling, and others, are applying GIS to their work [24]. The breadth of the field of integration of GIS and transportation system provides large opportunities for the development of new and innovative applications in transportation system of different transportation organizations [3].

2.2 Intelligent Transportation systems (ITS)

Intelligent Transportation Systems (ITS) are identified as the means to achieve sustainable and environmental friendly transportation for the 21st Century [25]. Advanced information and communication technologies are required for ITS. These include Geographic Information Systems (GIS), Data Storage & Processing Equipment, Wireline & Wireless Communication Systems, Global Positioning Systems (GPS), Sensors, Smart Cards and so forth. In addition to the above technologies, institutional and market factors play an important role in successful ITS deployment. ITS application functionality includes collection and processing of real-time data, generating and utilizing information for various purposes such as controlling and managing traffic, handling fleet operations (public transport and private carriers), emergency management and assisting users in their travel related decisions. The benefits of ITS include reduction of traffic congestion, enhanced safety, mitigation of environmental impacts of transportation system, enhanced energy performance, and improved productivity [4]. The ITS development in the city of Guangzhou is still immature, correspondingly for the developed world cities such as Paris. The main issue is that ITS with individual components has not been integrated completely. For instance, transit network data is scattered over different transit enterprises.

Fragmented ITS solutions have led to the situation where data sources are also
so fragmented and isolated as to cause inconsistencies, inaccuracies and repetition of data [5]. Such a fragmented ITS will inevitably cause a lack of federalisation of data and co-ordinated system of urban transportation management and planning. In contrast, an Integrated ITS (IITS) would give transportation management and planning many benefits as following [5].

- Bring together all of the different streams of ITS with all of its component unified in a homogenous environment,
- Be used as a domain wide decision support system in all phases, including monitoring, planning, management and designing and,
- Facilitate the federalization and sharing of data between different agencies.

2.2. Towards an integration of GIS and transportation system

Considering the complexities of the integrated transportation data, there is an urgent need to adopt lasted concepts and technologies for designing and developing the information resource management of transportation infrastructure in Guangzhou. Presently, GIS is an important tool in transportation engineering, and play an even more important role in providing the capability to perform transportation, planning and analyses [20]. GIS is the ideal information management and analysis tool for many aspects of the transportation industry including both the public and the private sectors [24].

The first advantage of the integration of GIS and transportation system to various transportation organizations is its potential for data integration which provides and integrated source or data hub of information for traffic and transportation related data [6]. In a GIS platform, the transportation database is generally extended by integrating attribute datasets and spatial data through its linear referencing system [2]. Moreover, the application of GIS will facilitate integration of all other socio-economic data with transportation system database for wide variety of management functions, such as estimating transportation costs.

The second advantage of the integration of GIS and transportation system relies in its ability to access and analyze spatially distributed data, and respects to its actual geographic spatial data of the area that allows analysis not possible with the other database management systems. The main benefit of using the GIS is not merely the user-friendly visual access and display, but the spatial analysis capability and the applicability. The particular capability and applicability provide standard GIS functionalities (i.e. thematic mapping, charting, network-level analysis, access and manipulation to spatial data), and even the ability to interface with external program and software for decision-making support, simulation, and user-specific purposes [2].
The large effort of integrating GIS and transportation system, along with the multiple presentations of results on a digital electronic map, will allow the transportation planners/professionals a better reception of the problem, enable better decisions, and allow a better understanding of what is to be achieved in a broader sense.

Presently, many transportation agencies and private sectors in Guangzhou integrate GIS with traffic/transportation applications for the purposes of analysis, planning, management and monitoring. The following and non-exhaustive list gives the organizations and their responsibilities or GIS applications.

- Guangzhou Committee of Traffic and Transportation (GZCT) is responsible for the strategic developmental policy and planning of transportation system. It also directly supervises some research institutes such as Guangzhou Institute of Transportation Management. This research institute focuses on studies in various transportation research (i.e. ITS, traffic control, environment pollution and so on);

- Guangzhou Administrative Department of Passenger Transportation, as a branch of GZTC, directly takes in charge of the analysis, planning and management of transit network for providing more efficient, swift and convenient transportation modes to travellers;

- Guangzhou Traffic Police Department has constructed CCTV in most of intersections and traffic corridors for real-time surveillance of traffic flow and safety.

- Transit enterprises, such as bus companies, also construct applications within GIS for their special objectives. For instance, the Guangzhou Third Bus Company has implemented an Intelligent Dispatch System by combining GIS and GPS. Most of trucking and deliver companies integrate GIS and GPS to track their shipments and dispatch their trucks.

2.4 Related work

Increasingly, researchers/transportation professionals are realizing that the synthesis of traditional transportation research methods with the added value of GIS resources provides a robust platform for both traditional and innovative transportation activities [3]. Claramunt et al. constructed a new framework for the integration, analysis and visualization of urban traffic data with GIS, for promoting a flexible view of multi-layered approach to the integration, analysis, animation, manipulation and visualization of urban traffic data within GIS [28]. Their research aimed to implement the visualization of very dynamic phenomena within very dynamic GIS (VDGIS, a new framework allows the analysis of spatio-temporal phenomena at complementary levels of granularity within GIS). The target is to fill the lack of conceptual and physical interoperability with real-time computing
facilities in the management of very dynamic geographical phenomena within current GIS. Adam Etches proposed an integrated transportation database in support of a collaborative Network Information System (NIS) including NIS, GIS and ITS to transportation application [6]. His work focused on implementing a reference model and to identify the methodological, conceptual and practical principles of the process of implementing a collaborative network information system, and enveloping an Urban Transport Information System (UTIS) prototype. This prototype includes a database modeling achieved by using MADS (Modeling of Application Data with Spatio-temporal features) to provide a wide range of support services for a transportation network.

In Europe, GIS for transportation is emerging as an important planning and management tool for transportation agencies. Many European nations are making huge investments in transportation infrastructure. The highways agency in the Loire of France has been using GIS since 1989 for many purposes: Traffic accident patterns are visualized and safety improvements are made where they are most needed [7]. By collecting significant data for the whole network, repairs and works budgeting have become more reliable and calculated in advance. First creating the optimal route between locations and then using GIS to decide how and where to sign, improved directions and movements in the road network and helped avoiding congestion [8]. ATAC, the public transportation company in Rome, has successfully implemented a comprehensive GIS-based management system for the city bus network. The system coordinates the work of a number of departments including information control, breakdown management, marketing, and ticket distribution. The departments use and maintain the same database, which minimizes redundancy and maximizes efficiency. Integrating the management system with established monitoring procedures allows the collection, visualization, and analysis of disruptions on the transportation network, showing where and when the events take place. The company is also planning a reservation service for the disable. The customers will indicate their needs by telephone, which then be put into the database. From the database, a daily schedule will be produced for each vehicle required to provide pickup services.

3. Current transportation infrastructure and applications of the city of Guangzhou

China has enjoyed strong economic growth since the opening to foreign investment in the late seventies. Annual growth in the most advanced eastern provinces, such as Guangdong, has reached double-digit rate, stimulated by an increasingly rapid transition of a market economy. His growth put an intense pressure on city transport systems, and traffic congestions has been increasing constantly in recent years. However, Guangzhou is feverishly constructing roads and highways, but still cannot keep pace with the explosion in the number of private vehicles on the roads, leading to heavy traffic congestion, especially in urban
centers. If traffic congestion is allowed to increase unchecked, it will have serious implications for personal mobility, economic growth, and the quality of the urban environment. Nowadays Guangzhou, which has the largest numbers of automobiles in China, is suffering from severe pollution from exhaust emissions. And traffic jams are the problem that triggers the most complaints from city dwellers. More arable land has given way to roads and parking lots to ease transportation bottlenecks and accommodate a rapidly increasing number of vehicles. The main causes appear to be underinvestment in urban transport infrastructure, the rapid pace of motorization (for both person and freight movements) and fragmentation of responsibility for urban transportation system conditions. While all traffic suffers from the effects of congestion, though the authorities stress the priority development of public transportation services in suburban regions, the main victims are public buses which are now deteriorated at a time when demand for travel is generally rising with increasing affluence.

Compared to developed countries, the public transportation system of metropolitan cities has played the most important part of urban transportation. Paris as an historic and dynamic world city, for example, with a population of over two million faces of many of the same challenges in order to achieve an efficient and economically priced transport for all its citizens. Indeed, since early seventies, the Paris public transportation system operated by a body that is largely state-controlled, has been superbly modernized and extended and it is now regarded by many as the finest of any major world city [9]. The Paris public transport system is based around three main modes of transport: the bus, the metro and the Réseau Express Régional (RER) which is the commuter railway [10]. In Paris, public transport is viewed as being a necessary social and economic well-being [11].

Nowadays, many Chinese cities such as Guangzhou have to urge the top-priority development for public transportation services, but have to deliver some similar infrastructure and related monitoring in a quite smaller time. Increased traffic noise and air pollution, and increased community severance, are other undesirable manifestations of the urban transport problems.

### 3.1 Overview of urban transportation network of Guangzhou

By the end of 2000, the area of urban district of the city of Guangzhou has reached 297.5 square kilometres and has, since this time, been largely developed [12]. This section presents an overview of the transportation infrastructure of this urban district.

- **Road network**

As a transportation hub of the Southern China, the road network in Guangzhou has been extended in all directions with 2053 km of road length (including 157.7
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kilometres of highway), 619 intersections (including 89 pedestrian bridges and 67 cloverleaf junctions), and with 7 tunnels. Figure 1 shows the arterial road network of the city of Guangzhou. The density of the road network is 8.43 kilometres per square kilometre. The total road area reached 28.05 million square meters, and the mean road area is 6.78 square meters per person.

![Fig. 1: Sketch map of arterial road network of the city of Guangzhou](image)

Presently the road network in Guangzhou, main infrastructure of traffic flows, is being in some problems as following.

1. An unbalance distribution of building blocks and roads. For example, the joins of different levels (high level, medium level and low level) of roads are out of proportion;

2. Insufficient road load, especially for the load of arterial road network;

3. A number of traffic congestion points (traffic bottlenecks) are existing in current road network;

4. Uneconomically build new roads in central area of the city. The population congregates in the central area, where the buildings are serried. These
factors cause that building new roads in the central area of the city of Guangzhou have to pay high price.

- **Metro**

  Guangzhou Metro has two routes (Line 1 and Line 2) by 2005: Line 1 is 18.5 Km long with 16 stations and line 2 is 23.3 Km long with 20 stations. The first segment of the line 3 including 8 stations opened at the end of 2005. A wide-ranging transportation network in the city of Guangzhou includes an airport express rail service will be connected with the three lines of Guangzhou metro to form an extensive transportation system. In 2010, the total length of the Guangzhou metro network (Line 1 to Line 9) is expected to be 255 Km (without the inter-city lines). Figure 2 presents the layout of Guangzhou metro lines in 2010.

![Sketch map of Guangzhou Metro, 2010](image)

Fig. 2: The layout of Guangzhou Metro, 2010

- **Bus and taxi**
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There are 16 bus companies with about 7000 buses in Guangzhou. These companies are responsible for 5 million passengers each day. The bus transit network is composed of 320 bus routes. Presently, there are about 16000 taxis including 7150 taxis equipped with a GPS terminal system support for intelligent dispatching and surveillance of safety.

- Private cars

The municipality of Guangzhou always reaffirms and emphasizes that the government cannot take any policy to block the development of private cars. Therefore the continual increase of private car number and the augment of all kind of travelling demands stir up an intensive increase of the traffic flows. The pace of building new roads is behind in contrast to the increase of traffic demands [12].

The numbers of private cars in the well-off city of Guangzhou were exploding. By the end of 2000, the number of private cars in Guangzhou has reached 116587, 28.6 percent more than at the end of 1999. 17% of high-income families in this capital of south China's Guangdong province have private cars, according to a survey conducted by the Guangzhou City Statistics Bureau in 2001. The number of private cars in Guangzhou keeps soaring increase. In 2005, private vehicles including cars, vans and passenger cars amounted to over 320000 according to the survey of Guangzhou Auto Association.

3.2 Transportation system participants and related needs

As a highly open public system, the urban transportation system has three levels of participants: planners and administrators, operators and final end-users [13]. The different groups of participants have different preoccupations, needs and view of the urban transportation system. Each has an approach of the network that corresponds to its comprehension, perception and use.

3.2.1 Planner and administrator

Planners and administrators’ primary aim is to have a comprehensive view of the whole transportation system. Their main hope is that the citizens, which derives from the producing and living activities, can be mostly satisfied, and that the occupation of resources and impacts to environment to be diminished as much as possible. At the same time, they anticipate that the urban transportation can positively feed back and promote the economic development and land-use pattern of the city [13]. Therefore, they try to work on the project that is expected to reduce transport bottlenecks affecting socio-economic development. They also try to obtain a lower passenger and freight transport costs. These will have direct benefits for the travelling of public, commercial and industrial producers through an improved access to, from and within the commercial city of Guangzhou. Such an objective is
also designed to promote the sustainability of benefits through more effective management and maintenance of road assets. Planners and administrators also anticipate improving health and quality of the citizens’ lives by reductions in motor vehicles emissions, and push the development of local technical and management capacity.

3.2.2 Operator

The operators are often the companies and enterprises such as bus companies and trucking & delivery companies. Their concerns are how to provide for the society the best transportation services with lowest costs, that is, to realize the maximum ratio of “benefit/cost” during the operational process of the companies [13]. For example, the local bus operators need to design the efficient bus routes and make scheduling that satisfy travelling demands. Trucking & delivery companies need to build applications to track their shipments for safety and find the optimal route for reducing costs.

3.2.3 Final end-user

Transportation is a part of daily life. The changes in transportation modes (including personal transportation modes and public transportation modes) faithfully reflect the changes in people's life style. The changes in transportation modes inevitably lead to the changes in the needs of travelers and society activities. Table 1 presents the changes of transportation modes from 1984 to 2005 in the city of Guangzhou.

<table>
<thead>
<tr>
<th>Time</th>
<th>Personal transportation mode</th>
<th>Public transportation mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before 1980’s</td>
<td>Walk</td>
<td>Bus</td>
</tr>
<tr>
<td>1980’s</td>
<td>Bicycle</td>
<td>Bus, Ferry (from Haizhu District to Fanchun District)</td>
</tr>
<tr>
<td>1990’s</td>
<td>Bicycle/Motor cycle</td>
<td>Bus, Metro (after 1997)</td>
</tr>
<tr>
<td>2005</td>
<td>Car</td>
<td>Bus, Metro, Taxi, Train, Plane</td>
</tr>
</tbody>
</table>

Table 1: Guangzhou 1984-2005: from bicycle to private car

From end-users (i.e. pedestrians, cyclists, private car owners or public traffic passengers) point of view, the main concern is the extent to which the transport system can satisfy their demands of swiftness, safety, low costs and comfort in travelling [13]. One important demand is also to minimize the travelling time. When they want to travel, they usually have to select a transportation mode which is best for them to get to their destination. The main factor that influences the traveller’s
perception of a good traffic information service relies on the ability to provide to end-users, and the right information at the right time that is both before and during their journeys. For pedestrians, cyclists or private car owners, pre-trip information may include navigation data such as street maps and directions for optimum routes from origin to destination. A public traffic passenger may be more concerned with the obtaining of timetable information prior to departure and may require route data about the available services. The passenger may additionally need pre-trip information about the location of the bus stops or stations for access to and from the network. During the journey, waiting time and delays are perceived as penalties to the passenger and this constitutes the main cause of user’s dissatisfaction with public traffic [6]. As previously mentioned, the users of different modes have distinct needs in terms of the types of information they require.

3.3 Current traffic/transportation applications

So far, in order to satisfy the needs of the growth of the urban transportation and traveling demands, Guangzhou mainly relied on building new roads so as to expand the scale of road network and improve traffic services in despite of encountering many limitations. These limitations, i.e. overloaded land-use, rapid growing private car number, population unreasonable distribution and heavy load of roads, severely block the further development of the transportation system of the city of Guangzhou. Moreover, the main issue is the bleak state of public transport in Guangzhou. In past decades, the capital spending on public transport in Guangzhou was low. In most cases, the money was invested in building new roads, expanding at 9% a year [19]. Whereas, building new roads is a chronic and long term and can’t thoroughly solve the various problems in UTIS. By contrast, traffic congestion on the road emerges more frequently as the umbers of the private vehicles are growing rapidly. It is now crucial for Guangzhou to find efficient solutions to tackle different problems and meet a variety of travelling demands. Therefore first step towards a viable solution have been initiated during the recent years and, in spite of many lacks, the current applications involve both transportation domain and traffic domain.

3.3.1 Current applications in transportation agencies

Transportation has the ability to provide some powerful benefits to society. In addition to supporting specialization, transportation provides us with the sort of mobility and accessibility. Generally, there is widely accepted link between economic well-being and good transportation. However, there is a price to pay for good transportation. This comes in the form of undesirable side effects such as environmental impacts, energy consumption, land-use, congestion, casualties and money required to build infrastructure. Growing concern about the impact of these undesirable side effects has influenced most developed countries to move away from the “build it and they will come,” infrastructure-intensive, capital-intensive transportation strategies, toward more balanced and sustainable transportation
solutions [14]. There intelligent integration of GIS and transportation system is adopted and it holds the promise of sustainability.

The integration of GIS and transportation system would play an important role of transportation planning, traffic safety, energy consumption, vehicle emission and other related issues. During recent years, the fundamental applications of the integration of GIS and transportation system in Guangzhou have been investigated, tested and implemented. The following table gives some current applications in different transportation agencies of the city of Guangzhou.

<table>
<thead>
<tr>
<th>Application</th>
<th>Agency</th>
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<tbody>
<tr>
<td>Traffic Control and Command System</td>
<td>Guangzhou Traffic Command Centre</td>
</tr>
<tr>
<td>Traffic and Transportation Management Information Network</td>
<td>Guangzhou Traffic and Transportation Control Centre</td>
</tr>
<tr>
<td>Real-time Monitoring of Road Transport</td>
<td>Guangzhou Traffic Police Bureau</td>
</tr>
<tr>
<td>Guangzhou Public Traffic Management System</td>
<td>Guangzhou Administrative Department of Passenger Transportation</td>
</tr>
<tr>
<td>Freight Information Management Platform</td>
<td>Guangzhou Container and Delivery Company</td>
</tr>
</tbody>
</table>

Table 2: Current applications in different transportation agencies of the city of Guangzhou

The Traffic Control and Command System (TCDS) favours the real-time traffic light/signalling control and surveillance of the conditions of most intersections. It even displays the disposal of traffic policemen based on electronic maps in the Traffic Command Centre. This system implements harmonious commands and rapid reactions in traffic incidents by combining the decisions of administrators and the analysis of expert systems.

Different transportation agencies are linked to an information exchange network based on a 1 Gigabyte Ethernet Network. The Traffic and Transportation Control Centre builds high dependability data warehouse, and employs cluster technology to implement the sharing of data warehouse.

Guangzhou Traffic Police Bureau has constructed a closed-circuit television (CCTV) monitoring system so as to constantly monitor traffic safety and flow. This system is composed of 87 CCTV monitors and 184 road sensors that cover most of
intersections and traffic corridors including the highway from Guangzhou to Shenzhen.

As an open system, the CCTV monitoring system provides the real-time pictures which indicate the temporal traffic situations of intersections to the Traffic Information Radio Station. Through integrating these pictures and other information derived from traffic reporters on the spot, the radio station broadcasts the real-time traffic information to the travellers to conduct traffic flow. This real-time traffic information also can be attained from Internet based on Web GIS. Through an access to the real-time traffic information, the travellers (i.e. pedestrians, public passengers, private car owners, taxi drivers) can determine the best time to travel, the best route to take and the best mode to choose.

In 2002, the Guangzhou Public Traffic Management System based on GIS was developed and implemented at Guangzhou Administrative Department of Passenger Transportation. The following subsection presents this system in detail. Based on the spatial database of this system, a bus transit information querying subsystem was developed. This subsystem was integrated in "Guangzhou Guide" which is a travelling and touring information sharing platform based on touch-interactive device (touch screen). "Guangzhou Guide" can be found in railway station, airport, hotels or prosperous commercial centres to provide transit information services to both of domestic and foreign tourists.

Freight Information Management Platform (FIMP) has been established by Guangzhou Container and Delivery Company. This system aimed to improve the circulating of cargo to reduce the costs of transport. Through the exchange of electronic messages, this system helps operators to plan, organize and control the cargo, and meets the needs for goods’ distributing, loading, transporting and storing.

### 3.3.2 Current realisation

Nowadays, passenger transportation in the city of Guangzhou mainly relies on bus transit system. The rationality of transit network planning, therefore, directly influences the travel time and transfer rate of passengers, and overall running cost of the transportation system. An ideal bus transit network, which is feature by large service area, small non-linear rate, short travel time, and high accessibility, should be able to match the needs of the majority [15]. As a dynamic city, Guangzhou’s urban extending and population distribution change so quite rapid that the lever of the bus transit network may be reduced gradually, which has cause impact on the sustainable development of urban transportation and the benefits of citizens and transit enterprises. To cope with such a serious issue, the existing bus transit network has to be adjusted and improved. One of the most adopted technologies is GIS technology which possesses remarkable geographic spatial analysis abilities. GIS and other advanced information technologies (i.e. DBMS, Component Object
Model) combine to form a comprehensive information platform to support for decision-marking of adjustment/planning which has once been conducted by mainly relying on the practical experience of planners/designers. For these reasons, Guangzhou Administrative Department of Passenger Transportation decided to implement GuangZhou Public TRAffic Management System (GZPTRAMS) in 2002 [16]. The large effort in the development of GZPTRAMS was to devise and construct an efficient and flexible bus transit network planning prototype. This prototype integrated spatial analytical methods within GIS and sophisticated mathematic models for different planning options and purposes.

### 3.3.2.1 System architecture

The system architecture of GZPTRAMS is based on Client/Server framework and Component Object Model Geographic Information System (COMGIS) platform. To easy the difficulty of developing applications, we employed an objective libraries and ActiveX control: MapObjects, to perform spatial and attribute-based queries with external applications, and build customize application interfaces in conjunction with object-oriented development environment: Visual Basic [17]. The core of the GZPTRAMS is the bus transit network data (bus routes, stops, vehicles and related facilities) seamlessly sorted and organized in MS SQL2000.

![Diagram of functional modules of system](image_url)

At the basis of the efficient transit data model, system not only provides professional applications (data collecting, management, extracting, analysis and evaluation) to support planners for bus transit network planning, but renders
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information and services to the final beneficial users. The system mainly included three modules as listed below. Figure 3 presents that the transit data model is the core and fundament of system, which private’s interface and access to data process, and supports the querying and statistic analysis and the planning to meet users’ needs and special purposes.

1. Data management and manipulation module;
2. Querying and statistic analysis module;
3. Planning module.

3.3.2.2 Functional modules

The Public traffic data management and manipulation module provides an interface and accesses to data process, i.e. data collecting, defining, editing, retrieving, updating and so on. The transit data is seamlessly sorted and organized in database in term of definite data storage structures that explicitly define and construct the relationships of the public traffic facilities.

![Fig. 4: Data manipulation](image)

The transit network database is the core component of GZPTRANS, which is built based on MS SQL2000 and a middleware named ESRI ArcSDE (Spatial Data
Engine, SDE). ESRI ArcSDE is a server software product used to access massively large multiuser geographic databases stored in relational database management systems (RDBMSs). It is an integrated part of ArcGIS and a core element of any enterprise GIS solution. Its primary role is to act as the GIS gateway to spatial data stored in a RDBMS. ArcSDE provides a suite of services that enhance data management performance, extend the range of data types that can be stored in a RDBMS, enable schema portability between RDBMSs, and offer configuration flexibility. Figure 4 shows an example of adding visually the geospatial characteristics of a bus route into RDBMS and exchanging information between Client and RDBMS based on ArcSDE.

**Querying and statistic analysis module** aims to extract essential information from raw data. This module offers timely, accurate information querying and statistic analysis services, such as thematic mapping and charting, which are developed based on planning and travelling demands. For example, the transfer bus routes querying function was developed based on end-users’ needs: (i) where does the nearest stop locate in, (ii) which right line to take or transfer and, (iii) how to get to destination in swiftness, safety and low cost. Figure 5 presents an example of searching information about how to transfer the optimal bus route from origin to destination.

![Fig. 5: Optimal transfer bus route information](image-url)
To achieve transfer route querying, we developed an optimal transfer route algorithm (OTRA) based on bus transit network [16]. Besides the transfer rate, professionals (planners) focus on analyzing passenger flow through origin-destination statistic and finding out the basic characteristics of route (i.e., length, non-linear coefficient) for transit network layout. Figure 6 shows an example of variation of passenger flow values along the time line for a main bus stop.

Fig. 6: Public passenger flow statistic and analysis chart

Planning module aims to assist planners to promote the efficiency and accuracy of bus transit network adjustment/planning through providing professional applications, especially the spatial analytical methods within GIS. Without the support of GIS, some geographic characteristics and parameters of efficiency evaluations of bus transit network are too complicated to be accomplished by traditional methods and practical experience, such as the service area covering rate of stops in a traffic region. Table 3 explicitly shows that the bus route distribution is quite non-equilibrium in 2002, bus routes are mainly aggregated in 2 districts (Yuexiu District and Dongshan District). Figure 7 shows the distribution of bus transit network of the city of Guangzhou in 2002.
Table 3: Bus transit density of every district of Guangzhou

| Density (km/km²) | 1.78 | 0.8  | 4.84 | 6.4  | 5.26 | 2.43 | 1.03 | 1.78 |

Fig. 7: The distribution of bus transit network of Guangzhou in 2002

3.3.2.3 Bus transit network planning

The purpose of bus transit network planning is to facilitate residents’ trips, and at the same time requires taking into account the transit enterprises’ profit. The network planning ought to meet certain criteria other than is solely dependent on planners’ practical experience which can then be referred to help optimize the outputs of the planning. To meet the travelling needs, an effective transit network carries the following characteristics [15]:

- Reach ability, i.e. making most of the capacity to meet the demand of the entire network;
- Low transfer rate, i.e. providing the passengers with as much direct service as possible;
• Short travel time, i.e. laying out the transit routes according to distances to reduce the overall passenger travel time of the whole service area;
• High network efficiency, i.e. prioritizing the layout of those transit lines with the densest passenger flow to utilize the network and the vehicle capacity.

The bus transit network is based on road network. Building an efficient network needs to take into account the characteristics involve geospatial data analysis and calculations, i.e. service area of stops, non-linear coefficient, length of route, density of roads/routes in a certain district. Developing this system aims to construct an optimization model based on road network, passenger origin-destination and spatial analytical methods within GIS support for decision-making of planning. For instance, using this system can achieve minimum transfer rate and passenger flow distribution in the road network as shown in figure 8 and figure 9, non-linear rate as constraints and other parameters.

The major functionality of this system is to offering a relevant support of analysis and comparison of different planning alternative, such as historical, predicted and current planning. The optimization model allows integrated of historical and predicted and current public transportation data within GIS. Table 4 shows the comparison of non-linear coefficient between current network and proposed layouts.
Fig. 8: The passenger flows distribute at the different scales of granularity in the road network according to the survey of public passenger flow carried out by Guangzhou Administrative Department of Passenger Transportation in 2002.

Fig. 9: The crude passenger distribution of main stops in the transit network

<table>
<thead>
<tr>
<th></th>
<th>Current</th>
<th>Layout 1</th>
<th>Layout 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial routes</td>
<td>1.47</td>
<td>1.36</td>
<td>1.36</td>
</tr>
<tr>
<td>Basic routes</td>
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<td>1.59</td>
<td>1.59</td>
</tr>
<tr>
<td>Average rate</td>
<td>1.53</td>
<td>1.50</td>
<td>1.50</td>
</tr>
</tbody>
</table>

Table 4: The comparison of non-linear coefficient between current network and proposed layout

4. Towards new applications, services and data model

4.1. Data issues in the current applications
The traffic/transportation data collected from the urban monitoring systems can be extremely complex and disparate. Moreover, recent technologies allow gathering gigabytes and even more data per day. The data that supports the integration of data modelling will be required by several user domains and will consist of multiple formats. Each transportation agency will likely have datasets and other meta-information about practices and processes that are unique to their operations. They will have rules about how their legacy databases can be used or modified, and they will have internally collected and maintained attributes that are not shared by any other transportation organizations, that is, different organizations may demand different functionalities, and they may require different levels of aggregation and precision of representation in their data. However, it is difficult for many organizations, particularly for smaller agencies and those without years of transportation GIS experience to understand the best way to implement a good data model [3].

4.1.1. Problems in current data processes

Currently the valuable information related to existing transportation infrastructure of Guangzhou is scattered all over the city at different organizations and in multiple formats, particularly some datasets in simple textual, tabular format, e.g. bus time table information. Because of lack of co-ordination of data use and application, data collected for one purpose is rarely usable for others. If two agencies need the same data or very similar data, the data is often collected twice. In addition, some of the existing transportation/traffic management systems don’t allow the user to manipulate access and query the database other than in a very limited way. The user is limited to textual queries only, the selection and viewing of attribute data with respect to spatial and topological relationship is not possible. This poor level of data management is often a result of the difficulties of promoting the efficient use of urban transportation system in an environmentally sustainable way. Although the GIS technologies have been introduced into the traffic/transportation data management in the city of Guangzhou, however, the current GIS applications don’t encompass the set of functions to make this technology compatible with the integrated data model used for transportation management and planning. In particular the current form of integration of GIS and transportation still is incomplete and use loosely coupled methods such as passive file transfer and separate user and data interfaces.

4.1.2 Required tasks

As the complex and disparate characteristics of traffic/transportation data, the data process requires very specific tasks needed to achieve of the transportation data modelling. The required tasks are presented in a following list.
1. How to represent the data according to a coordinate system and at the different levels of granularity, aggregation and precision of multiple representation;

2. How to manage the data isolated across different departments of the city of Guangzhou into a uniform and robust approach;

3. How to seamlessly store, organize and integrate the multiple formatted data.

Consistent with the tasks of transportation data modelling, this paper proposes a preliminary framework for an integrated transportation data model within GIS for the city of Guangzhou to help face the challenges in linking GIS with transportation. Integration of GIS and transportation system is a quite difficult and complicated issue. How to successfully construct a compatible, effective and flexible prototype, which involves many important concepts such as transportation infrastructure, traffic facilities, travel demand, economy, land-use, environment pollution and so on. Goodchild [29] has mentioned several research challenges facing the full development of GIS-T:

- Develop a digital representation process that accommodates the lack of standards in transportation and overcomes the lack of positional accuracy;

- Devise a representation for the full range of information types for a comprehensive approach to GIS-T and ITS;

- Develop methods of inter-computer negotiation that produce communication of location emulating the traditional practice of inter-human negotiation;

- Build an economic models for the development of the GIS-T industry;

- The GIS-T research community so should maintain the flexibility and creativity to take quick advantage of the new technology stream;

- Find fields that are substantively analogous to GIS-T, and make research advances by taking advantage of a broadly conceived approach that sees the parallel between widely disparate applications.

### 4.2 New applications and services

Taking into consideration the needs of different agencies and private sectors of the city of Guangzhou, the potential applications of integration of GIS and transportation for specific purposes are shown in the following non-exhaustive table 5.

<table>
<thead>
<tr>
<th>Agencies</th>
<th>Applications</th>
</tr>
</thead>
</table>


### Table 5: Applications for different transportation agencies of the city of Guangzhou

Although this table shows the various nature of above applications, there are many common elements among these applications as well. For example, most of these applications are concerned with some activities that take place in a transport network. Additionally, many of them deal with the maintenance or inventory of equipment, incidents, or other assets that are used for transportation-related activities. These common elements are the foundation for an essential data model.

#### 4.2 Towards an integrated transportation data model

GIS are valuable aids in transportation planning and operations for both facility
and fleet management, and are particularly useful in supporting modeling efforts for the analysis of planning options, and for real-time vehicle dispatch and traffic control [18]. The transportation data modeling implies to identify, manage, share and integrate data model. We aim to implement a transportation prototype, which will be to favor transportation planning and sustainable urban development based on an integrated transportation data model. The Guangzhou Transportation System (GTS) is a quite complex and dynamic system with a chain of impacts, such as heavy traffic congestion in rush hour, large amount of population and urban environment pollution and so forth. The transportation modes of the city of Guangzhou includes pedestrian, bicycle, bus, metro, taxi, passenger/cargo ship, train and airplane. However, GTS still fills with energy to develop rapidly, especially for the metro. By the end of 2005, total 3 metro routes were available, and there will be total 9 lines in run in the city of Guangzhou in 2010. The metro will continue to extend in all directions to provide travelers with a swift, safe and convenient transportation mode.

4.2.1. Transportation data modeling

In the studies of transportation data model, we will begin at the identification of use cases, for leading to an assessment of data needs and a data model. To identify use cases, we will need to lay out the types of decisions that will be made using the system, and the groups responsible for making those decisions. And then in the following step we will focus upon proposition, analysis and designing of an integrated and spatio-temporal transportation data model within GIS.

Transportation data modeling is used to develop information to help making decision on the future development and management of transportation system. An integrated transportation data requires the intelligent integration of essential components (i.e. temporal-spatial tools within GIS, comprehensive spatial database, sophisticated mathematic models, and mathematical equations/relationships) for data process, representing traveling demands, and making forecasts. Generally identifying transportation data model designing is a process of determining what data is necessary and available, defining data structure, identifying correlations between different sort of data, and then deciding how that the data should be organized to reach integrating efficiently and sharing data. To construct an integrated transportation data model, we will first identify the kind of data that can occur (i.e. granularities, geographical nature, real-time or not) and define the identifiers and relations of various transformation/traffic data. Secondly will establish a preliminary definition of model required the postulated problems, parameters, constraint conditions and calibration. The following list gives the elements that we will emphasize in developing the transportation data model.

- Analyze the basic concepts and principles of the archetype of transportation data model, such as the boundary of modeling, sophisticated mathematic
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models, the mathematical equations and relationships. We aim to make a clear and comprehensive understanding of the transportation data modeling.

- Identify the coefficients, parameters and constraint conditions (boundaries) of multiple representations to match existing data. For example, as a result of the diversity among transportation data, applications and their users, there are numerous conceptions of how the objects related to transportation should be represented. The transportation data model seeks to handle such diversity through multiple representations of transportation network data.

- Constitute guidelines to direct the devising and implementing of the model, and set calibration and adjustment process to evaluate the efficiency of the model.

- The model can be modified flexibly to be compatible with a particular application or project.

4.2.2. The expected benefits of an integrated transportation data model

The purpose of our further research is to establish a robust transportation prototype so that the particular applications, services and projects can be easily to be implemented, namely that the transportation departments/agencies, private sectors and individuals can enjoy the benefits of this prototype. An efficient, flexible and integrated transportation data model is the key core of this prototype. The goals that we try to achieve are developed for the quality of transportation service, environmental impacts and costs. Along with goals it is important to identify more specific objectives and criteria which can be used to specifically measure how well alternative applications and services in satisfying the more general goals. Target application should be complex enough and involve different departments and might imply kind of end-users.

The transportation data model is an essential data model intended to be used by a broad range of agencies and end-users across the spectrum of the transportation community. The transportation data model will provide an essential set of objects, features, equations and relationships that are integrated into a seamless and logical prototype to visually present and simulate real transportation network. The prototype supported by an integrated transportation data model, which are intended to help agencies begin any application/project. For instance, for transportation planning, the prototype is used to forecast future land-use and economic condition and understanding of how people make travel choice. Moreover, the prototype aims to develop alternative plans and evaluate the results of forecasts used to compare the performance of alternatives in matching goals and ultimately decisions, which are made by appropriate elected or appointed groups for future transportation projects. Once decisions are made, plans should be further developed and refined for implementation. This may include more detailed analysis for design and evaluation following the same process as above.
5. Conclusion

This paper discusses current applications developed on different demands/needs where the essential and common element is the integration of GIS and transportation system, and surveys the conditions, needs and problems existing in current transportation system of the city of Guangzhou. The various travelling needs introduced in this paper illustrate the potential applications are wide-ranging within the Integrated Transportation GIS, and the developers and operators of those applications are from diverse group. For instance, local bus operators implement applications for routing and scheduling. Trucking and delivery companies build applications to trace their shipments. Municipalities develop routes for their sanitation services and so on. Transportation professionals use powerful technologies within GIS to design new optimal routing algorithms or improve on those that are currently in use. Retailers direct their customers to their locations with applications on transportation. The consideration of a final end-user (pedestrian and public traffic passenger) is to access valuable information to determine the best time to travel, the best route to use, the best transportation mode to choose, and get to his destination in swiftness, safety, low costs and comfort. To meet such a variety of needs, a robust intelligent and integrated transportation GIS prototype is required.

In this paper, we aim to explore the directions, goals and avenues of studies, and propose a preliminary framework for an integrated transportation data model within GIS, taking into account existing applications, demands and problems. Designing a spatio-temporal and integrated transportation data model are the milestones in research of an integrated transportation GIS prototype. This data model will reconcile the engineering and geographical views of a transportation system and development of a computing architecture. The aim is to support real-time integration and management of transportation data, and the exploration and implementation of data analysis and mining processes that will bring the gap in between data and information, that is, in between the engineering and the final user views, these final users being transportation and city planners, private car owners, public traffic passengers, pedestrians and so on. The further research is oriented to the development of an integrated transportation GIS whose objective will be to favor transportation planning and sustainable urban development of the city of Guangzhou.

6. References

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